Upper Vindhyan biota and Precambrian/Cambrian Boundary

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The upper age limit of the Vindhyan Supergroup is yet a point of debate. The evidences from structural biological remains, megafossils and organic-walled microfossils, from the Bhander Group support the view that the upper age limit of Vindhyan Supergroup does not extend beyond Vendian. This fact also gets support by the absence of Ediacaran fauna and vendotaenids in Bhander. All the evidences now point to the fact that the deposition of the Vindhyan sediments ceased before the Precambrian/Cambrian Transition interval.

Key-words — Organic-walled microfossils, *Obruchevella*, Bainkuian, Bhander Group, Vendian (India).

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साराँश

उपरि विन्ध्य जीविता एवं कॅम्ब्रिय-पूर्व/कॅम्ब्रिय सीमा

प्रभात कुमार माइती एवं रूपेन्द्र बाबू

विन्ध्य महासमूह की ऊपरी आयु सीमा अभी भी विवादास्पद है। भन्डेर समूह से प्राप्त जीवन के प्रमाण, गुरुजीवाश्म तथा कार्बनिक-भित्तिदार सूक्ष्मजीवाश्म इस कथन की पुष्टी करते हैं कि विन्ध्य महासमूह की ऊपरी आयु सीमा वेन्डियन से अधिक नहीं हो सकती। भन्डेर में एडियाकरन जीवजात और वेन्डोटीनिडों की अनुपस्थिति भी इसकी द्योतक है। अभी तक उपलब्ध सभी प्रमाणों से यह व्यक्त होता है कि विन्ध्य अवसादों का निक्षेपण कॅम्ब्रिय-पूर्व - कॅम्ब्रिय परिवर्तन के पहले ही रुक गया था।

THE age for the upper limit of the Vindhyan sediments had been a controversial topic since long. Geologists, palaeobiologists and physicists have given different opinions. Oldham (1893) suggested a Cambrian age for the Vindhyan. Auden (1933) stated that the age of the Vindhyan may be anything from Algonkian to Devonian. Sitholey *et al.* (1953) assigned a Cambrian age to Upper Vindhyan. Boileau (quoted in Krishnan & Swaminathan, 1959) considered the topmost bed of Vindhyan to be Lower Carboniferous. Salujha (1982) on the basis of palynological studies, extended the upper limit of the Vindhyan up to Early Silurian.

Contrary to this, Sarkar *et al.* (1964) considered the upper age limit of the Vindhyan to be less than 600 Ma because they unconformably overlie the folded Malani Rhyolites. Maithy and Mandal (1983) assigned a Late Proterozoic age to Shikaoda Sandstone (= Upper Bhander Sandstone). Later, Maithy and Meena (1989), on the basis of their biotic studies, considered the upper limit of the Vindhyan to be 600 Ma. Rao *et al.* (1977), on the basis of their study on stromatolites put the age of Upper Vindhyan from 900-600 Ma.

Geophysical dates are not available for the upper part of the Bhander Group. The only date available is by the fission track method for Bundi Hill Sandstone (= Lower Bhander Sandstone), i.e., ± 650 Ma (Srivastava & Rajagopalan, 1988). Crawford and Compston (1970), on the basis of their Rb/Sr isochron, put a younger age limit (550) Ma for the uppermost Vindhyan bed.

The Bhander Group is the youngest group of the Vindhyan Supergroup. The generalised lithostratigraphic scheme for the different formations of Bhander Group are detailed below (after Sastry & Moitra, 1984). This scheme is useful for large part of the Vindhyan Basin. Slight modifications owing to the absence or addition of one or two formations may be required in other areas of the basin.

BHAVPURA SHALE FORMATION
(= DHOLPURA SHALE)
BALWAN LIMESTONE FORMATION
(= UPPER BHANDER LIMESTONE)
SHIKAODA SANDSTONE FORMATION
(= UPPER BHANDER SANDSTONE)
SIRBU SHALE FORMATION
BUNDI HILL SANDSTONE FORMATION
(= LOWER BHANDER SANDSTONE)
LAKHERI LIMESTONE FORMATION
(= LOWER BHANDER LIMESTONE)
GANURGARH SHALE FORMATION

BIOTIC ANALYSIS

Ganurgarh Shale Formation

Maithy and Babu (1993, p. 49) recorded organic-walled microfossils from an outcrop exposed along the railway cutting about 2 km west of Mid-Ghat, Bhopal District, Madhya Pradesh. The recorded OWM are remarkable and comprise acritarch (simple with incipient processes), tubular filament and multicellular sheath. The acritarch are *Leiosphaeridia sensu* Jankauskas, *Granomarginata, Symplassosphaeridium, Vavosphaeridium, Nucellosphaeridium* and *Cymatospheroides.* The filamentous tubular forms are represented by aseptate simple tubes clumped together in filamentous sheath, comparable to *Polythricoides lineatus* Jankauskas.

This assemblage resembles the Neoproterozoic of Arcoona Quartzite Member of the Tent Hill Formation, South Australia (Damassa & Knoll, 1986); grey black shales of Kubis and Schwarrand subgroups of the Nama Group (Germs, Knoll & Vidal, 1986); Upper Vendian of Baltic region (Volkova, 1969; Korkutis, 1981); Assemblage III, Upper Redkino in the bore holes of Zimne Gorey in the Valdai Series, north western Arkhangelesk District (Ragozina & Sivertseva, 1990).

Lakheri Limestone Formation (= Lower Bhander Limestone)

Interesting macrofossils (structural biological remains and ?ichnofossils) and organic-walled microfossils are now better known. OWM were recorded previously by Maithy and Gupta (1983) and Maithy and Meena (1989). The reported forms are as follows.

Algae — Sphaerophycus parvum, Myxococcoides psilata

Septate tubular forms — Biocatenoides sphaerula, *Gunflintia minuta*

Aseptate tubular forms — Eomycetopsis sp., *Animikiea septata*

Acritarch — Protosphaeridium, Orygmatosphaeridium, Kildinosphaera

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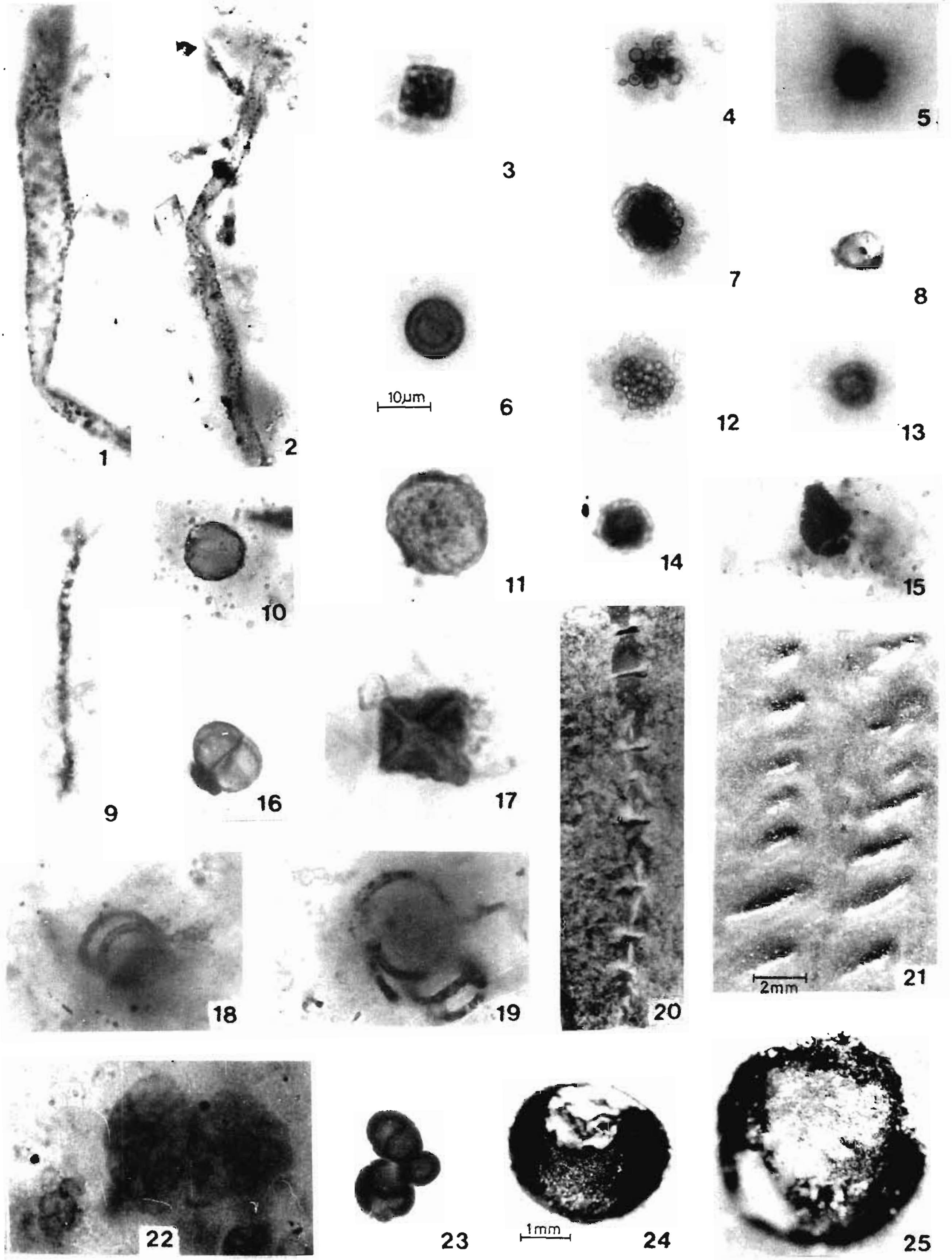
PLATE 1 →

Magnification : (figs 1-19, 22, 23 as per bar in fig. 6; figs 20, 21 as per bar in fig. 21; figs 24, 25 as per bar in fig. 24).

1. *Siphonophycus*, Slide no. BSIP 11908; Lakheri Limestone Formation, Khemri-Kotar, Satna District, M.P.
2. *Eomycetopsis*, Slide no. BSIP 11908; Lakheri Limestone Formation, Khemri-Kotar, Satna District, M.P.
3, 17. *Octaedryxium*, Slide no. BSIP 11910; Lakheri Limestone Formation, Bainkuian, Rewa District, M.P.
4, 7, 12. *Sphaerocongregus variabilis*, Slide no. BSIP 11911; Sirbu Shale Formation, Khemri-Kotar, Satna District, M.P.
5. *Micrhystridium*, Slide no. BSIP 11906; Lakheri Limestone Formation, Bainkuian, Rewa District M.P.
6. *Margominuscula*, Slide no. BSIP 11912; Lakheri Limestone Formation, Bainkuian, Rewa District M.P.
8. *Sphaerophycus parvum*, Slide no. BSIP 11909; Lakheri Limestone Formation, Khemri-Kotar, Satna District, M.P.
9. *Biocatenoides*, Slide no. BSIP 11909; Lakheri Limestone Formation, Khemri-Kotar, Satna District, M.P.
10. *Granomarginata*, Slide no. BSIP 11909; Lakheri Limestone Formation, Khemri-Kotar, Satna District, M.P.
11. *Favososphaeridium*, Slide no. BSIP 11911; Sirbu Shale Formation, Khemri-Kotar, Satna District, M.P.
13. *Sphaerophycus miriabilis*, Slide no. BSIP 11908; Lakheri Limestone Formation, Khemri-Kotar, Satna District, M.P.
14. *Cymatiosphaera*, Slide no. BSIP 11910; Lakheri Limestone Formation, Bainkuian, Rewa District, M.P.
15. *Melanocyrillium*, Slide no. BSIP 11910; Lakheri Limestone Formation, Bainkuian, Rewa District, M.P.
16, 23. *Eosynechoccus* sp., Slide nos. BSIP 11906, 11914; Lakheri Limestone Formation, Khemri-Kotar, Satna District, M.P.
22. *Eoentophysalis*, Slide no. BSIP 11913; Lakheri Limestone Formation, Khemri-Kotar, Satna District, M.P.
18, 19. *Obruchevella varra*, Slide no. BSIP 11907; Lakheri Limestone Formation, Khemri-Kotar, Satna District, M.P.
20. Single trails, Specimen no. BSIP 37772; Lakheri Limestone Formation, Bainkuian, Rewa District, M.P.
21. Paired trails, Specimen no. BSIP 37773; Lakheri Limestone Formation, Bainkuian, Rewa District, M.P.
24, 25. *Sekwia eccentrica*, Specimen nos. BSIP 37774, 37775; Lakheri Limestone Formation, Bainkuian, Rewa District, M.P.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10μm
2mm
1mm

PLATE 1

Recently, Maithy and Babu (1994) have reported endosporulating cyanobacteria *Sphaerocongregus variabilis* Moormann from Damoh. This form is a global biostratigraphic marker for the Vendian (Zang & Walter, 1992).

Several marker OWM have been recorded by us in our recent studies in the black chert from Bainkuian, Rewa District. The acritarch forms are *Micrhystridium* (Pl. 1, fig. 5), *Cymatiosphaera* (Pl. 1, fig. 14), *Margominuscula* (Pl. 1, fig. 6) and *Octaedryxium* (Pl. 1, figs 3, 7). The last form is a Vendian marker. In addition, vase-shaped microfossil *Melanocyrillium* Bloesser (Pl. 1, fig. 15), a Neoproterozoic form, is also recorded.

The study on the silicified oncolites from the Khemri-Kotar, Satna District has shown the presence of unbranched tubular aseptate forms referable to *Biocatenoides* (Pl. 1, fig. 9), *Eomycetopsis* (Pl. 1, fig. 2), *Siphonophycus* (Pl. 1, fig. 1), *Granomarginata* (Pl. 1, fig. 10), and the spirally coiled form *Obruchevella varra* (Pl. 1, figs 18, 19) along with the coccoid form *Sphaerophycus parvum* (Pl. 1, fig. 8), *Sphaerophycus miriabilis* (Pl. 1, fig. 13), *Eosynechoccus* sp. (Pl. 1, figs 16, 23)) and *Eoentophysalis* (Pl. 1, fig. 22). Presence of *Obruchevella* is significant as it is commonly known from the Vendian though it ranges up to the Cambrian.

In Samaria Shale Formation, Maithy and Mandal (1983) reported *Gloeocapsamorpha karauliensis* and *Orygmatosphaeridium plicatum*. So far *Gloeocapsamorpha* is known to occur from Neoproterozoic onwards, but is not known to occur in the Mesoproterozoic.

From Bainkuian (Rewa District), megafossil *Sekwia excentrica* Hofmann 1981 is reported for the first time in the Vindhyan. This form was previously recorded from the Neoproterozoic of Sekwi Brook area, Mackenzie Mountain, north-west Canada. The Bainkuian specimens are preserved as discoidal cast (Pl. 1, figs 24, 25) measuring 2-4 mm in diameter with a distinct globular area, which may be eccentric. Hofmann (1981) considered this form to be possibly medusoid. However, it shows morphological similarity to cocoons of Annelida.

Doubtful 'ichnofossils' (surface trails) are known from Bainkuian, Rewa District. The forms are preserved as paired trails (Pl. 1, fig. 21), single trails (Pl. 1, fig. 20) and rentering trails.

Bundi Hill Sandstone Formation (= Lower Bhander Sandstone)

Maithy and Mandal (1983) reported the presence of OWM *Protoleiosphaeridium*, ? germinating cell and ? budding cell from the Karauli-Sapotra region of northeast Rajasthan. Signatures of biogenic activity were registered in the form of burrows and bioturbation of sediments from the silicaclastic tidal flat deposits of Bundi Hill Sandstone exposed around Maihar, Satna District (Chakrabarti, 1990). The burrows vary from large-diameter, near-vertical stubby forms to microscopic thread-like feature cutting across the physical sedimentary structures. Thin section study of the large-diameter burrows (Chakrabarti, 1990) shows two different patterns in the nature of burrows fill — (i) staggered concave upward internal laminae showing broad based 'U' in 'V' structures resembling *Monocraterion*, and (ii) an ill-defined arrangement of the upward laminae of the burrow fill, the stubby thumb-like burrow being borderd by clay lining on the burrow wall. On the basis of this evidence Chakrabarti (1990) fixed the age of Lower Bhander Sandstone Formation at a much younger level than Late Riphean, possibly Late Precambrian.

Sirbu Shale Formation

The Sirbu Shale Formation preserves OWM comprising algal filaments and acritarch (Maithy & Mandal, 1983; Maithy & Meena, 1989), e.g., *Archaeorestis, Taeniatum, Eomycetopsis, Gunflintia minuta, Sphaerocongregus variabilis, Leiosphaeridia, Granomarginata* and *Baltisphaeridium*. The assemblage is lacking in acanthomorphic acritarch, but is dominated by *Leiosphaeridia* which were earlier assigned to *Kildinosphaera, Orygmatosphaeridium* and *Protosphaeridium*. A recent examination of the Sirbu Shale of Satna-Maihar and Bundi-Kota sections adds to our knowledge the presence of *Favososphaeridium* (Pl. 1, fig. 11) and *Sphaerocongregus variabilis* (Pl. 1, figs 4, 7, 12).

Shikaoda Sandstone Formation (= Upper Bhander Sandstone)

Algal forms and acritarch have been reported by Maithy and Mandal (1983, 1984) in the siltstone and shale beds exposed 2 km north of Karauli on Hindaun Road. The recorded remains are *Corymbococcus, Vindhyacapsiopsis, Palaeoglaucocystis*, ? germinating cell and *Granomarginata*.

The form *Vindhyacapsiopsis* has previously been reported from the Proterozoic of Queensland (Licari *et al.*, 1969; *Eucapsiopsis*?)

Balwan Limestone Formation (= Upper Bhander Limestone)

So far only one form of stromatolite *Collenia* is known from this bed (Prasad, 1980).

Bhavpura Formation (= Dholpura Shale Formation)

The Bhavpura Shale Formation constitutes the youngest stratigraphic unit of the Vindhyan Supergroup (Prasad, 1984). This bed is exposed only at Lakheri, Rajasthan. Maithy *et al.* (1992) claimed the presence of Ediacaran(?) biota in the ferruginous siltstone exposed approximately at the base of a small hillock near Bhavpura (25°41' : 76°13') and referred them to *Cyclomedusa davidi, Medusinites asteroids* and *Beltaneformis brunsae*. The former two forms show more or less circular outline with central circular area as in the forms referred to *Cyclomedusa*. The outer area shows concentric and radial thickenings. Sharma *et al.* (1992, p. 30 , text-figs 25, 26) have without examining the described specimens (according to them the specimens are not available in BSIP repository), considered them to be a product of weathering and to be non-fossils. To us the statement of Sharma *et al.* (1992) seems to be a biased one as all the specimens show well-organised distinct organisation and are still available for examination in the BSIP repository. A re-examination of the so-called Ediacaran forms reveals that they show similarity to the forms recently recorded as sponges by Gehling and Rigby (1996) from the Neoproterozoic of South Australia.

CONCLUDING REMARKS

Knoll and Walter (1992) favoured a Proterozoic-Cambrian boundary at ± 540 Ma. According to them the end of the Proterozoic Eon was a time of pronounced biological, biogeochemical, climatic and tectonic changes. Worldwide the latest Proterozoic shows the presence of Ediacaran animals and comprises a morphologically distinctive fauna of architecturally simple, unskeletalised invertebrates. The Ediacaran fossils are known now from at least 24 localities. There is a general agreement that Ediacaran assemblages occur only in a discrete interval of latest Proterozoic time, but it is not clear whether all assemblages are strictly coeval.

According to Crimes (1987) ichnofossils provide additional and largely independent evidence of Proterozoic animal evolution. The assemblages of simple tracks, traces and burrows found in Proterozoic rocks are distinct from those in basal Cambrian and younger deposits, and they seem to recognisable globally in siliciclastic sediments.

Likewise fossil protists and prokaryotes have important role in marking the Terminal Proterozoic. According to Knoll and Walter (1992) photosynthetic organisms are abundantly represented in the uppermost Proterozoic rocks, but their stratigraphic potential varies widely. Seaweeds are morphologically complex, but they get rarely preserved. However, exceptions are there. The problematic organic ribbons known as vendotaenids occur regularly in the uppermost Proterozoic sediments (Gnilovskaya, 1990). Cyanobacteria and cyanobacteria-like microfossils are widely distributed in the uppermost Proterozoic rocks, but all have close similarities both to the older fossils and living taxa. Amongst the known forms, *Sphaerocongregus* is recognised as Vendian marker and the helical *Obruchevella* is known to occur in uppermost Proterozoic and Lower Cambrian. The most important fossils for Neoproterozoic biostratigraphy are the acritarch, and organic-walled microfossils produced by the phytoplanktonic protists. Both sphaeromorphic and acanthomorphic forms have useful role in correlating the rocks of Neoproterozoic-Cambrian succession. Recent studies show that the size of sphaeromorphids increases towards the close of Proterozoic. Contrary to this the acanthomorphic forms are larger in size in Neoproterozoic and show gradual reduction towards Precambrian/Cambrian transition. But the processes are complex and more in length particularly Cambrian onwards.

In recent years isotopic chemostratigraphy has played a significant role in correlation of Precambrian/Cambrian transition. Detailed isotopic curves for the Neoproterozoic Eon show marked variation and changes in the world ocean and as such provide a useful stratigraphical signal.

Analysis of the recorded biological remains from the Bhander Group indicates total absence of Ediacaran fauna and Vendotaenids. The organic-walled microfossils are marked by the Vendian forms. The *Leiosphaeridia* shows increase in size, however, the known marker acanthomorphic acritarch of the uppermost Proterozoic sediments are totally absent. The ichnofossils so far recorded from the Bhander Group also do not show any similarity to the ichnofossils of Neoproterozoic. Recently S.K. Bhattacharya of P.R.L. investigated the $\delta^{13}C$ from the Lakheri Limestone Formation provided by us. According to his analysis the $\delta^{13}C$ shows positive incursion of ± 2.9 to ± 4.0. Therefore, all the evidences presently indicate that the upper limits of Vindhyan extend only up to Vendian and not beyond. Most probably due to regression of sea level the sedimentation in the Vindhyan ceased much before the Precambrian/Cambrian Transition interval.

REFERENCES

Auden JB 1933. Vindhyan sedimentation in the Son Valley, Mirzapur District. *Mem. geol. Surv. India* **62** : 141-250.

Bloesser B 1985. *Melanocyrillium*, a new genus of structurally complex Late Proterozoic microfossils from the Kwagunt Formation (Chuar Group), Grand Canyon, Arizona. *J. Paleontol.* **59** : 741-765.

Chakrabarti A 1990. Traces and dubiotraces: examples from the so-called Late Proterozoic siliciclastic rocks of the Vindhyan Supergroup around Maihar, India. *Precambrian Res.* **47** : 141-153.

Crimes TP 1987. Trace fossils and correlation of Late Precambrian and Early Cambrian strata. *Geol. Mag.* **124** (2) : 97-119.

Crawford AR & Compston W 1971. The age of Vindhyan System of peninsular India. *J. geol. Soc. London* **125** : 351-371.

Damassa SP & Knoll AH 1986. Micropalaeontology of the Late Proterozoic Arcoona Quartzite Member of Tent Hill Formation, Stuart Shelf, South Australia. *Alcheringa* **10** : 417-430.

Gehling JG & Rigby JK 1996. Long expected sponges from the Neoproterozoic Ediacara fauna of South Australia. *J. Paleontol.* **70** (2) : 185-195.

Germs GJB, Knoll AH & Vidal G 1986. Latest Proterozoic microfossils from the Nama Group, Namibia (Southwest Africa). *Precambrian Res.* **32** : 45-62.

Gnilovaskaya MB 1990. Vendotaenids - Vendian Metaphytes. *In* : Sokolov BS & Iwanoski AB (Editors) — *Vendian system. Palaeontology* **1** : 138-147. Akademika Nauka, USSR.

Hofmann HJ 1981. First record of late Proterozoic faunal assemblages in the North American Cordillera. *Lethaia* **14** : 303-310.

Jankauskas TV 1990. Plant microfossils of the Urals. *In* : Sokolov BS & Iwanoski AB (Editors) — *Vendian system. Palaeontology* **1** : 171-173. Akademika Nauka, USSR.

Knoll AH & Walter MR 1992. Latest Proterozoic stratigraphy and Earth history. *Nature* **356 (3)** : 673-677.

Korkutis V 1981. Late Precambrian and Early Cambrian in the east European Platform. *Precambrian Res.* **15** : 75-94.

Krishnan MS & Swaminathan J 1959. The great Vindhyan Basin of northern India. *J. geol. Soc. India* **1** : 10-30.

Licari GR & Cloud PE 1969. New Chrococcacean alga from the Proterozoic of Queensland. *Proc. natn. Acad. Sci.* **62** (1) : 56-62.

Maithy PK & Babu R 1993. Organic-walled microfossils from the Ganurgarh Shale Formation (Bhander Group), Vindhyan Supergroup, Hoshangabad, Madhya Pradesh, India. *J. Palaeont. Soc. India* **38** : 43-49.

Maithy PK & Babu R 1994. Occurrence of endosporulating cyanobacteria in the Lower Bhander Limestone Formation, Bhander Group exposed around Narsingharh, Madhya Pradesh. *Palaeobotanist* **42** (2) : 101-107.

Maithy PK & Gupta S 1983. Microbiota and organo-sedimentary structures from the Vindhyan Supergroup around Chandrehi, Madhya Pradesh. *Palaeobotanist* **31** (1) : 154-164.

Maithy PK & Mandal J 1983. Microbiota from Vindhyan Supergroup of the Karauli-Sapotra region of north-east Rajasthan, India. *Palaeobotanist* **31** (1) : 129-142.

Maithy PK & Mandal J 1984. Significance of algal remains from the Bhanders of Vindhyan Supergroup, Rajasthan. *In* : Sharma AK *et al.* (Editors) — *Evolutionay botany and biostratigraphy, A.K. Ghosh Commem. Vol.*: 245-250. Today & Tomorrows Printers & Publishers, Delhi.

Maithy PK & Meena KL 1989. Organic-walled microfossils from the Proterozoic succession of Vindhyan Supergroup exposed around Satna and Maihar, Madhya Pradesh. *J. Earth Sci.* **16** (3-4) : 178-188.

Maithy PK, Meena KL & Babu R 1992. Ediacaran (?) biota from the Dholpura Shale, Upper part of Vindhyan Supergroup near Lakheri, Rajasthan. *Indian J. Geol.* **64** (1) : 356-364.

Moormann M 1974. Microbiota of Late Proterozoic Hector Formation, south-western Alberta, Canada. *J. Paleont.* **48** : 524-531.

Oldham RD 1893. On the geological relation and probable age of several rock system of central India and Bengal. *Mem. geol. Surv. India* **30** (2).

Prasad B 1980. Vindhyan stromatolites stratigraphy in SE Rajasthan. *Misc. Publ. Geol. Surv. India* **44** : 201-206.

Prasad B 1984. Geology, sedimentation and palaeogeography of Vindhyan Supergroup, SE Rajasthan. *Mem. geol. Surv. India* **116** (1) : 1-102.

Ragozina AL & Sivertseva IA 1990. Plant microfossils of Valdai Series in the Northwestern Arkhangelsk District. *In* : Sokolov BS & Iwanoski AB (Editors) — *Vendian system palaeontology* **1** : 165-170. Akademika Nauka, USSR.

Rao KS, Lal C & Ghosh DB 1977. Algal stromatolites in Bhander Group, Vindhyan Supergroup, Satna District, Madhya Pradesh. *J. geol. Soc. India* **109** (2) : 38-47.

Sastry MVA & Moitra AK 1984. Vindhyan stratigraphy - a review. *Mem. geol. Surv. India* **116** (2) : 109-148.

Sarkar SN, Palkanov A, Gerling EK & Chukranov FV 1964. Geochronology of the Precambrians of peninsular India - a synopsis. *Sci. Cult.* **30** : 527-537.

Salujha SK 1982. Palynology of surface and subsurface Vindhyan sediments. *In* : Valdiya KS *et al.* (Editors) — *Geology of Vindhyanchal*: 113-124. Hindustan Publ. Corp. (India), Delhi.

Sitholey RV, Verma CP & Shrivastava RN 1953. Microfossils from the Upper Vindhyans with a discussion on the age of Vindhyans in light of plant fossils discovery. *Proc. natn. Inst. Sci. India* **19B** : 193-202.

Srivastava AP & Rajagopalan G 1988. FT ages of Vindhyan glauconitic sandstone beds exposed around Rawatbhata area, Rajasthan. *J. geol. Soc. India* **32** (6) : 527-529.

Volkova NA 1969. Acritarchs of the northwest Russian Platform. *In* : Rozanov Yu *et al.* (Editors) — *Tommotian stage and the Cambrian lower boundry problem. Trans. Acad. Sci. USSR* **206** : 234-236. (in Russian).

Zang Weng-Long & Walter MR 1992. Late Proterozoic and Early Cambrian microfossils and biostratigraphy of northern Anhuei and Jragsu, central eastern China. *Precambrian Res.* **57** : 243-323.

Significance of the Meso-Neoproterozoic microfossil assemblage from the Deoban Limestone, Garhwal Lesser Himalaya

Purnima Srivastava & S. Kumar

Srivastava P & Kumar S 1997. Significance of the Meso-Neoproterozoic microfossil assemblage from the Deoban Limestone, Garhwal Lesser Himalaya. *Palaeobotanist* **46** (1,2) : 7-12.

The microfossil assemblage from the Deoban Limestone comprises 75 morphotaxa which have been recognised from the study of petrographic thin sections of black bedded cherts. The assemblage consists of cyanobacterial, bacterial, algal, fungal, acritarchean forms along with forms possibly of animal affinity, and has a significant bearing for palaeobiological, palaeogeographical and palaeoecological studies. The dominance of cyanobacterial population suggests conservatism in cyanobacterial community in the microbial setting. In diversity and level of preservation, the assemblage is comparable to the Kheinjua Formation of the Vindhyan Supergroup. If animal affinity of the Deoban microfossil assemblage is accepted, it would indicate herbivore or heterotrophs dominated food chain in contrast to earlier producer or autotrophs dominated food chain.

Key-words — Microfossils, Proterozoic, Lesser Himalaya, Deoban Limestone, Garhwal, India.

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साराँश

गढ़वाल लघु हिमालय में देवबन चूना पत्थर से प्राप्त मीसो-निओप्रोटीरोजोइक सूक्ष्मजीवाश्मों का महत्व

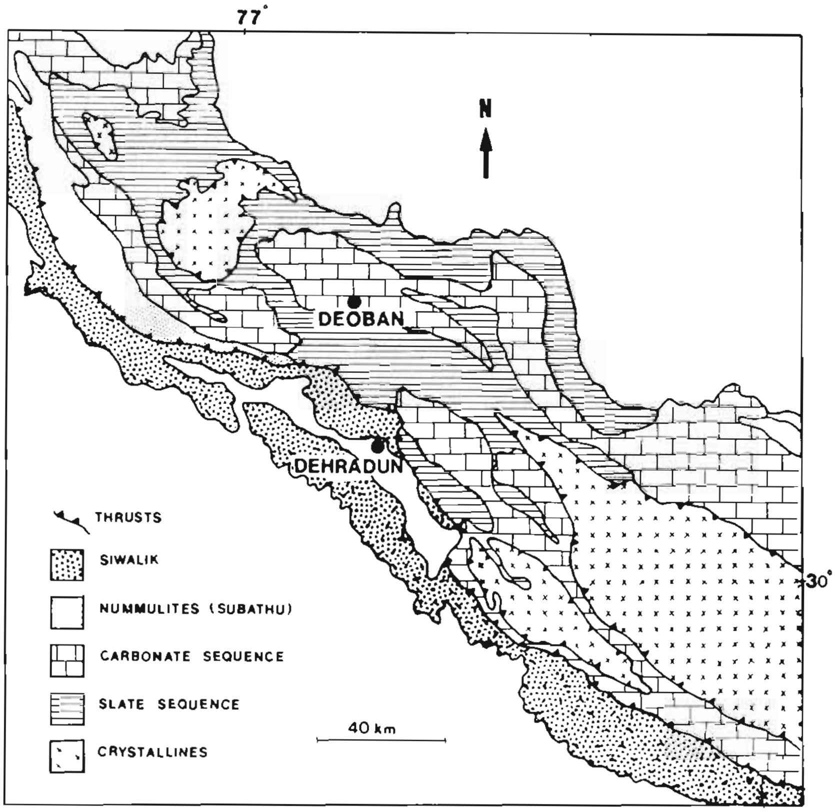
पूर्णिमा श्रीवास्तव एवं सुरेन्द्र कुमार

देवबन चूना पत्थर से प्राप्त सूक्ष्मजीवाश्म समुच्चय में 75 वर्गक विद्यमान हैं जिनका अभिनिर्धारण काले संस्तरित रामसैकाश्मों की पतली काटों के अध्ययन द्वारा किया गया है। इस समुच्चय में सियॅनोजीवाणुओं, जीवाणुओं, शैवालों, कवकों, एक्रीटार्कों तथा सम्भवतया जन्तुओं से सजातीयता व्यक्त करने वाले प्ररूप सम्मिलित हैं जिसके कारण इसका पुराजैविकीय, पुराभौगोलिक एवं पुरापारिस्थितिक दृष्टि से विशेष महत्व है। सियॅनोजीवाणुओं की बाहुल्यता से इस समुदाय की पुरातनता प्रदर्शित होती है। विविधता एवं परिरक्षण के आधार पर यह समुच्चय विन्ध्य महासमूह के खेंजुआ शैल-समूह से तुलनीय है। यदि देवबन सूक्ष्मजीवाश्म समुच्चय की जन्तुओं से सजातीयता मान्य है तो इससे स्वपोषी भोजन प्रणाली के स्थान पर विषमजीवी भोजन प्रणाली की विद्यमानता इंगित होती है।

LIFE during the Proterozoic Eon was typified by the hypobradytelic evolution of dominantly microscopic, asexual, unicellular or colonial prokaryotes, e.g., cyanobacteria, bacteria. Algae, fungi, acritarchs, trace fossils, stromatolites and soft bodied animals also represent Proterozoic life (see Glaessener, 1983a, 1983b; Awramik *et al.*, 1985; Schopf & Klein, 1992; Zhang & Walter, 1992). Any report about these fossils is significant for the better understanding of evolution of early life. Exceptional preservation of Meso-Neo-proterozoic microfossil assemblage, comprising taxonomically and morphologically varied taxa and morphotaxa, reported from the petrographic thin sections of black bedded chert of the Deoban Limestone (Kumar & Singh, 1979; Shukla *et al.*, 1987; Kumar & Srivastava, 1992; Srivastava & Kumar, 1995, 1997a & unpublished data), can be taken as one of the most diversified and advanced microfossil assemblage. In all, 75 morphotaxa have so far been described representing bacteria, cyanobacteria (prokaryotes), algae, fungi and acritarchs (eukaryotes) of plant kingdom and soft bodied animals (?) or multicellular organisation of animal affinity.

GEOLOGICAL SETTING

A thick carbonate horizon, about 500 m thick in northern part of Chakrata, Dehradun District, Garhwal Lesser Himalaya, was designated as the Deoban Limestone by Oldham (1883) (Text-figure 1). This sedimentary sequence shows low grade metamorphism and is tectonically much disturbed. The sedimentary features are still discernible. The



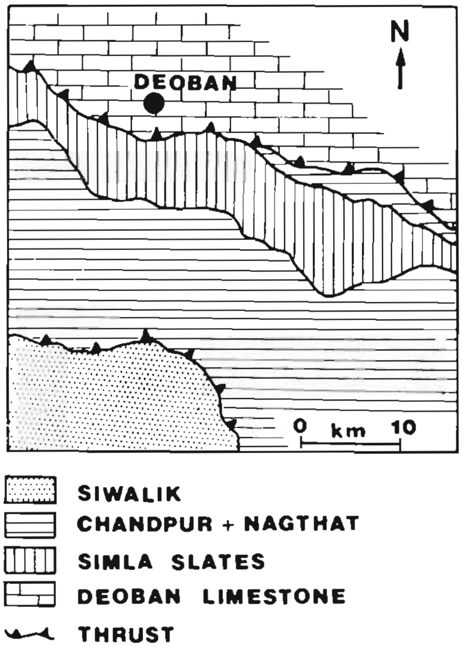
Text-figure 1—Location and geological map of Garhwal region of Uttar Pradesh (simplified after Gansser, 1964).

lithology is dominated by dolostone with thin lenses and bands of cherts, and intercalations of shales. No megafossil has so far been described from this horizon. The stromatolites are well reported from this area.

Stratigraphic position of the Deoban Limestone is still a matter of debate, there being no general agreement on this particular aspect (Auden, 1934, 1937; West, 1939; Gansser, 1964; Rupke, 1974; Prashra, 1977; Valdiya, 1980). Some workers consider that the Deoban Limestone overlies the Simla Slates and is underlain by the Mandhali Formation, while others consider it to be underlying the Simla Slates and overlying the Mandhali-Chandpur sequence (Table 1). In Chakrata area, it physically overlies the Simla Slates and is underlain by the Mandhali Formation (Text-figure 2). The Deoban Limestone is folded and faulted, the fossil bearing chert occurs within 3 meter thick horizon of micritic dolostone in the lower part of the Deoban Limestone (Text-figure 3) on the

Table 1—Stratigraphic position of the Deoban Limestone according to different workers

Auden (1934, 1937)	Gansser (1964)	Bhargava (1972)	Rupke (1972)	Prashra (1977)	Valdiya (1980)	Singh & Rai (1983)
	Krol Infra Krol Blaini					
Chandpur Nagthat (Jaunsar)	Nagthat	Nagthat Chandpur Mandhali		Mandhali Simla Slates	Nagthat Chandpur Mandhali	Simla Group Shali Group
Deoban	**Deoban**	**Deoban**	**Deoban**	**Deoban**	**Deoban** **(Gangolihat)**	**Deoban Gp.**
Simla	Shali Chandpur Mandhali Kakarhatti	Tiuni	Damtha	Atal Quartzite	Rautgara Fm Chakrata Fm	Garhwal Group

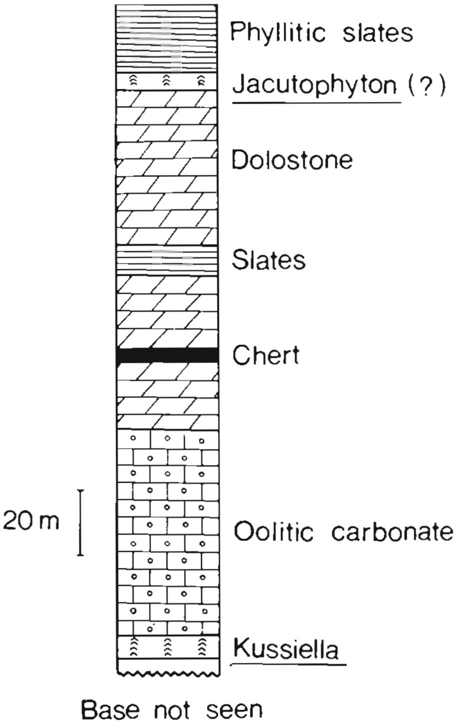


Text-figure 2 — Geological map showing distribution of stratigraphic units in Chakrata area, Garhwal Himalaya (after Sinha & Raaben, 1981).

northern limb of an anticline on Chakrata-Deoban mule track (Kumar & Srivastava, 1992).

AGE

Stromatolites are well developed in this sequence and are used for age estimation. Stromatolite assemblages reported from the Deoban Limestone are: *Collenia-Baicalia baicalica* assemblage (Valdiya, 1969), *Kussiella-Boxonia-Collenia columnaris-Collenia symmetrica-Stratifera* assemblage (Prashra, 1977), *Jacutophyton* (Kumar & Singh, 1979), *Ilicta deobanica* (Sinha & Raaben, 1981) and *Kussiella-Conophyton-Baicalia* assemblage (Tewari, 1983). Sinha and Raaben (1981) suggested a Cambrian age on the basis of a new stromatolite form *Ilicta deobanica;* though no Cambrian megafossil has been reported so far. Later, Tewari (1983) suggested an Early to Middle Riphean age. On the basis of microfossil assemblage, an Upper Riphean age is suggested (Srivastava & Kumar, 1997a).



Text-figure 3 — Position of fossiliferous cherts in the litholog of the Deoban Limestone (after Kumar & Srivastava, 1992).

DEOBAN MICROFOSSILS

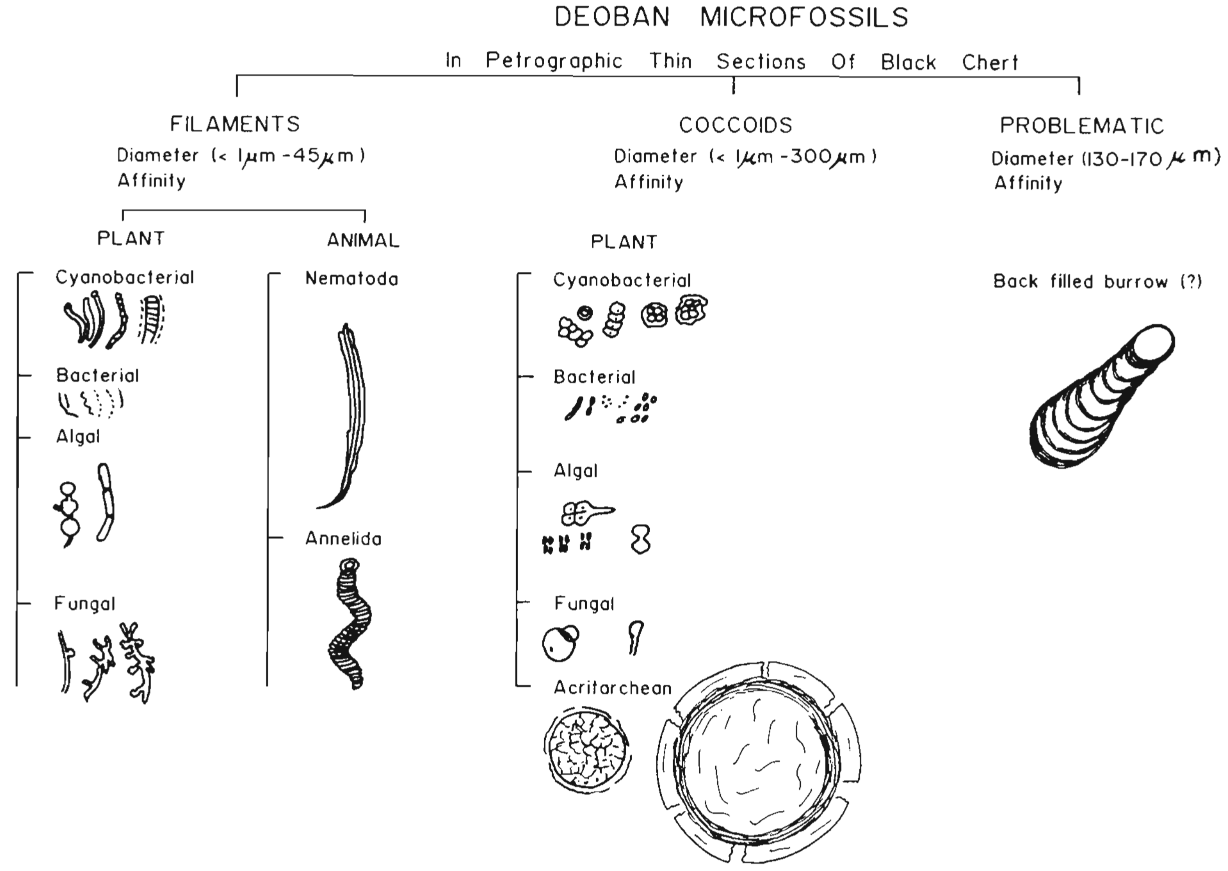
The Deoban microfossil assemblage comprises 75 morphotaxa (see Kumar & Singh, 1979; Shukla *et al.*, 1987; Kumar & Srivastava, 1992; Srivastava & Kumar, 1995, 1997a & unpublished data). The assemblage is grouped into filamentous forms, coccoid forms, acritarchs and problematic forms (Text-figure 4) which are as follows.

Filamentous forms

Filamentous forms are assignable to cyanobacterial, bacterial, algal, fungal and few forms possibly assignable to animal (?) affinity (Srivastava & Kumar, 1997a). These forms are : *Siphonophycus robustum, S. inornatum, S. kestron, Ramacia carpentariana, Oscillatoriopsis perornata, O. obtusa, Oscillatoriopsis* sp. 1, *Oscillatoriopsis* sp. 2, *Cyanonema* sp., *Rhicnonema* sp., *Obruchevella* sp., *Circulinema jinningence, Biocatenoides* sp., *Palaeoscytonema* sp., *Eomicrocoleus crassus, Polytrichoides* sp., *Palaeolyngbya* sp., *Archaeotrichion contortum, Tolypothrix* sp., *Cylindrospermum* sp., *Cladophora* sp. Two forms possibly of animal affinity are comparable to the extant members of Phylum Annelida and Nematoda, respectively.

Coccoid forms

Coccoid forms comprise morphologies assignable to the cyanobacterial, bacterial, algal, fungal and acritarchean affinities. These forms are : *Myxococcoides minor, M. inornata, M. grandis,*



Text-figure 4 — Categorization of the Deoban microfossil assemblage.

Glenobotrydion majorinum, *G. aenigmatis*, *Huroniospora psilata*, *H. microreticulata*, *Sphaerophycus parvum*, *S. minor*, *Eoentophysalis belcherensis*, *E. cumulus*, *E. magna*, *Tetraphycus major*, *T. cunjunctum*, *Palaeopleurocapsa* sp., *Eosynechococcus isolatus*, *E. medius*, *E. moorei*, *E. grandis*, *Scissilisphaera gradata*, *Conjunctiophycus* sp., *Coccus*, *Bacillus*, *Spirellum* sp., *Diplococcus* sp., *Chlorogloeopsis* sp., *Oedogoniopsis* sp., *Crucigenia* sp., *Gloeodiniopsis lamellosa*, *G. gregaria*, *G. micros*, *Gloeodiniopsis* sp., *Archaeophycus* sp., *Eophycomyces* sp., *Enterococcus lamellosus*, *Deobanisphaera trisecta*, *Polysphaeroides* sp., *Clonophycus* sp., *Desmidioideae* sp., *Ermosphaera* sp., *Germinosphaera* sp., *Myxosarcina* sp., *Garhwalia indica*, *Globophycus* sp., cf. *Fucus vesiculus*, cf. *Nostoc* Ball.

Acritarchs

Trachysphaeridium sp., *Mycrhystridium* sp., *Leiosphaeridia crassa*, *L. jacutica*, *Favosphaeridium* sp., *Baltisphaeridium* sp.

Problematic forms

A single specimen exhibiting some resemblance to a form described as a back filled burrow (Srivastava & Kumar, 1997a).

SIGNIFICANCE AND CONCLUSION

1. The assemblage comprises very small-sized (1µm) bacteria to large-sized (up to 300 µm) acritarchs and filamentous sheaths up to 80 µm thick.
2. Morphological diversity among filamentous forms varies from simple thin unornamented tubular sheaths to thick, septate or segmented forms, which may or may not be attenuated or dilated at ends. Straight to sinuous and at times helically coiled filamentous forms are with or without enveloping sheaths.
3. Helically coiled tubular sheaths assignable to *Obruchevella* suggest the initiation of coiling during the deposition of Deoban Limestone (Srivastava & Kumar, 1995).

4. Among coccoids, morphology varies from very simple organic-walled unornamented small-sized spheroids to well ornamented large-sized acritarchs.

5. Few division stages strikingly similar to some chlorophycean forms (like a form comparable to some extent *Fucus vesiculus*) and typical cellular organisation where small cells grouped in four, arranged in a rectangular colony as in extant chlorophycean form *Crucigenia*, support the presence of eukaryotes (Fritsch, 1965).

6. Considering the palaeoecological distribution of micro-organisms, mat building community is exclusively represented by the cyanobacterial population., whereas the mat dwelling community represents mixed population of variable affinities (including acritarchs). Planktic population is largely represented by acritarch and at places by thick sheaths of oscillatoriacean affinity.

7. Different mode of occurrences indicate two generations of microfossils. First generation is highly diversified and seen within algal clasts or oncolites, whereas the second generation occurs in interstitial spaces between the algal clasts or in between the coated grains. The second generation is dominantly represented by filamentous forms and rare occurrence of coccoids is noticed.

8. Specimens showing some resemblance with a pleurocapsalean form *Polybessurus* and also with an already reported form described as back filled burrow (Awramik *et al.*, 1985) like structure, enhance the complexity of the Deoban assemblage (Srivastava & Kumar, 1997a). If it is a burrow, it confirms the presence of animal life.

9. A nonseptate tubular form comparable with a living nematodean form and another annulated, sinuous and tubular body showing some resemblance with members of extant invertebrate Phylums Annelida and Nematoda are indicative of animal life in the Deoban assemblage.

10. In India, the only Proterozoic microfossil assemblage comparable to the Deoban assemblage is from the Kheinjua Formation of the Vindhyan Supergroup in Son Valley area, central India. All mentioned affinities except the forms possibly of animal affinity are well documented from this Formation (McMenamin *et al.*, 1983; Kumar & Srivastava, 1995; Srivastava & Kumar, 1997b; and unpublished data).

11. In diversity the Deoban assemblage is comparable with two other established Proterozoic microfossil assemblages; one from China, i.e., Changcheng Group (1850 Ma) and another Miroedikha Formation, USSR, 850 Ma (Schopf & Klein, 1992).

12. The dominance of cyanobacterial population is a common feature of Deoban microbial community as well as the modern microbial mats from Spencer Gulf, Shark Bay of Australia and Baja California, Mexico (Schopf & Klein, 1992). This suggests conservatism in the algal mat ecosystem since Proterozoic times.

13. If the presence of animal life in the Deoban assemblage is accepted then it would indicate relatively complex producer herbivore or heterotrophs dominated food chains. On the contrary, the earlier producer autotrophs dominated food chains based ecosystems were quite common and dominated the global scene for hundreds of millions of years. It can be inferred that the heterotrophy might have accelerated the pace of evolution of still unsolved and complicated living system, which gave rise to complex and much advanced multicellular animal organization in Late Proterozoic times (Srivastava & Kumar, 1997a).

ACKNOWLEDGEMENT

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REFERENCES

Auden JB 1934. The geology of Krol Belt. *Rec. geol. Surv. India* **67**(4): 357-454.

Auden JB 1937. The structure of the Himalayas in Garhwal. *Rec. geol. Surv. India* **71**: 407-433.

Awramik SM, McMenamin DS, Yin C, Zhao Z, Ding Q & Zhang S 1985. Prokaryotic and eukaryotic microfossils from a Proterozoic/Phanerozoic transition in China. *Nature* **315** : 655-658.

Bhargava ON 1972. A reinterpretation of the Krol Belt. *Him. Geol.* **2** : 47-81.

Boardman RS, Cheetham AH & Rowell AJ (Editors) 1987. *Fossil invertebrates.* Blackwell Scientific Publication, Boston.

Gansser A 1964. *Geology of the Himalayas.* Interscience Publishers, London.

Glaessener MF 1983a. *The dawn of animal life.* Cambridge University Press, New York.

Glaessener MF 1983b. The emergence of Metazoa in the early history of life. *Precamb. Res.* **20** : 427-441.

Fritsch FE 1965. *The structure and reproduction of the algae.* Cambridge University Press, Cambridge.

Kumar S & Singh SN 1979. Discovery of microorganisms from the bedded cherts of the Deoban Limestone (Late Precambrian), Lesser Himalaya, Uttar Pradesh. *Curr. Sci.* **48** : 209-211.

Kumar S & Srivastava P 1992. Middle to Late Proterozoic microbiota from the Deoban Limestone, Garhwal Lesser Himalaya, India. *Precamb. Res.* **56** : 291-318.

Kumar S & Srivastava P 1995. Microfossils from the Kheinjua Formation, Mesoproterozoic Semri Group, Newari area, central India. *Precamb. Res.* **74** : 91-117.

McMenamin DS, Kumar S & Awramik SM 1983. Microbial fossils from the Kheinjua Formation, middle Proterozoic Semri Group (Lower Vindhyan), Son Valley area, central India. *Precamb. Res.* **21:** 247-272.

Monty CLV 1967. Distribution and structure of recent stromatolitic algal mats, Eastern Andros Islands, Bahmas. *Ann. Soc. Geol. Belg. Bull.* **90(2)** : 55-100.

Oldham RD 1883. Note on the geology of Jaunsar and the Lower Himalayas. *Rec. geol. Surv. India* **16(4)** : 193-198.

Prashra KC 1977. Algal stromatolites of the Deoban Atal-Quartzites and Mandhali formations in the Tons Valley. *Rec. geol. Surv. India* **109**(2) : 112-122.

Rupke J 1974. Stratigraphic and structural evolution of Kumaon Lesser Himalaya. *Sedim. Geol.* **11** : 81-265.

Schopf JW & Klein C 1992. *The Proterozoic biosphere: a multidisciplinary study.* Cambridge University Press.

Shukla M, Tewari VC & Yadav VK 1987. Late Precambrian microfossils from the Deoban Limestone Formation, Lesser Himalaya, India. *Palaeobotanist* **35** : 347-356.

Singh IB & Rai V 1983. Fauna and biogenic structures in Krol-Tal succession (Vendian-Early Cambrian), Lesser Himalaya : Their biostratigraphic and palaeoecological significance. *J. palaeontol. Soc. India* : **67**-90.

Sinha AK & Raaben ME 1981. Lower Cambrian stromatolites from the Deoban Limestone of Lesser Himalaya. *Him. Geol.* **9**(1) : 317-323.

Srivastava P 1990. Late Proterozoic Deoban microbiota, Garhwal Lesser Himalaya, Uttar Pradesh and its significance. (Unpublished Ph. D. Thesis).

Srivastava P & Kumar S 1995. Significance of *Obruchevella* sp. Reitlinger in the Deoban Limestone, Garhwal Lesser Himalaya, Uttar Pradesh. *Group meeting on Seismotectonics and geodynamics of the Himalaya, Roorkee University* (Abstract).

Srivastava P & Kumar S 1997a. Possible evidences of animal life in Neoproterozoic Deoban microfossil assemblage, Garhwal Lesser Himalaya, Uttar Pradesh. *Curr. Sci.* **72**(2) : 145-148.

Srivastava P & Kumar S 1997b. Palaeobiological significance of microorganisms from Meso-proterozoic Kheinjua Formation (Semri Group), Son Valley Area, Uttar Pradesh. *Conference on Biosedimentology of Precambrian basins* (Abstract). Geology Department, Lucknow University.

Tewari VC 1983. Stromatolites and Precambrian-Lower Cambrian biostratigraphy of the Lesser Himalaya, India. *Proceedings V Indian geophytological Conference, Lucknow* : 71-97.

Valdiya KS 1969. Stromatolites of the Lesser Himalayan carbonate formations and the Vindhyans. *J. geol. Soc. India* **10** : 1-25.

Valdiya KS 1980. Lesser Himalayan stromatolites, their biostratigraphic implications. *Rec. geol. Surv. India. Misc. Publ.* **44** : 117-127.

West WD 1939. The structure of the Shali window near Simla. *Rec. geol. Surv. India* **76**(1) : 133-163.

Zhang W & Walter MR 1992. Late Proterozoic and Early Cambrian microfossils and biostratigraphy, Northern Anhui and Jiangsu, central-eastern China. *Precamb. Res.* **57** : 243-323.

Physical, geochemical and biological changes across Precambrian-Cambrian transition, northwest Himalaya, India

V.K. Mathur, P.K. Maithy, Ravi Shanker & Gopendra Kumar

Mathur VK, Maithy PK, Shanker R & Kumar G 1997. Physical, geochemical and biological changes across Precambrian-Cambrian transition, northwest Himalaya, India. *Palaeobotanist* **46** (1,2) : 13-18.

The Precambrian-Cambrian transition has been extensively studied in the Krol Belt of Lesser Himalaya and in Higher and Tethys Himalayan part in Kashmir, Spiti-Zanskar and Kumaun. A substantial amount of data that has now accumulated in both the areas on lithology, geochemistry and biological changes is analysed and possible inferences are drawn.

Key-words—Lithology, Geochemistry, Biological changes, Precambrian-Cambrian transition, Northwest Himalaya, India.

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सारांश

उत्तर-पश्चिम हिमालय में कॅम्ब्रियनपूर्व-कॅम्ब्रियन सीमा परिवर्तन पर भौतिक, भूरासायनिक एवं जैविक बदलाव

वी.के. माथुर, प्रभात कुमार माइती, रविशंकर एवं गोपेन्द्र कुमार

लघु हिमालय तथा काश्मीर, स्पिती-जन्सकर एवं कुमायुँ के उच्च तथा टेथीय हिमालय की क्रोल-ताल पट्टी में कॅम्ब्रियनपूर्व-कॅम्ब्रियन सीमा परिवर्तन का विस्तृत अध्ययन किया गया है। इन दोनों क्षेत्रों से शैलविज्ञान, भूरसायन एवं जैविक अवशेषों पर अभी तक उपलब्ध सभी आँकड़ों का विश्लेषण किया गया है तथा सभी सम्भव निष्कर्ष इस शोध-पत्र में प्रस्तुत किये गये हैं।

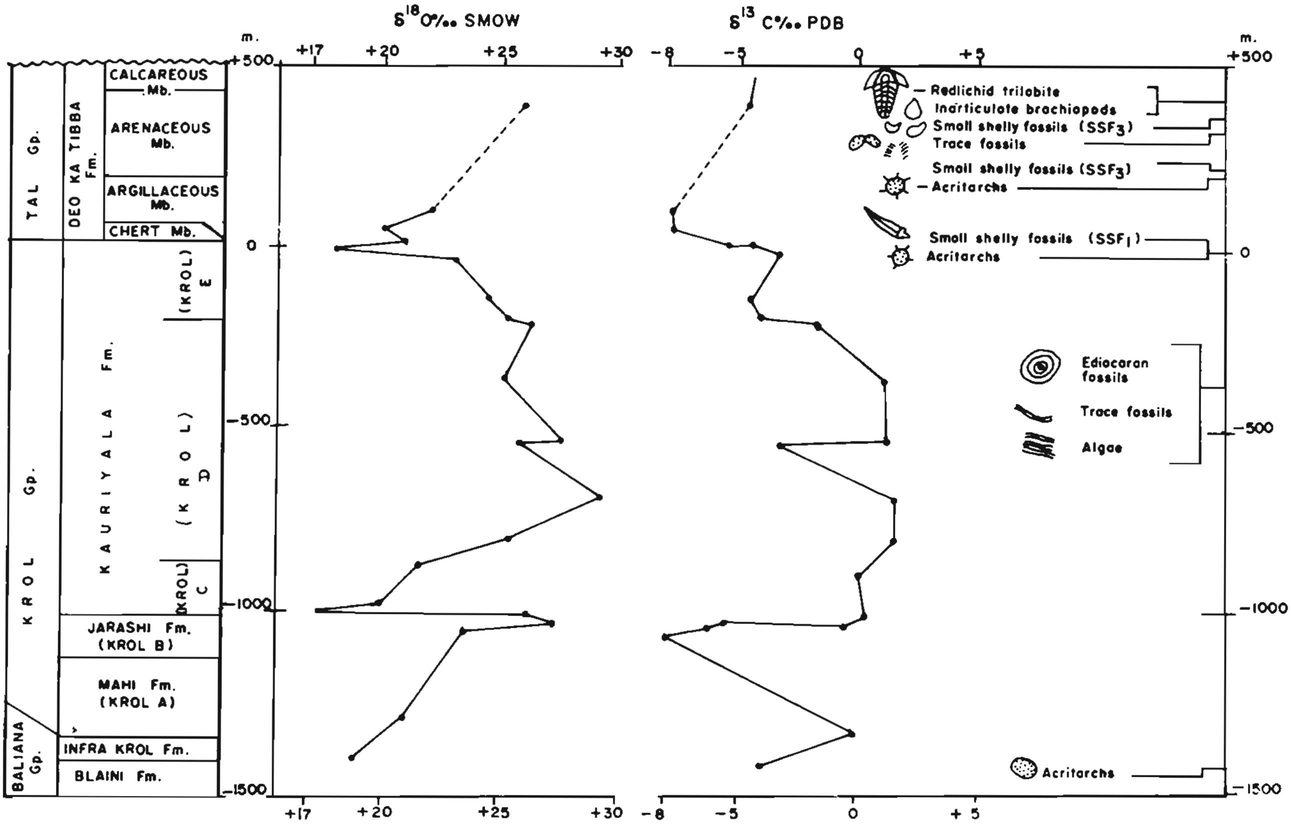
PRECAMBRIAN-CAMBRIAN transition is marked by major biotic changes, viz., emergence of soft bodied Ediacaran fauna and their subsequent extinction; emergence of fauna with hard parts or skeleton and chemical changes, particularly variations in the C- and Sr- isotopic compositions of the carbonates. All of them provide significant stratigraphic information which may be used for the correlation of Terminal Proterozoic-Early Cambrian strata (Knoll & Walter, 1992; Narbonne *et al.*, 1994). Nutrient-enriched water masses (NEW) with high levels of dissolved phosphate and silica, and low levels of oxygen have left a clear imprint on the history of fossil records of the latest Proterozoic-Early Cambrian (Brasier, 1992).

PHYSICAL CHANGES

The sedimentation of the Terminal Proterozoic-Cambrian succession, constituting the Supersequence-IV (Shanker *et al.*, 1989, 1996), commenced with a widespread marine transgression in parts now forming the northwestern Himalaya over the Supersequence-III comprising Salkhala with grandis *ca* 750 Ma, Simla Group and equivalent of Mesoproterozoic-Early Neoproterozoic age (Shanker *et al.*, 1996) in response to global warming after the Varangian glaciation (610-590 Ma, Knoll & Walter, 1992). It terminated with Pan-African orogeny in late Upper Cambrian. These sediments are now exposed in the Krol Belt, Lesser Himalaya, in Kashmir Basin in Higher Himalaya, and Spiti-Zanskar and Kumaun Basins in Tethys Himalaya. The sequence shows considerable variation in lithology due to variable conditions of depositional environment and climate and hence has been subdivided into three different formations; three groups in different sectors. In Krol belt it constitutes the Baliana, Krol and Tal Groups (Shanker *et al.*, 1993), the Ramsu, Machhal, Lolab and Karihul Formations in Kashmir, the Batal, Kunzam La and Parahio Formations in Spiti-Zanskar and the Rilkot, Bilju and Milam Formations in Kumaun; the Karihul and Parahio Formations are of Middle to early Late Cambrian age. Of these, the basal formations, the Baliana and Ramsu, are areno-argillaceous in nature with impersistent bands of conglomerate and or diamictite deposited under unstable shallow marine environment. The middle part of the succession is dominated by carbonate evaporate succession—the Krol Group, in the Krol belt. It is an algal mat facies deposited under stable platform conditions in an arid climate; lenticular and nodulous black chert in upper part indicating deepening of the basin. The development of chert may be related to Caldecote igneous event (*ca* 560-540 Ma; Brasier, 1985) recorded in English Midlands. The Machhal, Batal and Rilkot-Bilju Formations, dominantly argillaceous in nature, are the corresponding successions deposited in deeper euxenic environment. The upper part of the sequence constituting the Lolab and Kunzam La Formations is dominantly arenaceous indicating upliftment of the source area. The corresponding succession in the Krol Belt continues to be argillaceous with development of thick black chert with or without phosphorite forming the lower part of the Tal Group deposited in reducing environment under shallow marine neritic zone (Shanker, 1971). The upper part of the Tal Group is, however, dominantly arenaceous. The entire sequence in the Krol Belt bears close lithological similarity with the corresponding succession in Yangtze Platform, China (Kumar, 1984).

CHEMICAL CHANGES

Studies by Bhattacharya *et al.* (1996) on Carbon isotopes in the Krol Belt indicate the existence of four substantial depletions in $\delta^{13}C$ values in the Baliana-Krol-Tal groups. The first depletions in $\delta^{13}C$ values are noticed in the pink carbonates of Baliana Group, and the fourth in the carbonates of Kauriyala Formation (Krol E) and continues into lower part of Deo Ka Tibba Formation of Tal Group. The Baliana depletion corresponds to the end of Varangian glaciation. The fourth, in fact, occurs immediately above Ediacaran fossiliferous horizon in Precambrian-Cambrian transition sequence throughout the world (Knoll & Walter, 1992; Narbonne *et al.*, 1994). The other two depletions in $\delta^{13}C$, noticed in the carbonates



Text-figure 1—Integrated chemostratigraphy and biostratigraphy of Baliana-Krol-Tal succession, Lesser Himalaya, India (modified after Bhattacharya *et al.*, 1996).

of Kauriyala Formation (Krol D), may be due to local basinal conditions. Most of carbonate samples of the sequence with $\delta^{18}O$ values range from 20 to 30 per cent. SMOW are characteristic of Proterozoic sedimentary carbonate of inorganic origin.

Preliminary analytical data on clay separates of seven samples from the Baliana-Krol-Tal sequence show LREE enriched HREE depleted (fractional) pattern with no Eu anomaly from Baliana to middle part of Kauriyala (Krol D) Formation. However, the upper part of Kauriyala (Krol E) to lower part of Tal Group (Deo Ka Tibba Formation) shows LREE enriched pattern with a small sized -ve Eu anomaly. Similar decrease in concentration of Eu is observed in sediments at Precambrian-Cambrian transition which also coincides with upper Carbon isotopic excursion in the sequence (Bhattacharya *et al.*, 1996).

BIOLOGICAL CHANGES

In Himalayan Precambrian-Cambrian transition sequences of stromatolites, algae, acritarch, microphytolite, Ediacaran fossils, small shelly fossils, trace fossils besides redlichid trilobites and inarticulate brachiopods, are now well-known (Kumar, 1995). Rapid evolution and diversification of biota leading to the appearance of hard parts or skeleton in animals noticed above the fourth depletion in $\delta^{13}C$ values, i.e., above the Ediacaran fossiliferous horizon in the Baliana-Krol-Tal sequence in Krol Belt is globally identified.

The stromatolites in Baliana Group are simple stratified type - *Stratifera undata* (Sharma *et al.*, 1994) and become columnar and domal in Krol and Tal Groups. Recorded forms are *Conophyton garganicus* and *Baicalia baicalica* (Singh & Rai, 1977), *Aldania mussoorica, A. birpa, Collumnefacta vulgaris, Boxonia gracilis* and *Ilicta talica* (Tewari, 1988; Tewari *et al.*, 1988). Maithy *et al.* (1995) reported Hyellace forms in Baliana Group. Tewari (1988) reported Vendotaenid from Mahi Formation of Krol Group. Singh and Rai (1983) reported calcareous algae *Epiphyton* and *Renalcis* from the Kauriyala Formation. Ahluwalia and Bhargava (1987) recorded the spirally coiled form of algae *Obruchevella* in the chert Member of Deo Ka Tibba Formation. Microphytolite-oncolites and catagraphs are known from Kauriyala Formation (Gundu Rao, 1970). These forms are known from Late Precambrian of Siberian Platform, Russia. Prasad *et al.* (1990) and Venkatachala *et al.* (1992) have reported the assemblages of acritarch from Baliana-Krol-Tal sequence. Analysis of the reported forms shows that Leiosphaeridia Group is dominant in Baliana and Krol Groups while in Tal Group ornamented forms are the main constituents.

In Higher Himalaya, acritarch belonging to Sphaeromorphida, both simple and ornamented types, have been reported from the Machhal and Lolab Formations (Kumar *et al.*, 1984 a, 1984b; Maithy *et al.*, 1988).

First multicellular animals in the form of Ediacaran fossils—*Beltanella* sp., *Tirasiana* sp., *Medusinites* sp., ? *Pteridinium* sp., *Kimberella* sp., cf. *K. quadrata, Cyclomedusa davidi, Conomedusites lobatus, Charniodiscus?* sp. and *Zolotytsia biserialis* (Mathur & Shanker, 1989, 1990; Shanker & Mathur, 1992; Shanker *et al.*, 1997) have been recorded from the Kauriyala Formation (Krol D). The above reported forms are known world wide and are important time marker. Ediacaran assemblage in India also occurs in the rocks deposited during relatively stable $\delta^{13}C$ interval of +1 to +2 per cent PDB that occurs below Precambrian-Cambrian boundary.

The small shelly fossils are mainly recorded from the Chert Member to Calcareous Member of Deo Ka Tibba Formation (Azmi, 1983; Azmi & Pancholi, 1983; Bhatt *et al.*, 1983, 1985; Kumar *et al.*, 1983, 1987; Brasier & Singh, 1987). They have been grouped into following three assemblages in ascending order:

1. *Anabarites-Protohertzina-Circotheca,*
2. *Dimidia-Allonia*, and
3. *Pelagiella-Auriculatespira.*

Small shelly fossils of assemblage-I and II are correlated by Kumar *et al.* (1987) with Meishucunian Zone I and III of China. Small shelly fossils have also been recorded from the underlying Krol Group (Das *et al.*, 1987; Bhatt & Mathur, 1990). The biogenicity and identification of these records have been doubted by Bhatt (1989) and Kumar (1995).

The trace fossils are rich and diverse below the lowest occurrence of Lower Cambrian redlichid trilobites and inarticulate brachiopods of Botomian Stage (early Tsanglangpuian Stage of China) both in Lesser and Higher Himalaya. In Krol Belt, trace fossils recorded from the upper part of Krol Group are simple and are represented by *Gordia* sp., *Bilinichnus biserialis* and ichnogenus A (Shanker *et al.*, 1997). Complex type of trace fossils, viz., *Rusophycus* sp., *Cruziana* sp., *Monomorphichnus* sp., *Diplichnites* sp., *Astropolichnus* sp. and *Skolithos* sp. Assemblages equivalent to Ichnozone III of Crimes (1987) have been recorded from the Arenaceous Member of Deo Ka Tibba Formation of Tal Group (Kumar *et al.*, 1983; Singh & Rai, 1983; Mathur *et al.*, 1988).

The fossils from Kashmir are in fact of advanced organisation and have been grouped into following four assemblages in ascending order:

Assemblage I—*Planolites beverleyensis-P. reticulatus*,

Assemblage II—*Arenicolites-Gordia-Phycodes* (? *P. pedum*),

Assemblage III—*Monomorphichnus-Diplichnites-Astopolithon (Astropolichnus) Tephrelminthopsis circularis*, and

Assemblage IV—*Rusophycus didymus-Isopodichnus-Kupwaria fusiformis*.

Assemblage I is from the basal part of Razdain Member of Lolab Formation and has been assigned to Late Precambrian (Kumar *et al.*, 1984a, 1984b). In addition to *Planolites*, it also contains *Skolithos* and *Burgauria*. Assemblage II contains *Skolithos* and *Monomorphichnus*. In Assemblage III, trace fossils are ubiquitous and occur in upper part of Razdain Member (Kumar *et al.*, 1984a, 1984b), in Kunzam La Formation of Spiti (Bhargava *et al.*, 1982; Bhargava & Srikantia, 1982) and Arenaceous Member of Deo Ka Tibba Formation of Tal Group (Singh & Rai, 1983; Mathur *et al.*, 1988). The other characteristic fossils of this assemblage are *Dimorphichnus, Gyrochorte, Planolites corugatus, Phycodes palmatum, Bifasciculus, Bifungites*, etc. (Shah & Sudan, 1983; Bhargava & Srikantia, 1982). The ichnofossils of Assemblage IV are well developed in Spiti (Bhargava & Srikantia, 1982). Assemblages II, III and IV correspond to Assemblage II of Kumar (1988) that has been assigned an Upper Tommotian-Lower Atdabanian age as it contains SSF of Assemblage II correlatable to Meishucunian Zone III of China and Ichnozone III of Crimes (1987). Trace fossil assemblages I and II from Kashmir may possibly be correlated with Ichnozone I and II of Crimes (1987). Still more data is required for its establishment.

Based upon the above discussion the following inferences are drawn :

1. The stable carbon isotopic studies in Krol Belt, Lesser Himalaya record four depletions in $\delta^{13}C$ values in Baliana-Krol-Tal succession. The first corresponding to end of Varangian glaciation is in the basal part and the fourth lies in Precambrian-Cambrian Transition Zone, above the Ediacaran fossiliferous horizon.
2. There was a rapid evolution and diversification of biota with the appearance of hard parts above the level of fourth depletion in $\delta^{13}C$ values, which is globally identified.
3. Significantly, like many diverse assemblages of Ediacaran fossils of the world including type assemblage in Ediacaran hills of South Australia, Ediacaran assemblage in India also occurs in rocks deposited during relatively stable $\delta^{13}C$ interval of + 1 to + 2 per mil PDB that occurs below the Precambrian-Cambrian Boundary.
4. The record of -ve Eu anomaly in Krol-Tal sequence is also significant as it is known world wide in Phanerozoic sediments only.
5. Assemblage I (Small shelly fossils) recorded from the Chert Member of Deo Ka Tibba Formation of Tal Group is of earliest Cambrian age.
6. Precambrian-Cambrian Boundary has been globally demarcated in between Ichnozone I and II. The same is not marked in Indian subcontinent, as such the basal part of Cambrian may be missing in India.
7. Trace fossils of Ichnozone III are ubiquitous. Their presence is known in NW Himalaya and is correlatable with GSSP.
8. The Krol Belt succession bears close lithostratigraphic and biostratigraphic similarity with that of Yangtesse Platform, China excepting that the Meishucunian Zone II fauna has not been recorded so far from India.

REFERENCES

Ahluwalia AD & Bhargava CN 1987. Petrographic classification of phosphorites—two alternatives. *Mem. geol. Soc. India* **13** : 61-73.

Azmi RJ 1983. Microfauna and age of lower Tal phosphorite of Mussoorie Syncline, Garhwal Lesser Himalaya. *Himalayan Geol.* **11** : 373-409.

Azmi RJ & Pancholi VP 1983. Early Cambrian (Tommotian) conodonts and other shelly microfauna from upper Krol of Mussoorie Syncline, Garhwal Lesser Himalaya with remarks on the Precambrian-Cambrian Boundary. *Him. Geol.* **11** : 360-372.

Bhargava ON, Kumar G & Gupta SS 1982. Cambrian trace fossils from the Spiti Valley, Himachal Himalaya. *J. geol. Soc. India* **23** : 183-191.

Bhargava ON & Srikantia SV 1982. *Taphrelminthopsis circularis* from ? Cambrian sediments of northeast Kashmir Valley. *J. geol. Soc. India* **23** : 406-407.

Bhatt DK 1989. Small shelly fossils of Tommotian and Meishucunian stages and Precambrian-Cambrian boundary—implications of recent studies in Himalayan sequence. *J. palaeont. Soc. India* **34** : 55-69.

Bhatt DK, Mamgain VD & Misra RS 1985. Small shelly fossils of Early Cambrian (Tommotian) age from Chert-Phosphorite Member, Tal Formation, Mussoorie Syncline, Lesser Himalaya, India and their chronostratigraphic evaluation. *J. palaeont. Soc. India* **30** : 93-102.

Bhatt DK, Mamgain VD, Misra RS & Srivastava JP 1983. Small shelly microfossils of Tommotian age (Lower Cambrian) from chert-Phosphorite Member of Lower Tal Formation, Maldeota, Dehra Dun District, U.P. *Geophytology* **13**(1) : 116-123.

Bhatt DK & Mathur AK 1990. Small shelly fossils of Precambrian-Cambrian boundary from Krol-Tal succession in the Naini Tal Syncline, Lesser Himalaya. *Curr. Sci.* **59**(4) : 218-222.

Bhattacharya SK, Jani RA, Mathur VK, Absar A, Bodas MS, Kumar G & Shanker R 1996. Stable carbon and oxygen isotopic changes and rare earth elements across Precambrian-Cambrian boundary, Lesser Himalaya. *Proc. Symp. NW Himalaya and foredeep, Geol. Surv. India, Spec. Publ.* **21**(1) : 225-231.

Brasier MD 1985. Evolutionary and geological events across the Precambrian-Cambrian Boundary. *Geology Today* (Sept.-Oct.) : 141-146.

Brasier MD 1992. Nutrient enriched waters and the early skeletal fossil records. *J. geol. Soc. London* **149** : 621-629.

Brasier MD & Singh P 1987. Microfauna and Precambrian-Cambrian boundary stratigraphy at Maldeota, Lesser Himalaya. *Geol. Mag.* **124**(4) : 323-345.

Crimes TP 1987. Trace fossils and correlation of Late Precambrian and Early Cambrian strata. *Geol. Mag.* **124** : 97-110.

Das DP, Raha PK & Acharyya SK 1987. Tommotian shelly microfauna from basal part of upper Krol. *Indian Minerals* **41**(4) : 49-59.

Gundu Rao C 1970. A note on 'Oolites' in the Krol Series and their age significance. *Publ. Centre Adv. Geol. Punjab. Univ., Chandigarh* **32**: 127-129.

Knoll AH & Walter MR 1992. Latest Proterozoic stratigraphy and earth history. *Nature* **356** : 673-678.

Kumar G 1984. The Precambrian-Cambrian Boundary beds, northwestern Himalaya, India. *Proc. V Indian geophytol. Conf.* : 98-111. The Palaeobotanical Society, Lucknow.

Kumar G 1995. The Precambrian-Cambrian biostratigraphy of NW Himalaya and correlation. *In : Proc. Int. Conf. Global environment and diversification of plants through geological time, Birbal Sahni Centenary Vol., Society of Indian Plant, Taxonomists* : **5** : 159-165. Allahabad Univ., Allahabad.

Kumar G, Bhatt PK & Raina BK 1987. Skeletal microfauna of Meishucunian and Qiongzhusian (Precambrian-Cambrian boundary) age from the Ganga Valley, Lesser Himalaya, India. *Geol. Mag.* **124**(2) : 167-171.

Kumar G, Raina BK, Bhargava ON, Maithy PK & Babu R 1984a. The Precambrian-Cambrian boundary problem, NW Himalaya, India. *Geol. Mag.* **121**(3) : 211-219.

Kumar G, Raina BK, Bhatt PK & Jangpangi 1983. Lower Cambrian body and trace fossils from Tal Formation, Garhwal Synform, U.P., India. *J. palaeont. Soc. India* **28** : 105-110.

Kumar G, Raina BK, Maithy PK, Prasad B, Babu R, Bhargava ON & Srivastava RN 1984b. Demarcation of Precambrian-Cambrian boundary : status of work in IGCP-Project 29. *Geol. Surv. India.*

Maithy PK, Babu R, Kumar G & Mathur VK 1995. New cyanophycean remains from the Blaini Formation (Terminal Neoproterozoic sequence) of Mussoorie Syncline, Lesser Himalaya, India. *Palaeobotanist* **43**(1) : 39-44.

Maithy PK, Babu R, Raina BK & Kumar G 1988. Proterozoic microfossils from the Machhal and Lolab Formations of Kashmir Himalaya, India. *N. Jb. geol. Palaeont. Mh.* **10** : 639-644.

Mathur VK, Joshi A & Kumar G 1988. Trace fossils from Cambrian Tal Formation, Himachal Lesser Himalaya, India and their stratigraphic significance. *J. geol. Soc. India* **31** : 467-475.

Mathur VK & Shanker R 1989. First record of Ediacaran fossils from the Krol Formation of Naini Tal Syncline. *J. geol. Soc. India* **34**(3) : 245-254.

Mathur VK & Shanker R 1990. Ediacaran medusoids from the Krol Formation, Naini Tal Syncline, Lesser Himalaya. *J. geol. Soc. India* **36**(1) : 74-78.

Narbonne GM, Kaufman AH & Knoll AH 1994. Integrated chemostratigraphy and biostratigraphy of the Windermere Supergroup, NW Canada : implications for Neoproterozoic correlations and the early evolution of animals. *Geol. Soc. Am. Bull.* **106** : 1281-1292.

Prasad B, Maithy PK, Kumar G & Raina BK 1990. Precambrian-Cambrian acritarchs from the Blaini-Krol-Tal succession of Mussoorie Syncline, Garhwal Lesser Himalaya, India. *Geol. Soc. India Mem.* **16** : 19-32.

Shah SK & Sudan CS 1983. Trace fossils from the Cambrian of Kashmir and their stratigraphic significance. *J. geol. Soc. India* **24**(4) : 194-202.

Shanker R 1971. Stratigraphy and sedimentation of Tal Formation, Mussoorie Syncline, Uttar Pradesh. *J. palaeont. Soc. India* **16** : 1-15.

Shanker R, Kumar G, Mathur VK & Joshi A 1993. Stratigraphy of Blaini, Infra Krol and Tal succession, Krol Belt, Lesser Himalaya. *Indian J. Petr. Geol.* **2** (2) : 99-136.

Shanker R, Kumar G & Saxena SPA 1989. Stratigraphy and sedimentation in Himalaya—a reappraisal. *Geol. Surv. India, Spec. Publ.* **26** : 1-60.

Shanker R, Kumar G & Singh G 1996. Sequence stratigraphy and major geological events of Himalaya. *Geol. Surv. India, Spec. Publ.* **21** : 1-21.

Shanker R & Mathur VK 1992. Precambrian-Cambrian sequence in Krol belt and additional Ediacaran fossils. *Geophytology* **22** : 25-36.

Shanker R, Mathur VK, Kumar G & Srivastava MC 1997. Additional Ediacaran biota from the Krol Group, Lesser Himalaya, India and their significance. *Geoscience J.* **18**(1) : 79-94.

Sharma M, Mathur VK, Srivastava MC & Shukla M 1994. Systematics and significance of microbialite (stromatolite) *Stratifera undata* from Mussoorie Syncline, Lesser Himalaya. *J. geol. Soc. India* **43** : 705-712.

Singh IB & Rai V 1977. Occurrence of stromatolites in the Krol Formation of Naini-Tal area and its implications on the age of the Krol Formation. *Curr. Sci.* **46** : 736-738.

Singh IB & Rai V 1983. Fauna and biogenic structure in Krol-Tal succession (Vendian-Early Cambrian), Lesser Himalaya; their biostratigraphic and palaeontological significance. *J. palaeont. Soc. India* **28** : 67-90.

Tewari VC 1988. Discovery of Vendotaenids from India. (Abstract) *Indo-Soviet Symp. on Stromatolites and stromatolitic deposits, WIHG, Debradun* : 25-28.

Tewari VC, Mathur VK & Joshi A 1988. Discovery of Lower Cambrian (Lenian) stromatolites from Phulchatti Member (Tal Formation), Korgai syncline, Lesser Himalaya, (Abstract). *Indo-Soviet Symp. on Stromatolites and stromatolitic deposits, WIHG, Debradun* : 28-30.

Venkatachala BS, Shukla M, Shanker R, Mathur VK & Srivastava MC 1992. Stratigraphical significance of Precambrian-Cambrian acritarchs from Blaini-Krol-Tal succession of Garhwal Syncline, Lesser Himalaya, India (Abstract). *IV I.O.P. International de Palaeobotanique Congr., Paris, 1982.*

Terminal Proterozoic-Cambrian sequences in India: a review with special reference to Precambrian-Cambrian Boundary

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Kumar G, Shanker R, Maithy PK, Mathur VK, Bhattacharya SK & Jani RA 1997. Terminal Proterozoic-Cambrian sequences in India : a review with special reference to Precambrian-Cambrian Boundary. *Palaeobotanist* **46** (1,2): 19-31.

The Terminal Proterozoic marine sequences, grading into Cambrian, are present in the Krol Basin (Lesser Himalaya), the Kashmir, Spiti-Zanskar and Kumaun Basins (Higher Himalaya) and in Marwar Basin (western India). These sequences post-date a major tectono-thermal event associated with Cadomian Orogeny and rest on eroded older successions which include well dated Malani Igneous Suite (Malani Rhyolite 745 ±10 Ma; Siwana Granite 731± 14 Ma) in western India and over the Salkhala Group with granites (745 ± 50 Ma) or the Simla Group in the Himalaya. This cycle of sedimentation terminated with Pan-African Orogeny in Late Cambrian. These sequences are dominantly siliciclastic in basins in Higher Himalaya while those in Krol Basin and Marwar Basin show development of thick carbonate-evaporite facies with or without phosphorite. From the Upper Vindhyan and Bhima Groups in central and south India, respectively a *Chuaria-Tawuia* Assemblage along with sphaeromorphida Acritarch of Early Neoproterozoic age has been recorded. The $\delta^{13}C$ values range from +1.3 to +4.0 ‰ PDB and that of $\delta^{18}0$ from -5 to -9 ‰ PDB. These are, thus, not considered part of this sequence. In absence of age-determinating biota and radiometric dates from the basal part of the succession, the lower boundary of the Terminal Proterozoic can not be delineated and dated. However, a significant depletion in $\delta^{13}C$ values may be taken to mark the lower boundary.

The upper boundary of the Terminal Proterozoic (Precambrian-Cambrian Boundary) can not be demarcated in terms of GSSP due to absence of trace fossils of Zone-I (*Harlaneilla podolika* Zone) and Zone-II (*Phycodes pedum* Zone) in carbonate facies in Krol Basin and poor documentation of siliciclastic facies in Kashmir and Spiti-Zanskar Basins. The trace fossils correlative with ichnozone-III occur in all the sections in Himalaya and are useful for regional and global correlations. However, a significant depletion in $\delta^{13}C$ values has been recorded in the carbonate facies of Krol Basin between the horizons yielding Ediacaran and small shelly fossils of Meishucunian Zone-I. This has also been recorded in the Marwar Basin below the Phosphorite Bed. This depletion may be correlated with that recorded from the Precambrian-Cambrian transition in Siberian Platform, Anti Atlas Mountains, Morocco, China, etc. It may be taken into consideration to define and mark the boundary in the absence of trace fossils.

Key-words — Terminal Proterozoic, Cambrian Sequences, Precambrian-Cambrian Boundary, India.

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साराँश

भारत में अंतिम प्रोटीरोजोइक-कॅम्ब्रियन अनुक्रम : कॅम्ब्रियनपूर्व-कॅम्ब्रियन सीमा पर विशेष सन्दर्भ सहित एक समीक्षा

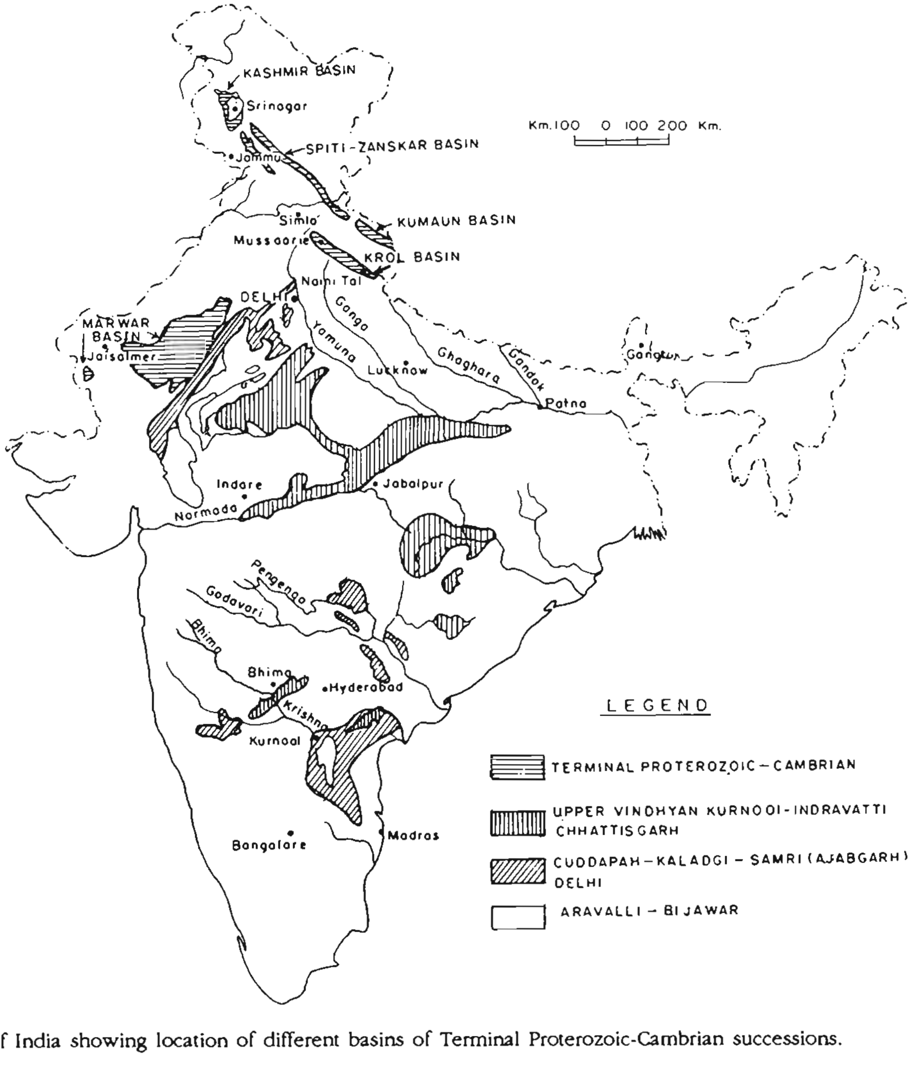
गोपेन्द्र कुमार, रविशंकर, प्रभात कुमार माइती, वी.के. माथुर, एस. के. भट्टाचार्य एवं आर. ए. जानी

अन्तिम प्रोटीरोजोइक समुद्री अनुक्रम क्रोल द्रोणी (लघु हिमालय), काश्मीर स्पिति-जन्सकार एवं कुमायुं द्रोणी (उच्च हिमालय) तथा पश्चिमी भारत में मारवाड़ द्रोणी में विद्यमान हैं। ये अनुक्रम कोडोमियन उत्पत्ति से सहयुक्त एक प्रधान विवर्तनिक-तापीय घटना के समकालीन हैं तथा अन्य शेष अनुक्रम पुरानी अनुक्रमों के ऊपर स्थित हैं। अवसादन का यह चक्र अनंतिम कॅम्ब्रियनकाल में पैन-अफ्रीकी उत्पत्ति के साथ-साथ समाप्त हो गया। उच्चतर हिमालय में ये अनुक्रम द्रोणीयों में सिलिसिक्लास्टिक से प्रभावी हैं तथा क्रोल एवं मारवाड़ द्रोणीयों में फोस्फोराइट युक्त अथवा फोस्फोराइट विहीन मोटे कार्बोनेट-इवेपोराइट संलक्ष्णीयों का धीमा विकास प्रदर्शित करते हैं। केन्द्रीय एवं दक्षिण भारत में क्रमशः उपरि विन्ध्य एवं भीमा समूहों से प्रारम्भिक निओप्रोटीरोजोइक आयु के एक्रीटार्को सहित एक *चुआरिया-तवुइया* समुच्चय अभिलिखित की गई है । डेल्टा कार्बन^{13} आँकड़े +1.3 से. +4.0 प्रति हजार पी.डी.बी. तथा डेल्टा ऑक्सीजन^{18} के आँकड़े -5 से -9 प्रति हजार की दर से आँके गये हैं जिसके कारण ये इस अनुक्रम में सम्मिलित नहीं किये गये हैं। इस अनुक्रम के आधारी भाग की आयु संबन्धी एवं रेडियोमितीय आँकड़ों की अनुपस्थिति के कारण अंतिम प्रोटीरोजोइक की सीमा सुनिश्चित नहीं की जा सकी है। तथापि डेल्टा कार्बन^{13} के आँकड़ों के आधार पर इसे निचली सीमा माना जा सकता है।

काश्मीर एवं स्पिती-जन्सकार द्रोणीयों में सिलिसिक्लास्टिक संलक्षणी की अल्प संख्या तथा क्रोल द्रोणी में कार्बोनेट संलक्षणी में मंडल-1 (*हार्लेनियॅल्ला पोडोलिका* मंडल) एवं मंडल-2 (*फाइकोड्स पीडम* मंडल) की अनुपस्थिति के कारण अंतिम प्रोटीरोजोइक (कॅम्ब्रियनपूर्व-कॅम्ब्रियन सीमा) की ऊपरी सीमा सुनिश्चित नहीं की जा सकती। इक्नोजोन-3 के समतुल्य ट्रेस जीवाश्म हिमालय में सभी खंडों में मिलते है तथा क्षेत्रीय एवं भूमण्डलीय तुलनाओं की दृष्टि से बहुत महत्वपूर्ण हैं। तथापि मीशुक्वान मंडल-1 के एडियाकरन एवं छोटे शैली जीवाश्म धारक संस्तरों के मध्य क्रोल द्रोणी की कार्बोनेट संलक्षणी में डेल्टा कार्बन^{13} के आँकड़ों में महत्वपूर्ण ह्रास देखा गया है। मारवाड़ द्रोणी में फोस्फोराइट संस्तर के नीचे भी ऐसा ही प्रेक्षित किया गया है। इस ह्रास की तुलना साइबेरियन प्लेटफार्म, एन्टी एटलस पर्वत, मोरक्को, चीन आदि में कॅम्ब्रियन पूर्व-कॅम्ब्रियन परिवर्तन से भी की जा सकती है। ट्रेस जीवाश्मों की अनुपस्थिति में सीमांकन करने में भी इसका सदुपयोग किया जा सकता है।

OF LATE, the marine sequences, referred variously as the Sinian, Vendian or Ediacaran, forming the latest Precambrian or Terminal Proterozoic and grading into Cambrian, are receiving an international cooperation in connection with defining the lower and upper age limits and identification of events for regional and global correlation. The question of placing the boundaries became the topic of international discussions which led to the formation of two working groups (WG), one under the aegis of IUGS-IGCP Project 29 for the Demarcation of the Precambrian-Cambrian Boundary in 1976 with the objective to recommend criteria for and identify a global stratotype section and point (GSSP) for the boundary. The other one under IUGS to study the Terminal Proterozoic System in 1988 with the aim to define the chronostratigraphic base of the period.

The section in Canada was ultimately chosen as the GSSP by the WG of IGCP 29 which was subsequently ratified by the Executive Committee



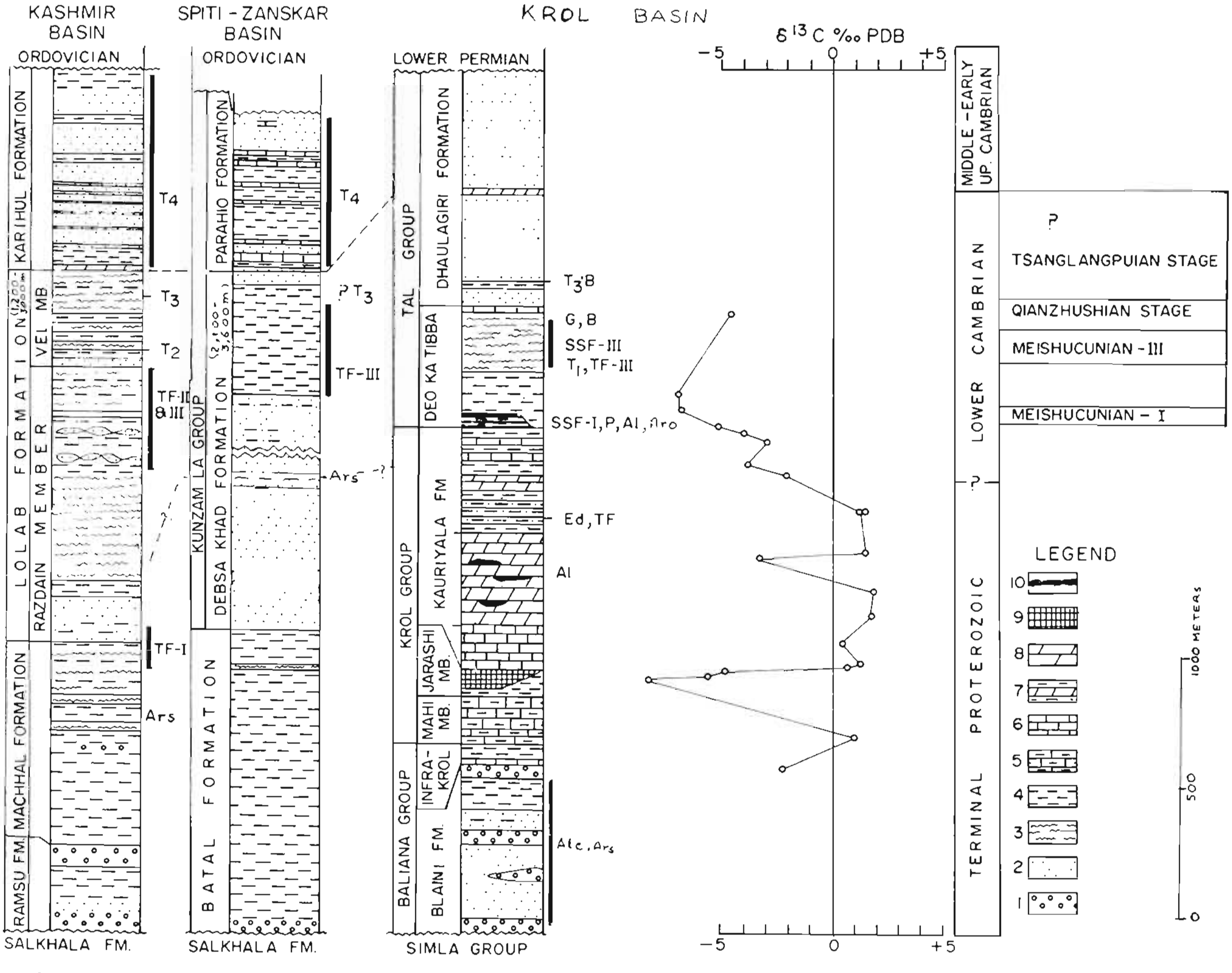
Text-figure 1—Map of India showing location of different basins of Terminal Proterozoic-Cambrian successions.

and Council IUGS in 1992 (Landing, 1994). This GSSP, however, did not meet the basic requirements of global correlation and posed certain problems as like other fossils, the trace fossils are also facies controlled being more abundant in siliciclastic facies. The stress, therefore, was given to develop an "integrated and refined global biostratigraphy, chemostratigraphy and event stratigraphy for the Precambrian-Cambrian interval" in another IGCP Project 303 formed in 1991.

In India, the Terminal Proterozoic succession grading into Cambrian, constituting the Supersequence IV (Shanker *et al.*, 1989, 1996), is represented in Krol, Kashmir, Spiti-Zanskar, Kumaun and Marwar Basins (Text-figure 1). This succession is of special significance as it contains large deposits of evaporites (gypsum and or salt), rock-phosphate, and oil and natural gas in certain sectors. Different sections in these basins were studied to identify lithostratigraphic, biostratigraphic, chemostratigraphic and event stratigraphic markers for defining the lower and upper age limits of the Terminal Proterozoic System for regional and global correlations. The studies were also extended to Bhima Basin in South India in addition to upper part of the sequence in the Vindhyan Basin of central India; as these successions were considered to grade into Cambrian.

KROL, KASHMIR, SPITI-ZANSKAR BASINS

The Terminal Proterozoic succession grading into Cambrian, forming the Supersequence IV (Shanker *et al.*, 1989, 1996), is exposed in the Krol

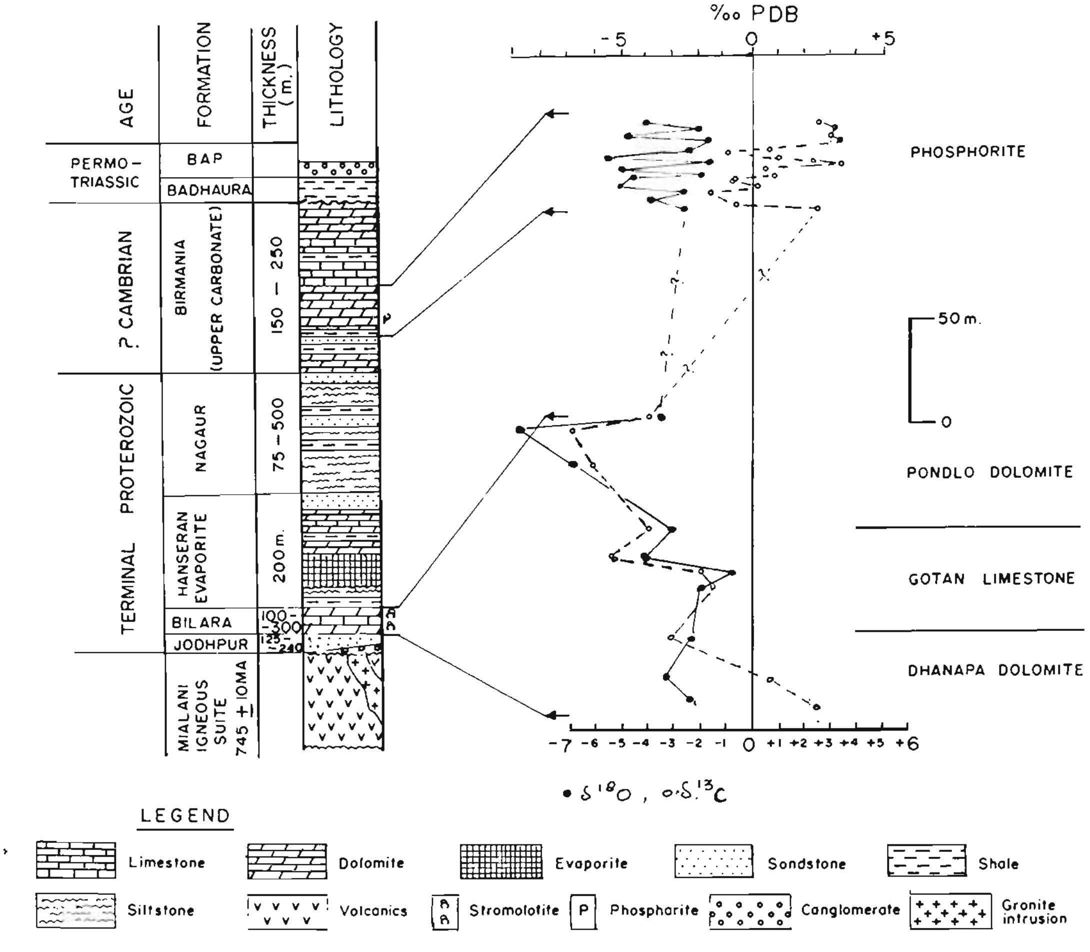


Text-figure 2—Generalised compositelithocolumns of Terminal Proterozoic Cambrian successions in Kashmir, Spiti-Zanskar and Krol Basins in Himalaya, India (1. Conglomerate/diamictite, 2-Sandstone, 3. Siltstone, 4. Shale, 5. Argillaceous limestone, 6. Limestone, 7. Interbedded dolomite and shale, 8. Dolomite, 9. Gypsum, 10. Chert; TF-I, II, III Trace fossil zones; T1-4- Trilobites; G- Microgastropods; B- Brachiopods; SSF-I, III- Small Shelly Fossils zones; Ed- Ediacaran fossils; Al-Calcareous algae; Alc- Cyanophycean algae; Ars-Acritarchs unornamented; Aco-Acritarchs ornamented; P-Phosphorite).

Basin (Lesser Himalaya), Kashmir Basin (Higher Himalaya) and Spiti-Zanskar and Kumaun Basins (Tethys Himalaya). These rest transgressively over the Early Neoproterozoic Simla Group or over the Salkhala Group with granites dating 745 ± 50 Ma or their equivalents (Text-figure 2). The successions in basins in Higher and Tethys Himalaya are unconformably overlain by Lower Ordovician sediments of Supersequence V (Shanker *et al.*, 1989, 1996), while in Krol Basin, the Lower Permian succession forming part of the Supersequence VI (Shanker *et al.*, 1996) rests unconformably over it.

The sedimentation in the Himalayan basins starts with a conglomerate or diamictite at the base but higher up, it is areno-argillaceous with bands of limestone/dolomite appearing in the upper part. The sequence is subdivisible into Ramsu, Machhal, Lolab and Karihul Formations in Kashmir Basin and Batal, Kunzam La and Parahio Formations in Spiti-Zanskar Basin. In the Krol Basin, the sequence comprises the Baliana, Krol and Tal Groups, in ascending order. The Krol Group is essentially a carbonate-evaporite deposit. The basal part of the Tal Group contains, at places, phosphorite beds with small shelly fauna of Meishucunian Zone-I.

The presence of Middle to early Upper Cambrian trilobites in the Karihul and Parahio Formations indicates the upper age limit of the succession being early Upper Cambrian. This cycle of sedimentation terminated with Pan-African Orogeny when the sea receded and the area was uplifted. The earliest trilobites recorded from the succession belong to the Tsanglangpuian Stage of Lower Cambrian and include *Paokannia magna* correlatable to *Drepanuroides* zone of Hongjingshao substage of China from Kashmir (Kumar & Verma, 1987) and *Redlichia noetlingi* of Wulnjing substage (upper part of Tsanglangpuian) of China from Lolab Formation (Shah *et al.*, 1980), in Kashmir and Kunzam La Formation, Spiti (Reed, 1910) and Tal Group, Krol



Text-figure 3—Generalised composite lithocolumn of the Marwar Group, western India showing stable carbon and oxygen isotope variations.

Basin (Kumar *et al.*, 1987). Some poorly preserved Redlichiid Trilobites in association with Meishucunian Zone-III small shelly fauna, have also been recorded from underlying beds of the Tal Group (Joshi *et al.*, 1989).

The record of various fossils occurring below trilobite bearing horizon (early Tsanglangpuian Stage) from different successions has been reviewed by Kumar (1995) and discussed by Mathur *et al.* (1997). Among these, records of trace fossils, small shelly fossils and Ediacaran fauna are of special interest for regional and global correlations. The trace fossils are diverse and abundant in silicilastic facies of Higher Himalayan ranges. These have been grouped in three assemblages, which in ascending order are: I-*Planolites beverleyensis-Planolites reticulatus*, II-*Arenicolites-Gordia-Phycodes*, and III-*Monomorphichnus-Dilichnites-Astropolichnus (Astropolithon)-Rusophycus* Kumar 1987. The assemblages I and II are known from Kashmir only and occur in the basal part of the Lolab Formation (Razdain Member).

Assemblage I also contains *Skolithos* and *Bergauria* and has yielded Late Precambrian microbiota (Maithy *et al.*, 1988). Assemblage III is ubiquitous and is recorded from the upper part of Razdain Member of the Lolab Formation (Raina *et al.*, 1989; Shah & Sudan, 1983; Bhargava & Srikantia, 1982) and Kunzam La Formation (Debsa Khad Member, Kumar *et al.*, 1984; Bhargava *et al.*, 1982; Bhargava & Srikantia, 1985). The other characteristic ichnofossils are *Dimorphichnus, Tapherhelminthopsis circularis, Gyrochorte, Planolites corrugatus, Phycodes palmatum, Kupwaria fusiformis, Bifasciculus, Bifungites*, etc. In Spiti, this zone can further be sudivided into *Rusophycus didymus-Isopodichnus* Subassemblage appearing at a higher level. This assemblage in Krol Basin occurs in association with small shelly fossils of assemblage II (Kumar *et al.*, 1987) considered equivalent to Meishucunian Zone-III of China.

STABLE ISOTOPE STUDIES

Stable isotopic studies in the Krol Basin, Garhwal Syncline, reveal four depletions in $\delta^{13}C$ values (Bhattacharya *et al.*, 1996) with corresponding increase in $\delta^{18}O$ values (see Mathur *et al.*, 1997). The first and the fourth depletion in $\delta^{13}C$ values are of

PLATE 1

1. Secondary filling resembling trace fossil in sandstone, Jodhpur Formation, Jodhpur, Rajasthan.
2, 3. Calcareous concretion in sandstone, Jodhpur Formation, Jodhpur, Rajasthan.

significance in defining/demarcation of the lower and upper boundaries of the Terminal Proterozoic System. These two depletions correspond to one recorded in the basal part of the successions deposited immediately after the Varangian glaciation, and the other above the Ediacaran horizon continuing into Cambrian (Knoll & Walter, 1992). The other two short-lived depletions may be related to basinal conditions as the lower one (second depletion) is in horizon containing evaporite deposits, and the upper (third depletion) in deeper carbonates with lenticular black chert. The development of chert may be related to Caldecote Igneous Event of English Midlands (Brasier, 1985). The record of a small-sized negative Eu-anomaly, coinciding with the fourth depletion is significant (Bhattacharya *et al.*, 1996).

MARWAR BASIN

The sediments unconformably overlying the Malani Igneous Suite (Malani Rhyolite 745±10Ma Crawford & Compston, 1970; Siwana Granite 731±14 Ma, in Kochhar & Dhar, 1993) or the older Proterozoic metasediments (Delhi & Aravalli Groups) constituting the Marwar Group (Marwar Supergroup; Pareek, 1981, 1984), are considered to be the southeastern extension of the Precambrian-Cambrian succession of the Salt Range, Pakistan. The sequence is also referred informally as the Trans-Aravalli Vindhyan though it does not form part of the Vindhyan Basin. It is unconformably overlain either by the Permian-Triassic or the Tertiary sequences in the northern and western parts. It is partially or wholly covered by the Neogene-Quaternary sediments of the Indo-Gangetic plain or the Thar Desert. Northwards it has been encountered in bore-holes (Das Gupta & Bulagauda, 1994; Peters *et al.*, 1995). These sediments are mainly exposed in Jodhpur-Nagaur area (also referred as Nagaur Basin). An outlier is also exposed around Birmania, north of Barmer which is considered to be deposited in another basin — the Birmania Basin (Pareek, 1981).

Based on surface and subsurface data (Shrivastava, 1971; Pareek, 1981, 1984; Das Gupta & Bulgauda, 1994; Peters *et al.*, 1995; Dasgupta, 1996) the Marwar Group has been divided into Jodhpur, Bilara, Nagaur and Birmania (Upper Carbonate) Formations in ascending order. The generalised lithostratigraphy is given below :

FORMATION	GENERAL LITHOLOGY
Birmania (Upper Carbonate)	Cherty limestone at base followed by calcareous ferruginous sandstone, quartzitic sandstone, phosphorite, limestone, dolomite at top.
	Unconformity
Nagaur (Tunklian sandstone)	Brick red claystone, siltstone, clay, gritty to pebbly sandstone with fragments and pebbles of chert, dolomite, quartz, quartzite, Malani rhyolite and granite.
	Disconformity
Hanseran Evaporite (Nagaur Sandstone)	Limestone, dolomite with gypsum, anhydrite, halite red to brick red sandstone, siltstone, claystone Khichan conglomerate with cobbles and pebbles and pieces of chert, dolomite, feldspars, sandstone.
	Disconformity
	Pondlo Dolomite : Foetid dolomite, cherty limestone with bands of claystone, siltstone and sandstone; stromatolites in upper 1.5 m.
Bilara	Gotan Limestone: Foetid laminated dark greyish dolomitic limestone and dolomite, stromatolite.
	Dhanappa Dolomite: Chert at base followed by cherty dolomite, siliceous dolomitic limestone.
	Girbhakar Sandstone: Purple, brick red to whitish medium grained to gritty, pebbly sandstone, with bands of shale at base.
Jodhpur	Diastem
	Sonia Sandstone: Buff to whitish, slabby, arkosic sandstone with calc. concretions, shale.
	Pokhran Boulder Bed: Conglomerate with boulders, cobbles and pebbles of Malani Rhyolite, granite.
	Unconformity

Malani Igneous Suite (Malani Rhyolite 745±10 Ma; Siwana Granite 731±14 Ma) and older Proterozoic metasediments of Delhi and Aravalli Groups.

The biostratigraphic studies show that the stromatolites in the Bilara Formation are of stunted growth and include *Collenia pseudocolumnaris* Maslov, *Collenia* sp., *Concollenia* sp., *Cryptozoan accidentalis* Dawson, *Irregularia* sp. and *Stratifera* sp. with occasional oncolites (Barman, 1980). The trace fossil-like structures were also noticed in the Jodhpur Formation; they are all of inorganic origin, some are rill-marks, while others are secondary fillings (Pl. 1, fig. 1). Some rounded calcareous concretions and their impressions after leaching out of the carbonate give the impression of medusoids (Pl. 1, figs 2, 3). The specimen reported by Khan (1973) as brachiopod *Orthis* was examined by one of us (GK) and found to be a pellet.

The preliminary stable isotopic studies show that the δ^{13}C values are in the range of +0.6 to +3.6‰ PDB in the basal part of the Bilara Formation while in upper part the value shows depletion in the range of - 1.3 to -6.9‰PDB which may continue in the overlying Hanseran (Nagaur Sandstone) Evaporite. There is again a short-lived positive excursion (+.4 to 3.6‰ PDB) in the Birmania Formation (Upper Carbonate) at the level of phosphorite bed. The stable carbon isotopic values in the heavy oil recovered from bore-holes in the Birmania Formation give -32.4‰PDB (Das Gupta & Bulgauda, 1994). The oil is non-biodegraded, and thermal-maturation-dependant biomarker ratios indicate generation from source rock which is 'age diagnostic and source dependant biomarkers' indicating that 'the oil originated from algal and bacterial organic matter in Infra-Cambrian, carbonate rich source rock deposited under anoxic marine conditions' (Peters *et al.*, 1995).

VINDHYAN BASIN

The generalised lithostratigraphy based on works of Sarkar, 1981; Mathur, 1981; Soni *et al.*, 1987 is given below:

	GROUP	FORMATION	MEMBER
Upper Vindhyan	Bhander	Bhavpura	
		Balwan Limestone	
		Maihar Sandstone	
		Sirbu Shale	
		Bundi Hill Sandstone	
		Nagod Limestone (Lakheri)	
		Ganurgarh Shale (Simrawal)	
	Rewa	Gahadra Sandstone	
		Jhiri Shale	
		Itwa Sandstone	
		Panna Shale	
	Kaimur	Dhandraul Quartzite	
		Bijaigarh Shale	
		Markundi Quartzite	
		Ghurma Shale	
		Ghagar Quartzite	
		Unconformity	
Lower Vindhyan	Semri	Rohtas Limestone	Suket Shale Nimbahera Limestone Bari Shale Jiran Sandstone Khori Conglomerate
		Glauconite Sandstone	
		Fawn Limestone	
		Olive Shale	
		Chopan Porcellanite	
		Kajrahat Limestone	
		Arangi	
		Unconformity	
Basement of Bundelkhand Granite (Archaean) or Mahakoshal Supergroup (Paleoproterozoic) and its equivalents.			

There is absence of materials for reliable dating and radiometric dates are conflicting (Vinogradov *et al.*, 1964; Crawford & Compston, 1970; Srivastava & Rajagopalan, 1988). There, however, appears to be a broad agreement in considering lower age limit of the Semri Group to be around 1400 Ma and the upper before the intrusion of the Majhgawan pipe dating 1,140 Ma. The sedimentation of the Upper Vindhyan (Kaimur Group) on the other hand, commenced around 940 Ma and was considered to have continued well into Phanerozoic.

On the basis of presence of *Chuaria-Tawuia* assemblage from the Suket Shale of the Rohtas Limestone, Semri Group, Maithy and Shukla (1977) suggested the upper age limit of the Lower Vindhyan to be around 1,000 Ma.

Recent magnetostratigraphic studies (Poornachandra Rao & Bhalla, 1996), preliminary in nature, did not contribute much in fixing the age as correlation and interpretation are primarily based on the assumption that Upper Vindhyan is equivalent to the Marwar Supergroup; the latter post-dates Cadomian Orogeny and possibly continues into Cambrian. The Vindhyan sequence does not record imprints of major events, such as, the tectono-thermal episode associated with the Cadomian Orogeny, marine transgression related to widespread Varangian glaciation, the development of evaporite-facies and phosphogenesis, which are well recognised in the Marwar Basin and also in the Himalayan basins.

Maithy and Babu (1997) reported a rich biota from the Bhander Group. Recently, Kumar and Srivastava (1997) have reported *Chuaria circularis-Tawuia dalensis* from Sirbu Shales of the Bhander Group and suggested a probable age of 700 Ma.

Preliminary result of carbon isotopic studies indicate $\delta^{13}C$ values in the range of +2.9 to +4.0‰ PDB which is comparable to that recorded from the Bhima Basin in south India and from Precambrian sequences elsewhere in the world. In the absence of imprints of Varangian glaciation and Cadomian Orogeny from the Upper Vindhyan succession, it appears that this sedimentation terminated before the on-set of the Cadomian Orogeny in Early Neoproterozoic itself, i.e., before 650 Ma.

BHIMA BASIN

The Bhima Basin in south India is one of the several small isolated basins which expose Proterozoic successions. It received attention in view of the recent record of *Sabellitids* along with *Chuaria-Tawuia* from the Halkal Shale and its assignment to Terminal Proterozoic (Das Sarma *et al.*, 1992). Biota assigning a Late Proterozoic to Cambrian age (Saluja *et al.*, 1971; Venkatachala & Rawat, 1972; Vishwanathiah *et al.*, 1976) has also been recorded.

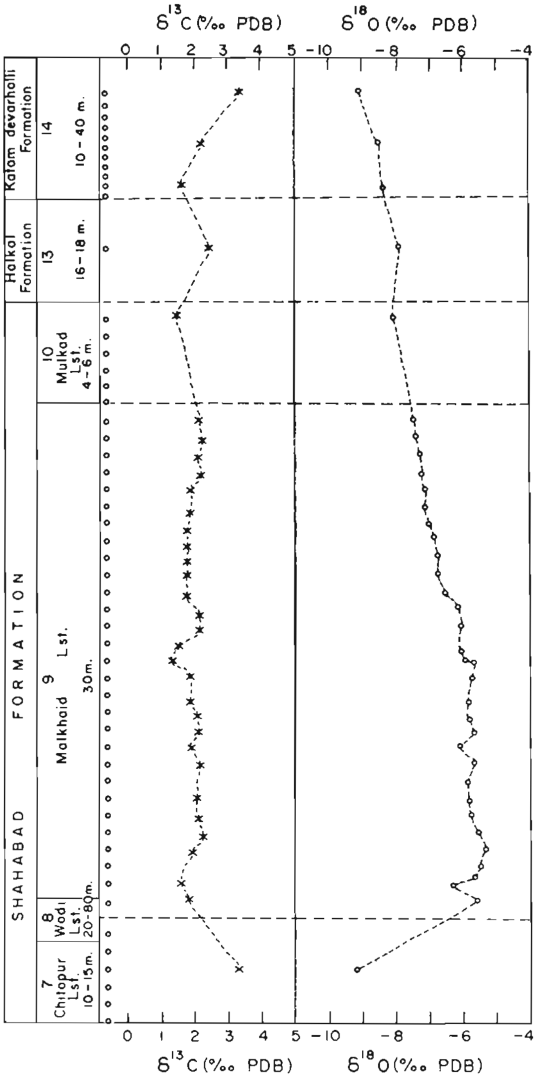
The Proterozoic sediments of the Bhima Basin constituting the Bhima Group (Bhima Series; King, 1872) rest unconformably over the Archaean basement and in turn is overlain by the Deccan Trap (Misra *et al.*, 1987; Kale *et al.*, 1990). The lithostratigraphy worked out by Misra *et al.* (1987) is given below:

SUBGROUP	FORMATION	MEMBER/LITHOLOGY	THICKNESS
	Harwal-Gogi	15 Shale	5-10 m
	Katamdevarhalli	14 Limestone	10-40 m
Andola (31-68 m)	Halkal	13 Fissile Shale	16-20 m
		12 Orthoquartzite	
		11 Chert Pebble Conglomerate	
		Para-unconformity	
		10 Flaggy	
		9 Argillaceous dark grey limestone	6-4 m
		8 Massive dark grey &	
		7 Bluish grey limestone	8-20 m
	Shahabad	6 Variegated & siliceous/ cherty limestone	20-80 m
Sedam (62-205 m)		Blocky, light grey to blush grey limestone	10-15 m
		Slabby & flaggy limestone	4-8 m
		4 Purple Shale	2-10 m
	Rabanapalli	3 Green/ Yellow Shale	5-15 m
		Siltstone	3- 4 m
		2 Quartzitic sandstone	5-15 m
		1 Conglomerate/grit	1-2 m

Stable Isotopic studies

A total of 49 samples of limestone were collected at one meter interval from the Shahabad and Katamdevarhalli Formations. Since the beds are horizontally disposed, continuous exposures are lacking and the sampling has to be done in different sections, exposing different litho-units (Text-figure 4). Of these samples, 39 samples belong to the Shahabad Formation, in which 6 samples of the basal unit were collected from quarry near Mudbol Village, 27 of the blocky grey and variegated units from quarry faces of the Rajashri Cement Factory at Adityanagar and 6 samples of massive bluish grey limestone exposed in a quarry at Mulkod. The remaining 10 samples were collected from the Katamdevarhalli Formation exposed in a hill near Kedihalli Village. Besides, a sample of carbonaceous matter from shale of Halkal Formation was also analysed.

The results of the stable isotopic analysis are given in Text-figure 4. The $\delta^{13}C$ and $\delta^{18}O$ values range between 0.89 to 3.59 ‰ PDB and -5.37 to -9.18 ‰ PDB, respectively. Majority of the $\delta^{13}C$ values cluster around 2 ‰ PDB excepting those in the basal unit of Shahabad Formation which have a mean value of 3.25‰ PDB. Though there are minor



Text-figure 4—Showing composite stable carbon and oxygen isotopic variations in the Bhima Group (black dots denote sample interval of 1 m).

deflections within positive $\delta^{13}C$ values, there is no negative deflection comparable to that observed at Precambrian-Cambrian transition elsewhere in the world in carbonate facies (Knoll & Walter, 1992) and also in Krol and Marwar Basins. These minor deflections may be related to changes in environment of deposition as evident by concommitant changes in $\delta^{18}O$ values.

The changes in oxygen isotopic ratios may be related to fluctuations in the basins at the time of deposition. In the basal part of the Sahabad Formation the $\delta^{18}O$ values are up to -9.18 ‰PDB which gradually decrease to -6‰ PDB as one moves upwards, to middle part which may be related to increasing influence of fresh-water due to regression of sea. In the uppermost part, the fluctuating depositional conditions with dominance of fresh water are indicated.

Biostratigraphic studies

The entire Bhima Group, excepting the basal Rabanpalli Formation was studied for microbiota and megafossils. Special efforts were made for collection of megafossils from the Halkal Formation from known localities, viz., Kolkur and Gangurti, from where *Sabellidites* was recorded by Das Sarma *et al.* (1992) and *Chuaria* (Suresh & Sundara Raju, 1983). This biota, described by Maithy and Babu (1996), includes *Chuaria circularis* Walcott 1899, *Tawuia dalensis* Hofmann 1979, *Protoarenicola baiguashanensis* Wang 1982, *Sinosabellidites huainanensis* Zheng 1980 and *Beltina danai* Walcott 1899. It has also yielded organic-walled microfossils referable to spheroidal leiosphaerids comparable to *Kildinella suketensis* Maithy & Shukla 1977, colonial spheroidal form comparable to *Myxococcoides* sp. and tubular forms assigned to *Eomycetopsis* sp. On the basis of similar macrofossil assemblage that occurs globally at 1000-900 Ma, Maithy and Babu (1996) considered the Bhima Group to be older than Varangian glaciation. It is interesting that similar biota also occurs in the Suket Shale of the Semri Group of the Lower Vindhyan sequence (Maithy & Shukla, 1977; Kumar & Srivastava, 1997).

The fossil collection of Das Sarma *et al.* (1992) was also examined. The specimen identified by them as *Sabellidites,* according to Maithy, lacks chitin, a characteristic of the form. The specimen shows more resemblance with the features of *Tawuia*.

Lower boundary of the Terminal Proterozoic System

The precise timing for initiation of sedimentation of the terminal Proterozoic-Cambrian succession is not known in absence of age diagnostic biota (which is primitive in nature) and radiometric dates. However, the distribution of sediments in northwestern and western India over different formations of older Proterozoic successions, including well dated Malani Igneous Suite (Ca 750 Ma), suggests a widespread marine transgression that followed the Cadomian Tectono-thermal event — the Malani Event. There are no evidences of Varangian glaciation (610-590 Ma) from the Indian-subcontinent. The absence of glaciogenic/glaciomarine sediments has to be reviewed in context of palaeogeographic position of the continent during this period. In the palaeogeographic reconstruction by Mekerrow *et al.*, 1992, fig. 1, India, alongwith Middle East, South China and northern part of the Siberia, occupies low latitudes (5°- 35°) in 'East Gondwana' Supercontinent (Kirschvink & Ripperdan, 1991). In this position, one can not expect glaciation due to warm-arid climate. The close lithological similarity of the Baliana-Krol-Tal Groups with that of the Yangtze Gorge succession, the Liantau-Nantau-Doushantau-Denying Formations resting unconformably over granites dating 819± 54 Ma (Kumar, 1984), is significant. The Nantau Formation is similar to Blaini Formation which was earlier considered to be glaciogenic/glaciomarine till Tangri and Singh (1982) argued for its non-glacial nature. The Nantau Formation is also considered to be glaciomarine, hence calls for its re-examination and detailed sedimentological studies in light of close lithological similarity with the Blaini and the position of the South China during Terminal Proterozoic. The development of evaporites with carbonates in the overlying succession further supports this contention. The Varangian glaciation is not as widespread as it was thought to be.

In the absence of age diagnostic biota, the lower boundary has to be defined in terms of stable isotopic curves. Knoll and Walter (1992) have shown that elsewhere in world, a substantial depletion in stable carbon isotopic values is noticed from the upper part of the 'glaciogenic' sediments 'the cap dolomite'. The preliminary chemostratigraphic data from the Marwar Basin, and detailed study in Krol

Basin have recorded two substantial depletions in $\delta^{13}C$ values, one in the pink carbonate bed occurring at top of the Blaini Formation, and basal part of the Bilara Group and the other in the overlying carbonates, which in Krol Basin lies above the horizon yielding Ediacaran biota but below the horizon contains Meishucunian Zone-I small shelly fauna. The former depletion which is globally recognised may be taken as a marker for defining the lower boundary of the Terminal Proterozoic succession in the 'East Gondwana'. Like the Precambrian-Cambrian Boundary, the stable carbon isotopic studies will be useful only in carbonate succession. The depletion is yet to be radiometrically dated.

Upper boundary of the Terminal Proterozoic System (Precambrian-Cambrian Boundary)

This boundary problem has been extensively studied in India (Kumar, 1995) and elsewhere in the world during last two decades leading to identification of GSSP in Chapal Island Formation, Fortune Head, south-east Newfoundland, Canada (Landing, 1994). The boundary has been placed between trace fossil Zone-I (*Harlaniella podolika* Zone) and Zone-II (*Phycodes pedum* Zone), 2-4 m above the base of the formation. Though the radiometric dates of the point are not available, the $^{207}Pb/^{206}Pb$ age of 530 ± 0.9 Ma of zircon from an ash bed from middle part the trace fossil Zone-III *(Rusophycus avalonsis Zone)* will place it around 545 Ma (Isachsen *et al.*, 1994). This ash bed was earlier dated as 545 Ma (Samson & Landing, 1992).

The trace fossils, like any other fossil, are also controlled by environment of deposition. They are more dominant in siliciclastic facies, and therefore, are not of much use in carbonate dominated facies. Due to this reason, the GSSP does not meet the basic requirement for global correlation. Therefore, some other criteria have to be evolved. Comparing and correlating the Himalayan sections with GSSP, it is evident that the Ediacaran and trace-fossil Zone III can be correlated but in absence or poor documentation of trace-fossils of Zones-I and II, the Precambrian-Cambrian Boundary can not be demarcated in terms of GSSP. In Krol, Kashmir and Spiti-Zanskar Basins, the trace fossils of Zone-III, which occur below the trilobites of Early Tsanglangpuian Stage of China, can be correlated with the *Rusophycus avalonsis* Zone of GSSP. The record of small shelly fossils of Meishucunian Zone III of China from the Tal Group in the Krol Basin from this level is significant in assigning its age. The trace fossils of Zones -I and II are known, so far, only from Kashmir. In the absence of diagnostic trace fossils, the Precambrian-Cambrian Boundary can not be demarcated precisely though it is located in the basal part of the Lolab Formation.

In Krol Basin, there is no record of trace fossils of Zones-I and II. However, the presence of small shelly fossils of Meishucunian Zone-I in association with phosphate from the basal part of the Tal Group is significant in view of $^{238}U/^{206}Pb$ age of 525±7 Ma and $^{207}Pb/^{206}Pb$ age of 539±34 Ma from a bentonite in unit 5 in the Meishucunian quary, China (Compston *et al.*, 1992). This bentonite has been suggested to be 'similar in age or older than 530.7 ± 0.9 Ma' of New Brunswicks ash bed (Ishachseu *et al.*, 1994). This helps in correlating the Meishucunian Zone I with basal part of *Rusophycus avalonsis* Zone (Chart 1). The Precambrian-Cambrian boundary may lie in still older underlying succession, i.e., the top part of the Krol Group (Krol E, Auden, 1934; Kauriyala Formation; Shanker *et al.*, 1993).

In absence of traces fossils in the Carbonate dominated succession, the chemostratigraphic studies may be useful for demarcation of the boundary. The studies on stable carbon isotope at this level record a substantial depletion in $\delta^{13}C$ values from positive to negative in Krol Basin (see Mathur *et al.*, 1997); from +0.6 to +3.6‰ in basal part, from - 1.3 to -6.9 ‰ PDB in upper part with a short lived positive excursion at the level of phosphorites in the Marwar Basin. Such changes in stable carbon isotopes have been recorded elsewhere in the world (Knoll & Walter, 1992) above the Ediacaran but below the Trace-fossil Zone-I. It is above this changes that rapid evolution and diversification in life has been recorded. Since the Precambrian-Cambrian Boundary has to be defined in terms of biostratigraphy, the small shelly fossils are useful in Carbonate facies.

The minor excursion at the level of phosphorite in Marwar Basin has also been recorded from China, in the Dahai Member of the Yuhucun Formation of Meishucunian Zone-II (Kirschvink *et al.*, 1991). The positive excursion has not been recorded by us in

Krol Basin, but the studies in Durmala section (D.M. Banerjee, Pers. comm.) and in Marwar Basin show a positive excursions at this level. Similar excursion have also been recorded from Morocco and Siberia, which according to Kirschvink *et al.* (1991) occur at Tommotian-Atdabanian Boundary. Such an assumption is incorrect in view that the overlying Meishucunian Zone-III in China is correlative with the *Rusophycus avalonsts* Zone of GSSP containing Trace Fossil of Zone -III (Chart 1).

CONCLUSIONS

1. In India, the Terminal Proterozoic-Cambrian succession, constituting the Supersequence IV post-dates Cadomian Tectono-thermal event (750 Ma) and terminated with Pan-African Orogeny (500 Ma). The sedimentation commenced with a wide-spread marine transgression over Supersequence III (Meso-Proterozoic) in Himalaya and Malani Igneous Suite (750 Ma) and older metasediments in western India.
2. In carbonate dominated successions, the development of evaporite and phosphate are two significant events useful for regional and global correlations.
3. The stable carbon isotope-curves are also useful for regional and global correlations in carbonate facies. The two depletions, one occurring in the basal part and the other above the horizon yielding Ediacaran Medusoids but below the beds containing Meishucunian Zone-I small shelly fauna, are related to global depletions recorded in the basal part of succession which post-dates Varangian glaciation and at or near the Precambrian-Cambrian Boundary, respectively. The other two depletions in between are related to development of evaporite in the lower level and to magmatic activity at higher level.
4. A short lived positive excursion, noticed at phosphorite level in the Birmania (Upper Carbonate) Formation, Marwar Basin, and in basal part of the Tal Group, in Krol Basin is also known from Meishucunian Zone-II level in China and Iran.
5. The successions in south India (Bhima Basin) and in central India (Vindhyan Supergroup) which contain *Chuaria-Tawuia* complex and give stable carbon isotope values in the range of +1.3 to +3.4‰ PDB in Bhima Group and +2.9 to + 4.0 ‰ PDB in Lower Bhander Limestone of

Chart 1—Correlation of Himalayan Zones (Krol Belt) with Early Cambrian chronological and biostratigraphical units (proposed by Mekerrow *et al*, 1992)

SIBERIAN SERIES	SIBERIAN STAGES	CHINESE STAGES		AVALON ZONES	LAURENTIAN ZONES	BALTIC ZONES	HIMALAYAN ZONES (KROL BELT)
Lenian	Toyonian	Maozhuangian		*Protolenus*	*Bonnia-Olenellus*	*Proampyx linnarssoni*	
		Longwangmiaoan					
				Strenuella			
							Redlichia-Paokannia
	Botomian	Canglangpuan					
		Qiongzhusian	V	*Callavia*		*Holmia kjerulfi*	—
					Nevadella		
Aldanian	Atdabanian						
			IV			*Holmia inusitata*	*Pelagiella-Auriculatespira*
		Meishucunian	III	*Camenella*	*Fallotaspis*	*Schmidtiellus*	*Allonia-Dimidia*
	Tommotian						
					—		
				Sunnaginia imbricata			
						—	
							—
—	Nemakit-Daldynian		II	*Watsonella crosbyi*			
				Rusophycus avalonensis			*Anabarites-Protohertzina Circotheca*
			I	*Phycodes pedum*			
							—

Upper Vindhyan Group, are not considered part of the Supersequence-IV and could be older.

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REFERENCES

Auden JB 1934. Geology of Krol Belt. *Rec. geol. Surv. India* **67** (4): 357-454.

Burman G 1980. An analysis of the Marwar Basin, western Rajasthan in light of stromatolite study. *Geol. Surv. India Misc. Publ.* **44**: 292-297.

Bhargava ON, Kumar G & Gupta SS 1982. Cambrian trace-fossils from the Spiti Valley, Himachal Himalaya. *J geol. Soc. India* **23** (4): 183-191.

Bhargava ON & Srikantia SV 1982. *Taphrhelminthopsis circularis* from ? Cambrian sediments of southeast Kashmir Valley. *J. geol. Soc. India* **23**: 406-407.

Bhargava ON & Srikantia SV 1985. Trilobite and other trace-fossils from the Kunzam La Formation, eastern Lahaul Valley, Himachal Himalaya. *J. geol. Soc. India* **26** (12): 880-886.

Bhattacharya SK, Jani RA, Mathur VK, Absar A, Bodas MS, Kumar G & Shanker R 1996. Stable Carbon and Oxygen isotopic changes across Precambrian-Cambrian Boundary, Lesser Himalaya. *Geol. Surv. India Spec. Publ.* **21** (1): 225-231.

Brasier MD 1985. Evolutionary and geological events across the Precambrian-Cambrian Boundary. *Geology Today*(Sept.-Oct. 1985): 141-146.

Crawford AR & Compston W 1970. The age of the Vindhyan System of peninsular India. *Q. J. geol. Soc. Lond.* **125**: 351-371.

Compston Q, Williams IS, Kirschvink JL, Zhang Z & Guogan M 1992. Zircon U-Pb ages from Early Cambrian time scale. *Q. J. geol. Soc. Lond.* **149**: 171-184.

Das Gupta U & Bulgauda SS 1994. An overview of the geology and hydrocarbon occurrences in western part of Bikaner, Nagaur Basin. *Indian J. Petrol. Geol.* **3** (1): 1-17.

Das Sarma DC, Raha PK, Moitra AK, Kumar P Ashok, Anantharaman S, Rama Rao M & Sundaram V 1992. Discovery of Precambrian-Cambrian transitional fossil Sabelliditids from India. *Curr. Sci.* **63** (3): 140-142.

Isachsen CE, Bowing SA, Landing E & Samson SD 1994. New constraint on the division of Cambrian time. *Geology* **22**: 496-498.

Joshi A, Mathur VK & Kumar G 1988. First record of Precambrian microbiota from the Blaini Formation in Mussoorie area, Lesser Himalaya, Uttar Pradesh. *Geophytology* **18** (1): 116-120.

Joshi A, Mathur VK & Bhatt DK 1989. Discovery of redlichiid trilobites from the Arenaceous Member of the Tal Formation, Garhwal Syncline, Lesser Himalaya, India. *J. geol. Soc. India* **33** (6): 538-546.

Kale VS, Mudholkar AV, Phansalkar VG & Peshwa VV 1990. Stratigraphy of the Bhima Group. *J. palaeont. Soc. India* **35**: 91-103.

Khan EA 1973. Discovery of fossil brachiopod of Cambrian affinity from Trans-Aravalli Vindhyan sequence near Jodhpur, Rajasthan. *Sem. Recent advances in Geology of Rajasthan and Gujrat*: 74-75 (Abstract).

King W 1872. The Kudapah and Kurnaul formations in the Madras Presidency. *Mem. geol. Surv. India* **8** (1): 1-346.

Kirschvink JL, Magaritz M, Ripperdan RL & Rosanov A Yu 1991. The Precambrian-Cambrian Boundary Problem-II. Magnetostratigraphic and Carbon isotopic correlations for Tommotian and Atdabanian Time between Siberia, Morocco and South China. *GSA Today* **1**: 69-91.

Kirschvink JL & Ripperdan RL 1991. Palaeomagnetic evidence against the existence of a Late Proterozoic Gondwana: Lower Cambrian magnetostratigraphy from Anti-Atlas Mountains, Morocco. *GSA Today* **1**: 95-104.

Knoll AH & Walter MR 1992. Latest Proterozoic stratigraphy and Earths history. *Nature* **356**: 673-678.

Kochhar N & Dhar S 1993. The association of Hypersolvus - subsolvus granites: a study of Malani Igneous Suite, India. *J. geol. Soc. India* **42** (5) : 449-467.

Kumar G 1984. The Precambrian-Cambrian Boundary beds, north-west Himalaya, India and boundary problem. *Proc. V Indian Geophytological Conference*: 98-111. The Palaeobotanical Society, Lucknow.

Kumar G 1987. Trace-fossil biostratigraphy in Precambrian-Early Cambrian sequences northwest Himalaya, India. *In: Trace fossils, small shelly fossils and the Pre-Cambrian-Cambrian Boundary, Proc. Symp. Aug. 1987. New York State Museum, Bull*: 463. St. Johns, New Foundland, Canada.

Kumar G 1995. The Precambrian-Cambrian biostratigraphy of northwest Himalaya and correlation. *In: Proc. Conf. Global Environment and Diversification of Plants through Geological Time.* Birbal Sahni Centenary Celebration, Allahabad University, Nov. 1991: 159-165. Society of Plant Taxonomists, Allahabad.

Kumar G, Bhatt DK & Raina BK 1987. Skeletal micro-fauna of Meishucunian and Qiongzhusian (Precambrian-Cambrian Boundary) age from the Ganga Valley, Lesser Himalaya, India. *Geol. Mag.* **124** (2): 167-171.

Kumar G, Joshi A & Mathur VK 1987. Redlichiid trilobites from the Tal Formation, Lesser Himalaya, India. *Curr. Sci.* **56** (13): 659-663.

Kumar G, Raina BK, Bhargava ON, Maithy PK & Babu R 1984. The Precambrian-Cambrian Boundary problem and its prospects, northwest Himalaya, India. *Geol. Mag.* **121** (3): 211-219.

Kumar G & Verma RN 1987. Early Cambrian (Tsanglangpuian Stage) trilobites from Vel-Nagabal, Anantnag District, Jammu and Kashmir, India. *J. palaeont. Soc. India* **32**: 131-135.

Kumar S & Srivastava P 1997. A note on the carbonaceous megafossils from the Neoproterozoic Bhander Group, Maihar area, Madhya Pradesh with special reference to the age of the Vindhyan Supergroup. *J. palaeont. Soc. India.* **42**: (in Press).

Landing E 1994. Precambrian-Cambrian boundary global stratotype ratified and a new perspective of Cambrian time. *Geology* **22**: 179-182.

Maithy PK & Babu R 1996. Carbonaceous macrofossils and organic walled microfossils from the Halkal Formation, Bhima Group, Karnataka with remarks on age. *Palaeobotanist* **45**: 1-6.

Maithy PK & Babu R 1997. Upper Vindhyan biota and Precambrian-Cambrian Boundary. *Palaeobotanist* **46** (1,2): 1-6.

Maithy PK, Babu R, Kumar G & Mathur VK 1994. New cyanophycean remains from the Blaini Formation (Terminal Neoproterozoic Sequence) of Mussoorie Syncline, Lesser Himalaya, India. *Palaeobotanist* **43** (1): 37-44.

Maithy PK, Babu R, Raina BK & Kumar G 1988. Proterozoic micro-fossils from Machhal and Lolab Formations of Kashmir Himalaya, India: *N. Jb. Geol. Palaeont.* Mh. **10**: 639-644.

Maithy PK & Shukla M 1977. Microbiota from the Suket Shale, Rampura, Vindhyan System (Late Precambrian), Madhya Pradesh *Palaeobotanist* **23** (3): 176-188.

Misra RN, Jayaprakash AV, Hans SK & Sundram V 1987. Bhima Group of Proterozoic-a stratigraphic puzzle. *Mem. geol. Soc. India* **6**: 227-237.

Mathur SM 1981. A revision of the stratigraphy of the Vindhyan Supergroup in the Son Valley, Mirzapur District, U.P. *Geol. Surv. India, Misc. Publ.* **50**: 7-20.

Mathur VK, Maithy PK, Shanker R & Kumar G 1997 Physical, geochemical and biological changes across Precambrian-Cambrian transition, northwest Himalaya, India. *Palaeobotanist* **46** (1,2): 13-18.

Mckerrow WS, Scotese CR & Brasier MD 1992. Early Cambrian continental reconstructions. *Q. J. geol. Soc. London* **149**: 599-606.

Pareek HS 1981. Basin configuration and sedimentary stratigraphy of western Rajasthan. *J. geol. Soc. India* **22** (11): 517-527.

Pareek, HS 1984. Pre-Quaternary geology and mineral resources of northwestern Rajasthan. *Mem. geol. Surv. India* **115**: 1-99.

Peters KE, Clark ME, Das Gupta U, Mc Caffrey MA & Lee CY 1995. Recognition of an infracambrian source rock based on biomarker in the Boghewala- 1. *Oil India AAPG Bull.* **10**: 1481-1494.

Poornachandra Rao GVS & Bhalla MS 1996 Magnetostratigraphy of Vindhyan Supergroup. *J. geol. Soc. India* **47**: 29-32.

Raina BK, Kumar G, Bhargava ON & Sharma VP 1983. Precambrian-Lower Cambrian ichnofossils from the Lolab Valley, Kashmir Himalaya, India. *J. palaeont. Soc. India* **28**: 91-94.

Reed FRC 1910. Cambrian fossils of Spiti. *Mem. geol. Surv. India palaeont. indica* NS **21**: 1-38.

Samson SD & Landing E 1992. U-Pb Zircon geochronology of Precambrian - Cambrian volcanics from the Avlon Terrane, New Brunswick. *Geol. Soc. Am. Abstracts* **24** (7): 113-114.

Sarkar AN 1981. Stratigraphy and structure of the Lower Vindhyan rocks of Palamau dist., Bihar. *Geol. Surv. India. Misc. Publ.* **50**: 21-30.

Saluja SK, Rehman K & Arora CM 1970. Plant microfossils from the Vindhyans of Son Valley, India. *J. geol. Soc. India* **12** (1): 24-33.

Shah SK, Raina BK & Razdan ML 1980. Redlichiid fauna from the Cambrian of Kashmir. *J. geol. Soc. India* **21** (10): 511-517.

Shanker R 1971. Stratigraphy and sedimentation of Tal Formation, Mussoorie Syncline, Uttar Pradesh. *J. palaeont. Soc. India* **16**: 1-15.

Shanker R, Kumar G & Saxena SP 1980. Stratigraphy and sedimentation in Himalaya: a reappraisal. *Geol. Surv. India Spec. Publ.* **26**: 1-60.

Shanker R, Kumar G & Singh G 1996. Sequence stratigraphy and major geological events of Himalaya. *Geol. Surv. India. Spec. Pub.* **21** (1): 1-12.

Shanker R, Kumar G, Mathur VK & Joshi A 1993. Stratigraphy of Blaini, Infra Krol, Krol and Tal succession, Krol Belt, Lesser Himalaya. India. *J. Petrol. Geol.* **2** (2): 99-136.

Shrivastava BP 1971. Rock stratigraphic nomenclature for the sedimentaries of west-central Rajasthan. *Bull. geol. Min. metall. Soc. India* **44**: 1-19.

Srivastava AP & Rajagopalan G 1988. FT ages of Vindhyan glauconitic sandstone beds exposed around Rawatbhata area, Rajasthan. *J. geol. Soc. India* **32** (6): 527-529.

Soni MK, Chakraborty S & Jain VK 1987. Vindhyan Supergroup: a review. *In* Radhakrishna, B.P. (Editor) —*Purana Basins of India. Mem. geol. Soc. India* **6**: 87-138.

Suresh R & Sundara Raju TP 1983. Problematic *Chuaria* from the Bhima Basin, South India. *Precambrian Res.* **23** (3): 79-85.

Tangri AK & Singh IB 1982. Palaeoenvironment of Blaini Formation, Lesser Himalaya. *J. palaeont. Soc. India* **22**: 35-48.

Venkatachala BS & Rawat MS 1972. Organic remains from the Bhima Basin and remarks on the age of Vindhyan and sub-surface sediments in Ganga Valley. *Geophytology* **2** (2): 107-112.

Vinogradov A, Tugarinov A, Zhykov C, Stapnikova N, Bibikova E & Khorre K 1964. Geochronology of Indian Precambrian. *22nd Int. Geol. Congr.* **X**: 553-581.

Viswanathiah MN, Venkatachalapathy & Doddiah D 1976. Palynofossils from the Bhima Basin, Karnataka, south India. *Proc. 7th Indian, Colloq. Micropaleontol. Stratgr.* : 384-389.

Branched microbiota from the bedded black chert of the Krol Formation (Neoproterozoic), Lesser Himalaya, India

Rajita Gautam & Vibhuti Rai

Gautam R & Rai Vibhuti 1997. Branched microbiota from the bedded black chert of the Krol Formation (Neoproterozoic), Lesser Himalaya, India. *Palaeobotanist* **46** (1,2): 32-40.

The bedded chert nodules of the lower part of the Krol Formation of Neoproterozoic age, near its type area in Solan District in the Lesser Himalaya, have provided a peep through the Proterozoic window where exceptionally well preserved organic walled microbial fossils show branching in its several forms. The phenomenon of branching is an event which indicates a sudden change in the pattern of life amongst the various morpho-entities of algal-cyanobacterial communities. This phenomenon shows advancement of life-forms towards future diversification in the Phanerozoic history of the earth. The occurrence of branching forms is significant as many of them resemble eukaryotic forms which differ from an earlier stock of prokaryotic cyanobacteria. Apart from branched filaments microfossils comparable to Bangiophyceae, a red alga with typical septate morphology is also recorded. The significance of the biota is discussed in the light of existing records from the Proterozoic successions all over the world.

Key-words — Microbiota, Algae, Krol Formation, Neoproterozoic, India.

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सारॉंश

भारत में लघु हिमालय के क्रोल शैल-समूह (निओप्रोटीरोजोइक) के स्तरित काले रामसैकाश्म से शाखायुक्त सूक्ष्मजीविता

रजिता गौतम एवं विभूति राय

लघु हिमालय में सोलन जनपद में प्ररूप क्षेत्र के समीप निओप्रोटीरोजोइक क्रोल शैल-समूह के निचले भाग में स्तरित रामसैकाश्म से महत्वपूर्ण सुपरिरक्षित कार्बनिक भित्तिदार शाखायुक्त सूक्ष्मजीवाश्मों के कई प्रादर्श मिले हैं। शाखाविन्यास की यह घटना शैवालीय सियॅनोजीवाणु समुदायों में जीवन के स्वरूप में सहसा परिवर्तन की द्योतक है तथा पृथ्वी के इतिहास में जीवन के स्वरूप में भविष्य में हुई विविधता की ओर संकेत करते हैं। यह परिवर्तन इसलिए भी उल्लेखनीय है क्योंकि इनमें से बहुत से प्रोकैरियोटी सियॅनोजीवाणुओं की अपेक्षाकृत यूकैरियोटी प्रादर्शों से अधिक सदृशता प्रदर्शित करते हैं। बैंगिओफाइसी कुल से तुलनीय शाखायुक्त सूत्रवत् सूक्ष्मजीवाश्मों के अतिरिक्त एक भित्तिदार लाल शैवाल भी अभिलिखित किया गया है। इसके अतिरिक्त विश्व भर से प्रकाशित आँकड़ों के आधार पर उपलब्ध जीविता की विवेचना भी की गई है।

THE Proterozoic history of life on the earth conceals the key to later evolutionary trends in the Phanerozoic. A cursory peep through several Proterozoic windows in the biosphere, occasionally provides significant information about the changing patterns in the life forms. These changes occur either in a series of evolutionary sequences or are sudden and unique and are termed as events. The Precambrian time span represents changes from earliest primitive prokaryotic, cells to higher levels of development through a succession of evolutionary events. One such event in the microbial community is the initiation of branching which provides significant clues about absolute changes from prokaryotic entities to eukaryotic diversification. The significance of such an event is enhanced when the recorded evidences are fewer but conclusive about their biogenic affinity.

Although there is general consensus about the timing related with the earliest evolution of eukaryotic life domain which dates back to approximately 2.1 billion years before present (Han & Runnegar, 1992), its record in microbial community is very limited in the entire Precambrian. Therefore, any such record which has a bearing on evolutionary event needs greater attention.

GEOLOGICAL SETTING

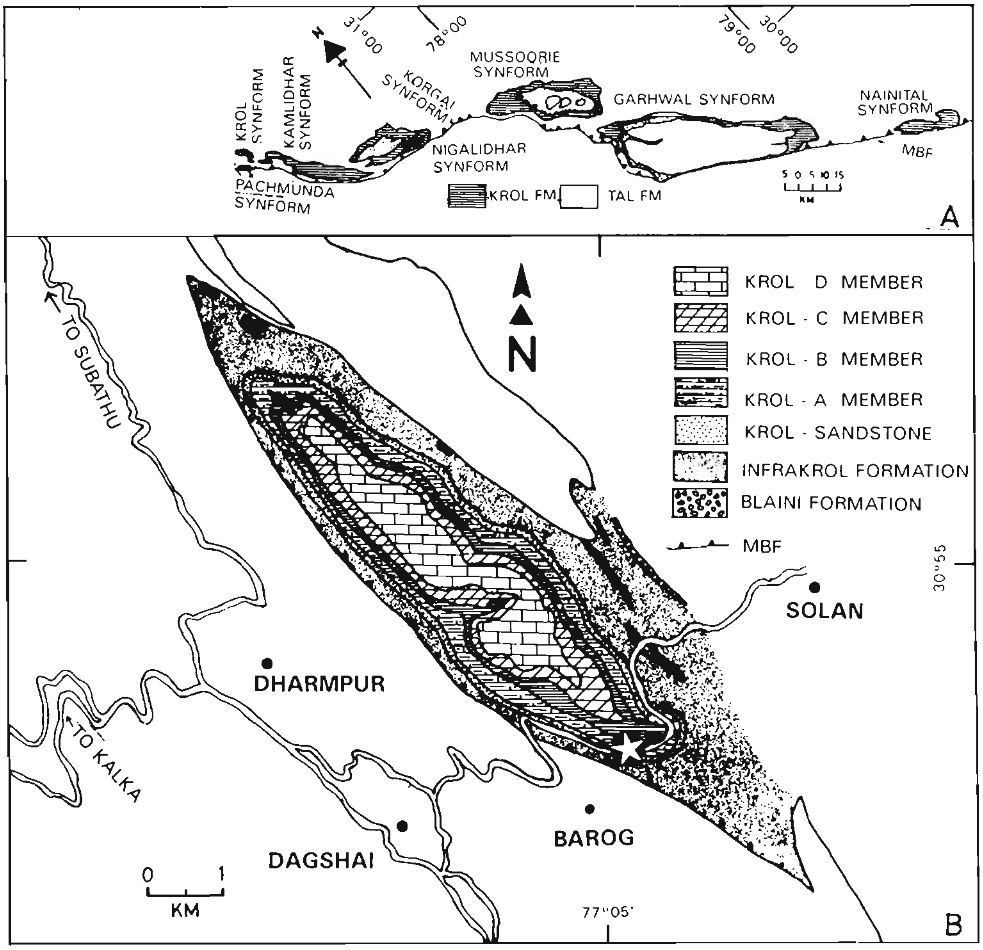
Geographical distribution and extent

The name 'Krol Group' was given by Medlicott (1864) to the calcareous suite of rocks exposed in the Krol Hill (lat. 30°57' N; long. 77° 06' E), north of Solan in Himachal Pradesh. Auden (1934) proposed the term 'Krol Belt' for this suite of rocks which form one of the important geological sequences in the Lesser Himalaya (Text-figure 1A). The 'Krol Belt' is exposed as a sequence of synformally folded sedimentaries between Kunihar Valley in Himachal Pradesh in the north-west and Nainital in the east. The Krol and the Pachmunda synforms in Himachal Pradesh form the western extremity of the Krol Belt. The other major exposed synforms occurring from west to east are Khanog, Rajgarh, Saindhar, Kamlidhar, Nigalidhar, Korgai, Mussoorie, Garhwal and Nainital synforms. The Outer Krol Belt comprises Pachmunda, Krol, Khanog, Rajgarh and Saindhar synforms while rest from Nigalidhar to Nainital are included under the Inner Krol Belt.

Lithostratigraphy

The Krol Belt includes the Blaini, Infrakrol, Krol and Tal Formations in ascending order constituting one conformable sequence. However, the Tal Formation does not occur in the Krol Belt of the Solan area. A detailed lithostratigraphy of the above formations as exposed in the Solan area (particularly in the Pachmunda Synform, Text-figure 1B) is as follows :

Blaini Formation – It is a marker horizon of the entire Krol Belt on account of its unique lithology of conglomerate/diamictite, grading upwards into carbonate beds. It consists of a lower Diamictite Member and an upper Calcareous Member.



Text-figure 1 — Location map of the fossiliferous horizons; **A.** Study area, **B.** Geological map of the Krol Belt, **C.** Geological map of the Pachmunda Synform (after Auden, 1934) showing fossil yielding horizon (marked by star).

Table 1–Nomenclatural classification of the Krol Belt as proposed by different workers

Oldham (1888)	Auden (1934)		Bhattacharya & Niyogi (1971)		Shanker *et al.* (1993)		Present study	
Upper Krol Limestone	Krol E	KROL SERIES	Krol E Formation	KROL GROUP	Kauriyala Formation (Upper)		Krol 'E' Member	KROL FORMATION
	Krol D		Krol D Formation				Krol 'D' Member	
	Krol C		Krol C Formation				Krol 'C' Member	
Red Shales	Krol B		Krol B Formation		Jarashi Formation (Middle)		Krol 'B' Member	
Lower Krol Limestone	Krol A		Krol A Formation		Mahi Formation (Lower)		Krol 'A' Member	
	Krol Sandstone		Krol Sandstone		Chambaghat Formation		Krol Sandstone	
	Infrakrol		Infrakrol Formation		Infrakrol Formation	BALIANA GP.	Infrakrol Formation	
	Blaini		Blaini Formation		Blaini Formation		Blaini Formation	

Infrakrol Formation – This unit is essentially made up of shales and slates. Auden (1934) described the slates of Infrakrol type to be so intimately connected with the Blaini as to be mapped as Blaini. Shanker *et al.* (1993) have grouped the Blaini and Infrakrol formations together under the Baliana Group. According to Bhattacharya and Niyogi (1971) the formation is made of rhythmic alternation of silt-shales, siltstones and very fine-grained sandstones. The shales are carbonaceous, particularly in the upper part of the formation.

Krol Sandstone – The Infrakrol Formation gradually transcends into the Krol Sandstone. Bhargava (1976) assigned it as a member unit within the Krol Formation while Bhattacharya and Niyogi (1971) called it the Krol Sandstone Formation. Shanker *et al.* (1993) have proposed the name Chambaghat Formation for this unit. This Formation is made up of sandstone, orthoquartzite and lenses of sandy units. Small pellets and lenticles of phosphorite occur along the bedding.

Krol Formation – Oldham (1888) divided the Krol succession into three sub-stages – Lower Krol Limestone, Red Shales and Upper Krol Limestone. Auden (1934) called it the 'Krol Series' and divided it into five units. Bhattacharya and Niyogi (1971) considered each sub-unit to be a formation under the Krol Group. Shanker *et al.* (1993) proposed a new nomenclature for the already existing lithounits. Table 1 gives a detailed account of the nomenclature proposed by various workers. However, the conventional nomenclature similar to the one proposed by Auden (1934) is being followed here. The depositional environment of the Krol Formation represents a shallow tidal sea, under oxygenated conditions, with deposits of intertidal-supratidal zone being abundant (Awasthi,1970; Kharkwal & Bagati,1976; Singh & Rai,1980; Singh *et al.,* 1980). Bhattacharya and Niyogi (1971) considered the rocks of Krol Group to be representing an environment of mixed clastic and carbonate deposits under a stable tectonic set-up.

Krol 'A' Member – This unit is made up of calcareous shales, siltstones and limestone. The shales are grey to greenish-grey in colour. The limestone is argillaceous at places. Limestone and shale occur in alternate bands. Black chert occurs within the shale/carbonate horizons as thin beds or nodules. The calcareous shales indicate deposits of open, shallow, tidal sea. There was probably an influx of fine-grained terrigenous material from the land. Minor lenses of gypsum indicate shallow conditions with low to moderate energy. Small-scale ripple marks, rhythmites, parallel bedding, cross-bedding, scour and fill, etc. are all indicative of shallow marine environment with continuous current and wave action. The deposition seems to have occurred in subtidal-intertidal zone (Singh *et al.*, 1980).

Krol 'B' Member – It is essentially made up of red shales. Thin, subordinate bands of green shale, cherty limestone and dolomites are also present.

Krol 'C' Member – This unit is essentially calcareous, made up of massive, jointed, bluish-grey carbonate which gives a putrid smell on breaking.

Krol 'D' Member – It is characterised by alternations of carbonate and shales. Lenticular cherts occur within the carbonate beds. This unit shows stromatolitic horizons and algal mats which continue upward into Krol 'E' unit.

Krol 'E' Member – The horizons containing stromatolites and algal mats grade upwards from Krol D into this unit. It is made of argillaceous carbonate and calcareous shale, the latter occurring in subordinate amounts.

AGE CONFIGURATION

Holland (1908) correlated the unfossiliferous systems of the Outer Himalaya with that of the peninsular India and gave it the name Purana. He was of the view that the system was wholly or partly Precambrian. Pilgrim and West (1928) placed the Krol Formation above the lower Gondwana while Auden (1934), Gansser (1964) and Krishnan (1968) considered the Krol Belt to be Palaeozoic-Mesozoic in age. Singh (1976) proposed a model giving the age for the Krol-Tal succession at Nainital as Late Precambrian-Cambrian. Singh and Rai (1977) and Singh and Rai (1983) on the basis of biological evidences gave the age of the Krol-Tal succession as Vendian-Lower Cambrian.

Ghosh and Srivastava (1962) reported trilete and pteridophytic spores from the Infrakrol-Krol, suggesting a Permo-Triassic age for this sequence. Tewari and Singh (1979) reported plant fossils like *Annularia, Gangamopteris, Glossopteris, Calamites,* etc. strengthening the view that Infrakrol were Permian in age. But deposits suggesting euxinic conditions render this find doubtful. Singh (1981) was of the view that the unit of Tewari and Singh must be an independent unit within the Subathu-Dogadda zone. On the basis of a well-developed stromatolitic assemblage (*Conophyton, Colonella* and *Baicalia*) from the Nainital area Singh and Rai (1977, 1980) considered the Krol Formation to be Proterozoic in age. Later Singh and Rai (1983) discovered archaeocyatha and calcareous algae, namely, *Epiphyton, Renalcis, Gemma* and *Girvanella* suggesting a Vendian age for the Krol Formation. Rai and Singh (1983) discovered trilobites from the Tal Formation indicating Lower Cambrian age for the succession. On the basis of above contentions a Precambrian-Cambrian age has been assigned to the Krol Belt. There are other fossil records on the basis of which a Late Precambrian to Early Cambrian age has been proposed for the Krol-Tal sequence (Shanker *et al.*, 1993).

FOSSIL YIELDING LOCALITY

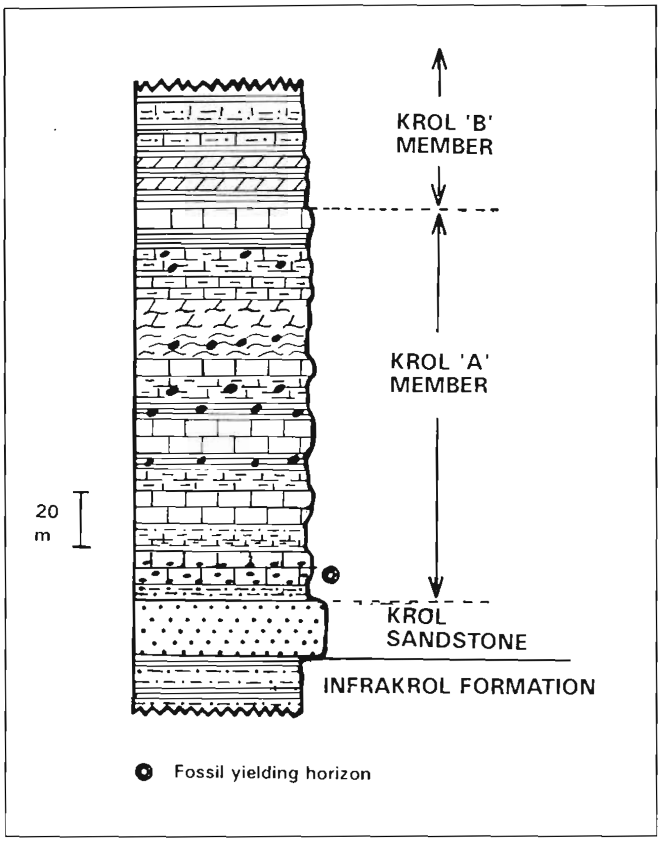
The lower part of the Krol 'A' Member is well exposed on the southern slopes of the Pachmunda hills along the National Highway No. 22 between Barog and Solan (Anjighat) (Text-figure 1C). About 5 meters above the orange coloured Krol Sandstone occurs a bedded calcareous horizon interlayered with black siltstone. Within the calcareous beds a number of black chert nodule bearing layers (Text-figure 2) are present. These black chert nodules have yielded the branched filamentous forms besides a highly developed cyanobacterial and acritarch assemblage.

Repository – The discussed fossil material in respective thin sections is deposited with the museum of the Department of Geology, University of Lucknow, Lucknow. The number of the thin section along with England Finder co-ordinates are given in the description of the plate.

TAXONOMIC NOTES

Archaeorestis is the first recorded genus of branched, filamentous microbial fossils from Precambrian (Barghoorn & Tyler, 1965). Some other genera of branched filaments are *Palaeosiphonella* (Licari, 1978), *Ramivaginalis* (Nyberg & Schopf, 1984), *Palaeovaucheria* (Hermann, 1981) and *Proterocladus* (Butterfield *et al.,* 1994). Besides, there are few more records of branching forms of uncertain taxonomic identity, viz., "branched septate microorganisms" (Schopf *et al.*, 1977), "branched tubes with ellipsoidal inclusions" (Lo, 1980), "narrow tubular sheaths in common organic matrix or enclosed by a larger tubular sheath" (Nyberg & Schopf, 1984) and "Filamentous Form 'A' " (Kumar & Srivastava, 1991).

The paucity of record and poor preservation of internal structure have made the correlation of these branched fossil forms with extant cyanobacteria or other algal groups difficult. Licari (1978) compared *Palaeosiphonella cloudii* with *Vaucheria* (Chrysophyta) and *Derbesia* (Chlorophyta), while Lo (1980) tried to correlate "branched tubes with ellipsoidal inclusions" with forms belonging to Stigonemataceae (Cyanophyceae) or small eukaryotes



Text-figure 2– Lithocolumn showing the fossiliferous chert horizons of Krol 'A' Member, Krol Formation, Lesser Himalaya (Solan area).

or fungal hyphae. Some of these forms may also be falsely branched and show an affinity to forms of the Family Scytonemataceae of Division Cyanophyta.

The bedded black cherts from the Krol 'A' Member of the Krol Formation in the Kandaghat area near Solan (from the Krol Synform) have yielded a rich assemblage of microfossils which include filamentous forms, coccoidal forms, acritarchs and certain problematic or bizarre forms (Kumar & Rai, 1992). In the presently studied section of the Pachmunda Synform, the filamentous forms constitute the largest group of microbial assemblage representing a wide variety of morpho-types. Generally empty sheaths of filaments are preserved but occasionally trichomes, with or without an enveloping sheath, are also preserved. Quite a number of forms exhibit septation. However, the phenomenon of branching is very rare and significant as it may indicate a change from a prokaryotic mode of life to eukaryotic one. Some rare branching forms recorded from this assemblage are described here in detail. Due to the occurrence of only a single specimen of each morphologic type, except Form A, no definite taxonomic position has been ascribed to these forms.

Form A

Pl. 1, figs 5, 6, 7

Tubular, branched, convoluted form with bulbous swellings; wall thin, psilate, light brown in colour. Plate 1, fig. 6 has a thread-like structure running through the central part of the filament. Remnants of cross walls visible at places. Branching lateral, at an angle of 51°. Width of main filament 13-15 μm, that of branches 8-11 μm. Length not definitely ascertained due to broken ends but preserved length about 200 μm. Plate 1, fig. 5 shows a second specimen of the above type with regular constrictions and swellings. Dark lensoid bodies/cellular material can be seen occurring at regular intervals. Branch arises from the main filament through budding or protruberance. The width of branches ranges between 6 to 10 μm due to pinching and swelling morphology. The form shows perfect stages of branching from the appearance of protruberance or budding to fully developed branches. A third specimen of the same type (Pl. 1, fig. 7) shows a thick broken main filament

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PLATE 1

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All photographs are from petrographic thin sections. Scale in all forms equals 15 microns.

1 Form 'B' (Slide No. BR17A/1, England Finder No. P48/4) Branched filament showing trichome preserved within an enveloping sheath.
2. Form 'E' (Slide No. BR3A/4, England Finder No. N26/3) *Bangia* - like, septate specimen. Pseudo-branched morpholgy is apparent.
3. Form 'C' (Slide No. BR3A/4, England Finder No. Q28/1-Q27/1)Branched form showing infilling of the filament cavity.
4. Form 'D' (Slide No. BR3A/4, England Finder No. U24/1) Straight broken filament showing 'V'-shaped branching or splitting.
5. Form 'A' (Slide No. BR3A/4, England Finder No. S23/4) Branched form with dark, lensoid bodies seen within the filament.
6. Form'A'(Slide No. BR27A/1, England Finder No. U26/0) Branched, convoluted form.
7. Form 'A' (Slide No. BS96/12, England Finder No. J27/0) Well developed branch emerging from a thick filament showing a possible 'neck' like part in the left portion of the main body. Dark lensoid body is present in the upper part of the branch.
8. Form 'D' (Slide No. BS96/8, England Finder No. L24/4) Branched Form showing resemblance with *Ramavaginalis uralensis*.

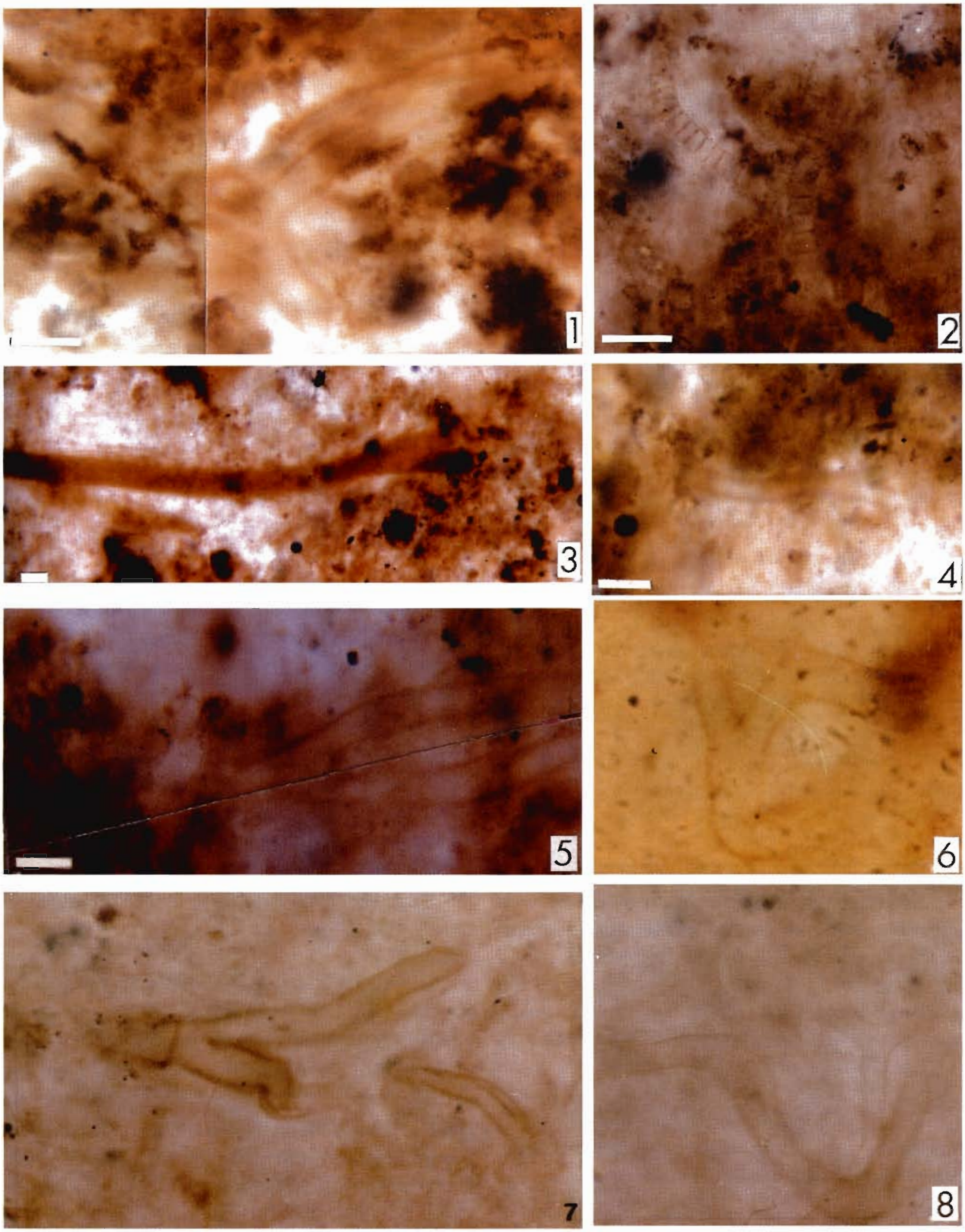

PLATE 1

of 13 μm width. It is separated from the branches by a distinct septa. The branches are broken, curved and 8-11 μm in width. A dark lensoid body is visible in the upper branch.

These forms are comparable to *Archaeorestis schreiberensis* (Barghoorn & Tyler, 1965). The difference lies in the granular filament wall is in the type specimen whereas the present specimens have a thin psilate wall and greater tube diameter.

Form B

Pl. 1, fig. 1

Non-septate, tubular form with branched trichome preserved within an enveloping sheath; sheath smooth, about 2 mm space between the trichome and sheath; trichome wall thin, indistinct. Branching 'Y'-shaped, lateral; cellular portions not preserved; branched junctions show greater sheath thickness; width varies from 11 to 16 mm for the filament and about 5 mm for the trichome.

This form shows a close resemblance with an unnamed illustrated form of Nyberg and Schopf (1984, fig. 11F). Their form shows numerous narrow tubular structures which are occasionally branched and enclosed within an organic matrix/ larger tubular sheath. The present specimen, however, shows only a single branched trichome preserved within the sheath.

Form C

Pl. 1, fig. 3

Non-septate, branched, broken filament with unclear margins, merging somewhat with the background; colour dark brown; surface appears mottled. Only short stub of branch is preserved as the specimen is broken. The main filament flares out or widens just before branching; width of filament 15 μm while that of branches 13-15 μm. Length of the preserved specimen is 410 μm. This form occurs surrounded by a cluster of filamentous forms. A filament overlaps this form and deceptively appears as an offshoot of the main filament.

The branching may be false being a result of rupture and flattening of the main filament during preservation. However, the width of the branches being equal to that of main filament such a conclusion seems doubtful. As only one specimen is recorded, its taxonomic position cannot be ascertained. The form is compared with *Palaeosiphonella* (Licari, 1978). Both these forms show similarity in being branched, siphonaceous filaments. The analogy with these modern algal forms strengthens the view that Form C is a eukaryotic alga. However, due to the absence of any well-preserved internal, cellular structure the taxonomic position of this form is uncertain.

Form D

Pl. 1, figs 4, 8

Non-septate, branched filament with thin psilate walls; branching dichotomous, with the dividing portions being broad, curved, like a tuning fork. Main filament (Pl. 1, fig. 8) 6-7 μm wide, constricted to 4 μm just before dividing. Ends broken, hence, length not definitely ascertained. Wall slightly thickened at the point of branching, very light brown in colour and merges with the background. A convoluted curved filament can be seen overlapping the form. The other specimen shown in Pl.1, fig. 4 shows 'V'-shaped splitting of the main tube with ends broken.

This form is comparable to *Ramavaginalis uralensis* (Nyberg & Schopf, 1984). They have ascribed this form to cyanobacteria belonging to either Scytonemataceae or Stigonemataceae. Since the trichomes are not preserved, true affinity can not be ascertained.

Form E

Pl. 1, fig. 2

Curved, septate, long filaments, occasionally appear to be branched; septa distinct, particulate, alternate septa visible on changing the focus. Cells cylindrical, 6 μm wide and 2.5 to 3 μm long. Walls thin, granular. Termini where seen tapering, rounded.

The form is highly curved being aligned in such a manner as to appear branched. The septa show a complex morphology in that alternate septa are visible at a particular focus. It may thus be deduced that alternate septa with an opening or pore occur in between complete septa ensuring cellular continuity.

This complexity in the morphology of the form represents a high degree of evolutionary development. The specimen shows a close resemblance with bangiophyte red alga (Butterfield *et al.*, 1990) where along the length of the filament, the cross partitions (or septa) also alternately occur as complete or with a central opening (hole). However, the specimens of Butterfield *et al.* (1990) exhibit a multiseriate structure with greater diameter of filament and modified basal ends.

DISCUSSION AND CONCLUSIONS

1. The occurrence of a diversified cyanobacterial and algal community in the Krol 'A' Member of the Krol Formation (Pachmunda Synform) indicates a major evolutionary step in the Neoproterozoic succession of the Lesser Himalaya.
2. A very rare biological phenomenon, i.e., initiation of branching in filamentous microbial community is recorded for the first time from the Neoproterozoic sequences of the Lesser Himalaya.
3. This phenomenon of branching is common in modern eukaryotic community. However, a few cyanobacteria also show branching. Comparison of the fossil material has been made with the modern branched algal-cyanobacterial forms.
4. The presence of well developed septate forms showing affinity with red and green algae indicates that in the present assemblage most of the branched filamentous forms are possibly eukaryotic in nature.

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REFERENCES

Auden JB 1934. The geology of the Krol Belt. *Rec. geol. Surv. India* **67**(4): 357-454.

Awasthi N 1970. Some aspects of the Krol Formation of the Himalaya, India. *Cont. Min. Petrol.* **28:** 192-220.

Barghoorn ES & Tyler SA 1965. Microorganism from the Gunflint Chert. *Science* **147**: 563-577.

Bhargava ON 1976. Geology of the Krol Belt and associated formations : A reappraisal. *Mem. geol. Surv. India* **106**(1): 168-234.

Bhattacharya SC & Niyogi D 1971. Geological evolution of the Krol Belt in Simla Hills, H.P. *Himalayan Geol.* **1:** 178-212.

Butterfield NJ, Knoll AH & Swett K 1990. A bangiophyte red alga from the Proterozoic of Arctic Canada. *Science* **250:** 104-107.

Butterfield NJ, Knoll AH & Swett K 1994. Paleobiology of the Neoproterozoic Svanbergfjellet Formation, Spitsbergen. *Fossils & Strata* **34**: 1-84.

Gansser A 1964. *Geology of the Himalayas.* Interscience Publications, John Wiley & Sons, New York.

Ghosh AK & Srivastava SK 1962. Microfloristic evidence on the age of the Krol beds and associated formations. *Proc. natn. Inst. Sci. India* **28** (A): 710-717.

Herman TN 1981. Occurrences of filamentous algae in the Miroedikha Formation (Upper Precambrian). *Palaeont. Zh.* **4:** 118-121. (In Russian).

Han Tsu-Ming & Runnegar B 1992. Megascopic eukaryotic algae from the 2.1 billion year old Negaunee Iron Formation, Michigan. *Science* **257**: 232-235.

Holland TH 1908. On the occurrence of striated boulders in the Blaini Formation of Simla with the discussion on the geological age of the beds. *Rec. geol. Surv. India* **37**(3): 129-135.

Kharkwal AD & Bagati TN 1976. Zoned carbonate crystals in the Krol Formation in Nainital area. *N. Jb. Miner.* **4**: 162-169.

Krishnan MS 1968. *The geology of India and Burma.* Higginbothams, Madras.

Kumar S & Rai V 1992. Organic-walled microfossils from the bedded black chert of the Krol Formation (Vendian), Solan area, Himachal Pradesh, India. *J. geol. Soc. India* **39**: 229-234.

Kumar S & Srivastava P 1991. Microfossils from the non-stromatolitic middle Proterozoic Vindhyan chert, Chitrakut area, Uttar Pradesh. *J. geol. Soc. India* **38**: 511-515.

Licari GR 1978. Biogeology of the Late pre-Phanerozoic Beck Spring dolomite of eastern California. *J. Paleont.* **52**(4): 767-792.

Lo Su-Chu C 1980. Microbial fossils from the lower Yudoma Suite, earliest Phanerozoic, eastern Siberia. *Precambrian Res.* **13**: 109-166.

Medlicott HB 1864. On the geological structure and relations of the southern portion of the Himalayan range between the rivers Ganges and Ravee. *Mem. geol. Surv. India* **3**: 1-209.

Nyberg AV & Schopf JW 1984. Microfossils in stromatolitic cherts from the upper Proterozoic. Min 'Yar Formation, southern Ural mountains, USSR. *J. Paleont.* **58(3)**: 738-772.

Oldham RD 1888. The sequence of correlation of the pre-Tertiary sedimentary formations of the Simla region of the lower Himalayas. *Rec. geol. Surv. India* **21(3)**: 130-143.

Pilgrim GE & West WD 1928. The structure and correlation of Simla rocks. *Mem. geol. Surv. India* **53**: 1-140.

Rai V & Singh IB 1983. Discovery of trilobite impressions in the Arenaceous Member of Tal Formation, Mussoorie area, India. *J. palaeont. Soc. India* **28**: 114-117.

Schopf JW, Dolnik TA , Krylov IN , Mendelson CV, Nazarov BB, Nyberg AV, Sovietov YK & Yakshin MS 1977. Six new stromatolitic microbiotas from the Proterozoic of the Soviet Union. *Precambrian Res.* **4**: 269-284.

Shanker R, Kumar G, Mathur VK & Joshi A 1993. Stratigraphy of Blaini, Infra-Krol, Krol and Tal succession, Krol Belt, Lesser Himalaya. *Indian J. Petr. Geol.* **2**(2): 99-136.

Singh IB 1976. Evolution of Himalayas in the light of marine transgressions in the peninsular and extra-peninsular India. *Proc. 125 Ann. Celebr. GSI Symp., Lucknow* (Preprint).

Singh IB 1981. A critical review of the fossil records in the Krol belt succession and its implications on the biostratigraphy and palaeogeography of the Lessor Himalaya. *J. palaeont. Soc. India* **25**: 148-169.

Singh IB, Bhargava AK & Rai V 1980. Some observations on the sedimentology of the Krol succession of Mussoorie area, Uttar Pradesh. *J. geol. Soc. India* **21**: 232-238.

Singh IB & Rai V 1977. On the occurrence of stromatolites in the Krol Formation of Nainital area and its implications on the age of Krol Formation. *Curr. Sci.* **46**: 736-738.

Singh IB & Rai V 1980. Some observation on the depositional environment of the Krol Formation in Nainital area. *Himalayan Geol.* **8**(**2**): 633-656.

Singh IB & Rai Vibhuti 1983. Fauna and biogenic structures in Krol-Tal succession (Vendian-Early Cambrian), Lesser Himalaya: Their biostratigraphic and palaeoecological significance. *J. palaeont. Soc. India* **28**: 67-90.

Tewari BS & Singh RY 1979. The significance and occurrence of Late Palaeozoic plant remains in the Infra-Krol sequence of Nainital, U.P. *Bull. Indian Geol. Assoc.* **12:** 263-266.

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Shukla PN & Bhandari N 1997. Physical, chemical and biological changes at geological boundaries : causes, consequences and clues based on the study of Indian sections. *Palaeobotanist* 46 (1,2): 41-62.

Significant and abrupt biological changes are known to occur at the geologic boundaries and are invariably accompanied by some specific physical and chemical changes in the sedimentary deposits. At the Cretaceous-Tertiary Boundary (KTB), for example, shocked minerals, nickel-rich spinels, anomalously high iridium concentration and a variety of other physical and chemical markers have been found. It is generally believed that the biological changes are a consequence of physico-chemical processes which are triggered by some high energy, physical events such as a bolide impact, supernova explosion in the vicinity of the Earth or volcanic episodes. To understand the cause and nature of these physico-chemical processes, a high resolution stratigraphic analysis of physical, chemical, geological, environmental and biological markers of stratigraphic boundaries has been made over the past few decades.

In this article, we summarise the main features of some important bioevent horizons based on typical stratigraphic sequences and then dwell upon various processes which could possibly be responsible for them. The Cretaceous-Tertiary and Permian-Triassic boundaries are discussed in some detail. The clues obtained from the study of stratigraphic sections from India are used to build possible scenarios prevailing at these bioevents.

Key-words — Mass extinction, Iridium anomaly, Deccan Volcanism, Siberian Volcanism, Asteroidal impact, Cometary impacts, Cretaceous-Tertiary Boundary, Permian-Triassic Boundary.

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सारॉंश

भूस्तरिक सीमाओं में भौतिक, रासायनिक एवं जैविक परिवर्तन : भारतीय खंडो के अध्ययन पर आधारित परिणाम

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भूस्तरिक सीमाओं पर महत्वपूर्ण और आकस्मिक जैविक परिवर्तन पाए गए हैं जिनका सम्बन्ध अवसादी निक्षेपों में कुछ विशिष्ट भौतिक एवं रासायनिक परिवर्तनों से है, उदाहरणार्थ क्रीटेश्यस टर्शियरी सीमा पर प्रघात खनिजकण, निकल-समृद्ध स्पिनेल, असामान्य उच्च इरिडियम सान्द्रण और अन्य भौतिक एवं रासायनिक सूचक-चिन्ह पाए गए हैं। जैविक परिवर्तनों के बारे में यह माना जाता है कि ये उन प्रक्रियाओं के परिणाम हैं जो बोलाइड संघट्ट, सुपरनोवा एवं ज्वालामुखी विस्फोट जैसी उच्च ऊर्जीय भौतिक घटनाओं के कारण होते हैं। इन भौतिक-रासायनिक प्रक्रियाओं के कारणों को समझने हेतु पिछले कुछ दशकों में स्तरिक सीमाओं के भौतिक, रासायनिक, भूवैज्ञानिक, पर्यावरणीय और जैविक अवशेषों के उच्च विभेदीय विश्लेषण किए गए हैं।

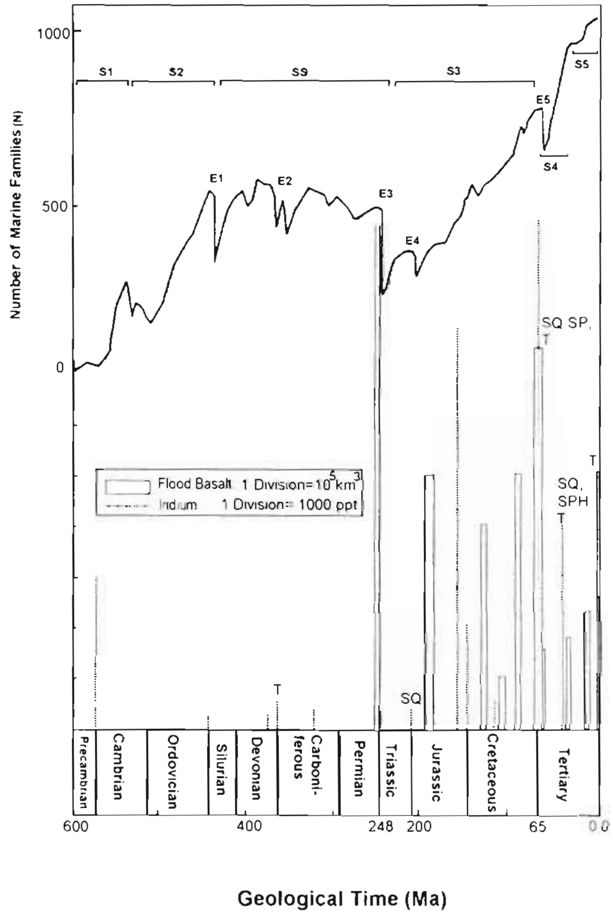
इस शोध-पत्र में हमने कुछेक ऐसी सीमाओं पर घटित विभिन्न परिवर्तनों को संक्षेप में उद्धृत किया है और उन प्रक्रियाओं की चर्चा की है जो उनके लिए उत्तरदायी हो सकती हैं। क्रीटेश्यस-टर्शियरी और पर्मियन-ट्रायेसिक सीमाओं का वर्णन कुछ विस्तार से किया गया है। भारत के समकालीन स्तरिक खंडों से प्राप्त संकेतों से इस जैविक विनाश के समय संभावित घटनाओं को दृश्यान्वित करने का भी प्रयास किया गया है।

SPECIATION and diversification of species is a complex process controlled by their inherent capacity to survive and evolve. The environmental factors, through continuous variation, provide interactive forces, both negative and positive, over the geologic history of the Earth. Extinction is the fate of all species; they become extinct when the rate of adaptation is not able to match the rate of environmental stress. Such extinction records are preserved in the sedimentary deposits on the earth and provide invaluable information on evolution, radiation and extinction of species.

RECORDS OF PALAEOBIODIVERSITY

Fossil records in marine and non-marine sediments show the evolutionary pattern of various species on the Earth. Sepkoski (1992) has compiled the data on initiation, speciation, diversification and extinction of various species. The biodiversity curves constructed from these data have been a subject of intense analysis and discussion over the past few decades. In Text-figure 1, we reproduce the biodiversity curve during the Phanerozoic for marine families as given by Sepkoski (1992).

Several features of these curves are striking. The sudden explosion of species at Precambrian-Cambrian boundary followed by an exponential rise and then a near steady state persistence for nearly 190 Ma, followed again by a steep exponential rise, each punctuated by a number of sudden catastrophic decreases or mass extinctions (Table 1) are clearly seen in Text-figure 1. Some of these features have been widely discussed (Van Valen, 1984). Valentine and Moores (1970) proposed that the empirical curve of taxonomic diversity through time is literally a "map" of continental positions (Raup, 1972) and the diversity change is related to the available extent of the coast line. In this paper, we first bring out some of the intriguing features of biodiversity curve (Text-figure 1) and then discuss the physical causes and chemical clues concerning the processes leading to mass extinctions.



Text-figure 1 — Diversity curve for marine families over geological times (adopted from Sepkoski, 1993). S1, S2, S3, S4, S5 represent epochs of rapid speciation and E1, E2, E3, E4 and E5 represent events of mass extinction. SS denotes era of near steady state in biodiversity. Histogram shows the volume (10^5 km^3) of lava emanating in major volcanic flood basalt episodes (after Rampino & Caldeira, 1993) and the iridium concentration (pg/g) at some horizons where high iridium anomaly has been found. Horizons where shocked quartz (SQ), microtektites (T), meteoric spinels (SP) and spherules (SPH) have been found are marked. Source of data are given in the text.

The exponential rise in number of faunal and floral families is quite consistent with evolutionary trends expected of multiplicative processes (Van Valen, 1984). While the exponents of the curves (Part S1, S2, S3, S4 and S5) reflect congeniality of the ambient life supporting conditions, the physical factors responsible for the rapid rise which govern the speciation and diversification during various epochs (S1 to S5) are not well understood and have not been quantitatively related to the observed rates of growth.

The most intriguing part is the steady state persistence (rate of change being nearly zero) defined by part SS of the curve covering 440 to 250 Ma period. Such a state prevailed for a long period spanning nearly 190 Ma in spite of severe perturbations in form of several catastrophic extinctions. Such a steady state is *unnatural* in a sense that it is not exhibited even by any physical or chemical system, much less sensitive or less dynamic than biological systems. This equilibrium or steady state level can not be explained by simple prey-predator models or continuation of "cosy" environmental conditions.

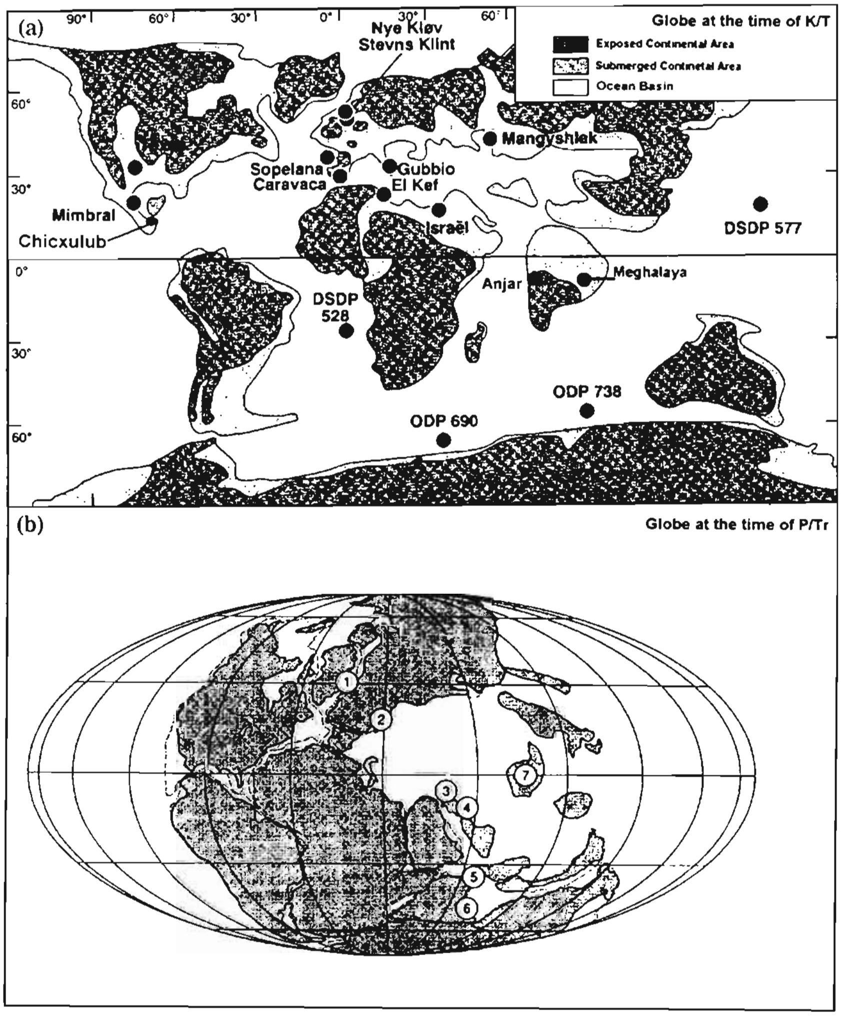
The major catastrophic extinctions which occurred at least five times during the Phanerozoic, i.e., during Late Ordovician, Late Devonian, Late Permian, Late Triassic and Late Cretaceous (Table 1b), in addition to a mid-Carboniferous event, are characterised by sudden onset and slow recovery. But the causative factors responsible for a more vigorous diversification following these catastrophes, surpassing the pre-catastrophic index of growth (dN/dt), have not been identified.

Doubts have been raised about extinctions being sudden and simultaneous for a large number of species at the same point of time since statistical biases exist due to sampling and preservation in sedimentary records (Signor & Lipps, 1982). The true nature of extinction and recovery phases needs to be established by high resolution and statistically significant data but it is clear that the extinctions are, geologically speaking, quite sudden. Selectivity of extinction could also provide vital clues concerning the agencies responsible for them.

Based on the physical, biological, chemical and sedimentary characteristics at various extinction boundaries, a number of hypotheses for mass extinction have been proposed. We shall discuss these observations later in this article. Here we concentrate on the observations related to K/T and P/T boundaries as changes at these boundaries have been the most severe and have been studied in detail. The positions of the continents on the globe at K/T and P/T times are shown in Text-figure 2. To start with, we briefly describe various hypotheses proposed for these extinctions.

Extinction Mechanisms

All the proposed mechanisms for extinctions can be grouped into two categories : terrestrial and extraterrestrial. The terrestrial causes include massive flood basalt volcanism and sea-level changes, which through climatic stress, can result in mass extinction.



Text-figure 2 — Location of various continents around K/T times (a) and P/T times (b). The locations of major K/T sites and continents and their submerged areas are shown in (a). The numbers in P/T reconstruction of the globe (b) shows approximate locations of various sites studied: (1) Greenland, (2) Southern Alps, (3) Iran-Armenia border, (4) Central Iran, (5) Salt Range, Pakistan, (6) Guryul Ravine and Spiti, India, (7) Meishan and other sections in South China. See Erwin (1994a) and Sweet *et al.* (1992) for more details. This figure is modified from Courtillot (1995).

The energy released in major volcanic flood basalt episodes is ~10^{33} ergs, and is sufficiently energetic, i.e., 10^6 times the annual internal energy release from the Earth, and occurs over long periods of time (million years or more), so that it can produce a cumulative stress to eventually result in mass mortality. The dust and gases released in volcanic episodes can significantly alter both the land and marine environment.The timing, intensity and location of major volcanic provinces on the Earth are shown in Text-figures 1 and 3. The synchroneity of volcanic episodes and extinction events (Text-figure 1) suggests a causal relation between them. The chain of physico-chemical processes triggered by volcanism is schematically shown in a simplified way in Text-figure 4a.

One of the extra-terrestrial hypotheses (Alvarez *et al*., 1980) envisages a large size asteroidal impact (10 km or bigger bolide). Impacts this magnitude are sufficiently energetic (10^{31} ergs) and moreover the energy is released instantaneously (seconds) to have far reaching consequences on the atmosphere and ecology. Other extra-terrestrial phenomena like a supernova explosion (within 10 kpc of the Earth) have also been discussed. One of the mechanisms suggested is that its intense radiation destroys the protective ozone layer thereby exposing both the marine and terrestrial organisms to the potentially lethal solar ultraviolet radiation (Ellis & Schramm, 1995; Van Den Bergh, 1994), ultimately damaging the fibre of life on the Earth. Other extra-terrestrial hypotheses include accumulation of dark matter which, in turn, can give rise to continental flood basalt volcanism by periodically generating heat inside the earth (Abbas & Abbas, 1996) and effect of thermal neutrons (Yayanos, 1983). Any of the mechanisms discussed above is capable of producing severe stress on life depending on its intensity but probably a combination of many of these mechanisms occurring together is required to culminate into an extinction event. We confine to the two most prominent processes : catastrophes by collisions of large interplanetary bodies with Earth and violence by volcanoes. The physico-chemical processes triggered by volcanism and impact are schematically shown in Text-figure 4a and 4b, respectively.

Table 1 — (a) Major periods of speciation and their rates of increase (Text-figure 1)

Epochs of Growth	Period (Ma)	Rate of change, dN/dt
Mean		+4.1
S-5	38-0	+1.04
S-4	65-38	+8.51
S-3	208-98	+2.64
S-2	505-438	+3.96
S-1	565-537	+3.75

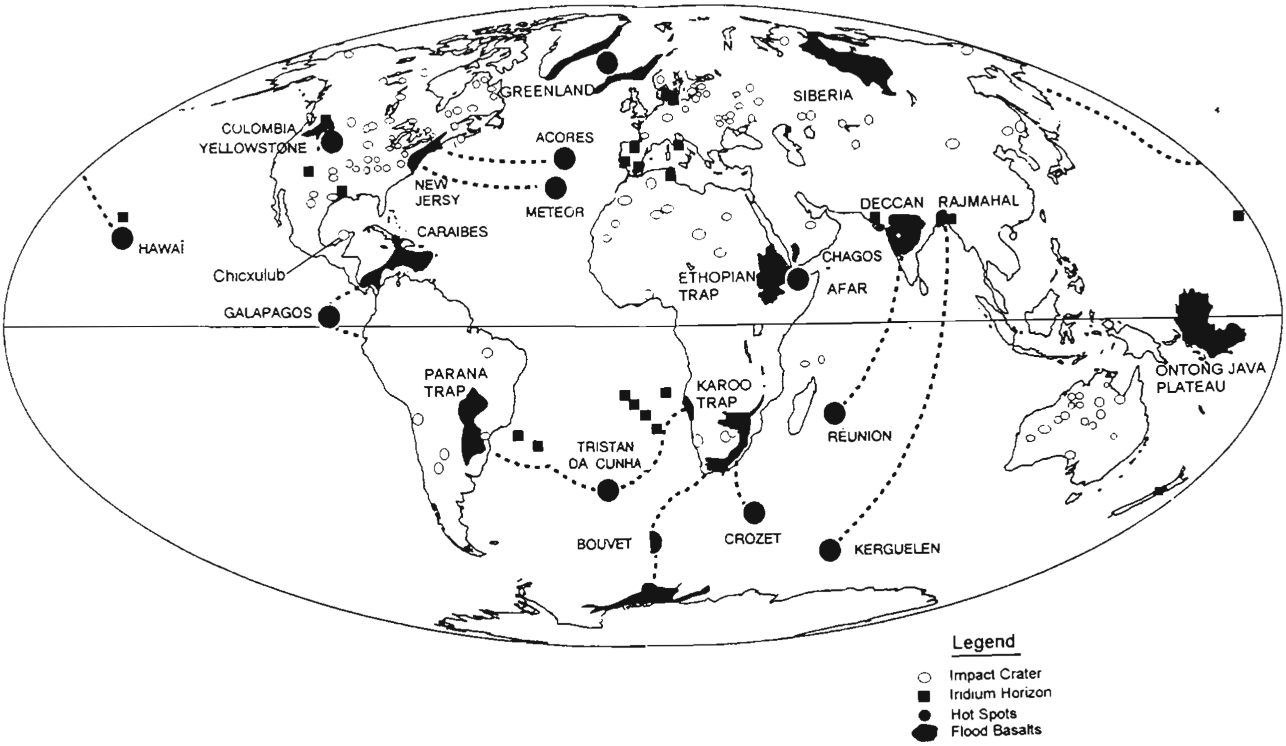
(b) Major events of extinction and their nature

Extinction events	Time (Ma)	Boundary	Extinction	Recovery
E5	65	Cretaceous-Tertiary	Abrupt	Gradual
E4	208	Triassic-Jurassic	Gradual	Gradual
E3	250	Permian-Triassic	Abrupt	Gradual
E2	360	Devonian-Carboniferous	Gradual	Gradual
E1	438	Ordovician-Silurian	Abrupt	Gradual

(c) Major period of steady state

SS	440-250=190 Ma

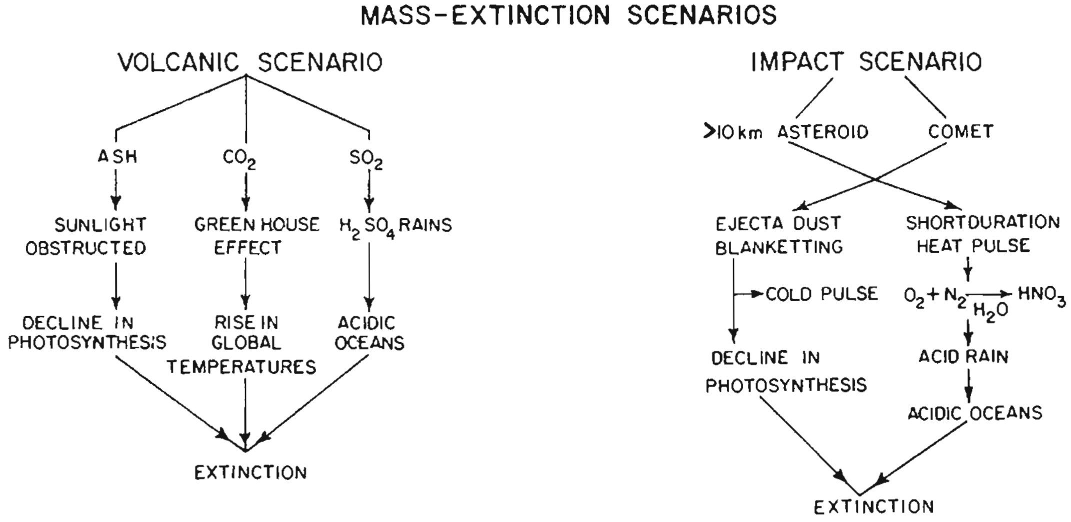
Dynamically, impacts due to stray extra-terrestrial bodies appear to be plausible as we can see from their remnants on the surfaces of the Earth, Mercury or Moon. Several Earth-crossing asteroids (Atens) and comets (Apollo, Amors) (Wetherill & Shoemaker, 1982; Weissman, 1982) and meteor streams are known to exist through which the Earth passes every year. Over a hundred impact craters on the Earth have been identified (Grieve, 1991) and their locations are shown in Text-figure 3. Impacts due to comets are more probable than asteroids (Wetherill & Shoemaker, 1982; Weissman, 1982). As the solar system goes through different regions of space, it encounters different bodies which may tear off the Oort's belt (containing ~10^{12} comets) and deflect a few of them (~10^5) to the inner solar system. A small fraction of them may acquire an Earth-crossing orbit resulting in a cometary shower impacting the Earth. The four main mechanisms which have been proposed for creating gravitational perturbation of the Oort's belt are due to (a) Planet X, (b) Nemesis, (c) Passing stars, and (d) Molecular clouds. In addition, the galactic debris, as the solar system passes through the galactic arms, can also give rise to certain phenomena on the Earth which can, through a series of physico-chemical processes result in mass extinction (Clube & Napier, 1986; Davis *et al.*, 1984; Hills, 1981). Some of these processes are briefly discussed here.



Text-figure 3 — Global distribution of impact craters, volcanic flood basalt provinces, hot spots and high Ir concentration in K/T boundary horizons.

Deflection of comets to the Inner Solar System

1. *Planet X*—Models of planetary formation suggest that the accretion of the outer planets may have left a residual disk of comets or icy planetesimals in the Uranus-Neptune region. Kuiper (1951) suggested that comet-like masses of 10^{17}-10^{18}g between 35-50 AU, perhaps 10^{11} in number, may have formed in this region. There is a small residual discrepancy in the motion of Uranus, Neptune and Pluto (Hoyt, 1980) which can be explained if a planet X exists at 50 to 100 AU with appropriate eccentricity (0.3) and inclination (45°) and a mass between 1 and 5 M_o (Matese & Whitmire, 1986). The planet X will, due to precession of its perihelion and aphelion, deflect periodically ~10^5 comets from this comet belt, to



Text-figure 4 —A simplified chain of physico-chemical processes following volcanism (a) and impact of a large bolide (b), leading to mass extinction.

the inner solar system, giving rise to short period comets, at least 73 of which are known with periods ranging between 3.3 and 13 years. The mean life of the short period comets is about 1,400 years and a small fraction of them can attain earth-crossing orbit to occasionally give rise to a comet shower on the Earth.

2. *Solar Companion Star (Nemesis)* — Another mechanism proposed for deflecting comets from the Oort's belt is due to a (hypothetical) low mass solar companion star Nemesis (Mass 0.05 to 0.3 M_o, an eccentric orbit with a = 90, 000 AU, period = 27 Ma, perihelion distance 10 to 2000 AU). When it passes close enough to the Sun, it would rattle the dense inner cloud of Oort's comet belt. The number of comets perturbed into earth-crossing orbit may be $2x10^9$ (Davis *et al.*, 1984).

3. *Passing Stars* — Hills (1986) has discussed that over the history of the solar system about 2.3 x 10^4 stars are expected to pass within 1 pc of the Sun and these might deflect comets from the Oort's cloud to the inner solar system. These may result in occasional comet showers impacting the Earth, but this phenomena will not be periodic.

4. *Giant cloud fragmentation model* — It is estimated that over 2/3 of the interstellar gas in the inner galaxy is in molecular form existing as giant molecular clouds (GMC) with mass ranging between 10^5 to 4 x $10^6 M_o$ Clube and Napier (1986) have worked out a detailed model for cometary deflection resulting from penetrating encounters of GMC with the solar system. It is estimated that during its life time, the Sun had close (<20 pc) encounters with 56 GMC's having $M \leq 3$ x $10^3 M_o$ and 8 encounters with GMC's having $M \leq 10^5 M_o$(Napier, 1985). Oort's cloud is thus disturbed quasi-periodically and the deflected comets arrive in the circum-terrestrial space and disintegrate into short-lived Apollo asteroids. The material goes through the processes

Table 2— Physical, chemical and isotope markers at various boundary horizons (from Bhandari, 1991; Rampino & Haggerty, 1996)

Boundary	Age (Ma)	Mortality	Iridium range (ng/g)	$\delta^{13}C$	$\delta^{18}O$
Near Pliocene-Pleistocene	2.3	Insignificant	One minor peak (0.11-4.7)	----	----
Eocene-Oligocene	36	Four sudden minor events	Iridium peak (0.10-4.1)	---	---
Cretaceous-Tertiary (K-T)	65	Severe	One sharp peak (5-180) on a broad hump and some minor peaks	Sudden decrease	Sudden decrease
Cenomanian-Turonian	94	Insignificant	0.56		
Jurassic-Cretaceous	144		7.8		
Callovian-Oxfordian			1		
Middle-Late Jurassic			3.2		
Triassic-Jurassic (T-J)	205	Major	Small peak (0.4)	Decrease	Decrease
Permian-Triassic (P-T)	250	Sudden and severe	(0.003-0.23)	Sharp decrease	--
Lower Mississiplan	33	--	(0.02-0.56)	--	--
Devonian-Carboniferous (D-C)	360	--	Four minor Iridium peaks (0.02-0.56)	--	--
Frasnian-Famennian (F-F)	367	Sudden and significant	Small Iridium peaks (0.08-0.3)	Decrease	Decrease
Late Ordovician	440?	Sudden	Weak Iridium anomaly (0.06-0.23)	--	--
Precambrian-Cambrian (PC-C).	~ 570	--	(0.002-2.9)	Decrease	Decrease

1. In addition to the main peak, some smaller peaks have been found (0.08 to 0.3 ng/g) which may be due to variation in carbonate content or perturbations of the main peak.

Table 3—Major observations at Cretaceous-Tertiary Boundary

Biological signatures	
1.	*Global extinction of a large number of marine and land species (Sepkoski, 1992)*: About 50% of genera and ~ 15% of families are believed to have become extinct. In severity, the K/T extinction is only next to P/T extinction. The extinction is gradual, step-wise or sudden is still debated.
2.	*Extinction is believed to be selective*: Studies of Kaiho (1994) shows difference between extinction of planktonic and benthic foraminifera. It has been suggested that extinction was mainly confined to tropics and had some latitudinal dependence (Keller, 1994).
3.	*Near disappearance of pollen and plants*: At the base of the KTB *Micula murus* zone has been identified.
Geological signatures	
1.	*Deccan flood basalts, timing and duration*: Available ^{40}Ar/^{39} Ar ages of these basalt flows range between 63 Ma to 68 Ma (large scale (10^{6}km^3) flood volcanism in central and western India). It has been suggested that bulk of the basalts erupted within a short interval of time of less than 1 Ma around KTB (Courtillot *et al.*, 1996). However, Venkatesan *et al.* (1993) point out that major peak of Deccan eruptions predated KTB by more than 1 Ma and its duration was not less than 3 Ma.
2.	*Chicxulub Crater*: (a) Chicxulub crater (diameter ~200 km) in the Yucatan peninsula has been identified as the crater formed at the KTB (Sharpton *et al.*, 1996). (b) The age of melt crater rocks at 64.98±0.05 Ma (Swisher *et al.*, 1992) is the same as the age of tektites from Haitian KTB site (Izett *et al.*, 1991). (c) Apart from the 65 Ma resetting age, the zircons from various K/T sites (Colorado, Beloc and Sakatchewan) also give ages of ~545 Ma similar to the age of Chicxulub platform, indicating that it is the only large impact crater at KTB (Bohor *et al*, 1993; Krogh *et al.*, 1993; Kamo & Krogh, 1995). (d) The geometry of the crater and the ejecta indicates that the bolide hit from southeast direction at a low angle (20 to 30°)and the ejecta was thrown in a northwesterly direction.
3.	*Sea-level changes*: Sea-level changes causing regression and transgression are believed to be the main factors in causing extinctions at KTB (Hallam, 1992). A sharp drop of 100 m prior to KTB and an equally rapid rise thereafter have been observed for various sections (Haq *et al.*, 1987; Holser & Magaritz, 1992; Schmitz *et al.*, 1992). It has been argued that these fluctuations would affect even the terrestrial reptiles because of lowering of water tables.
Chemical and isotopic signatures	
1.	Global occurrence of enhanced level of iridium with orders of magnitude higher concentration above the background. In some sections, the Ir peak is superimposed on a broad hump whereas a few sections show multiple Ir peaks (Graup & Spettel, 1989; Bhandari *et al.*, 1995).
2.	Presence of amino acids (-amino isobutyric acid), probably of extraterrestrial origin below and above the KTB but not at KTB (Zhao & Bada, 1989). It has been suggested that these amino acids are derived from cometary sources (Zahne & Grinspoon, 1970).
3.	A sharp decrease in δ^{13}C at and above the K/T boundary (Hsu & McKenzie, 1990) attributed to planktonic extinction, indicative of strangelove ocean, followed by planktonic boom (Hollander *et al.*, 1993).
4.	Excursions in δ^{18}O values indicating changes in sea water temperature of several degrees before and after the K/T event (Sarkar et al., 1992). A slow cold wave is followed by a sudden warm epoch.
5.	An increase in strontium isotopic ratio (^{87} Sr/^{86} Sr) attributed to enhanced weathering due to impact induced acid rain (Martin & macDougall, 1991). However, Nelson *et al.*,. (1991) suggest an increase in this ratio prior to KTB also.
6.	Enrichment in N and S isotopic ratios (^{15}N/^{14}N,^{34} S/^{32}S) attributed to interaction of acid rain with organic matter in case of N (Gardner et al., 1992) and an anoxic event in case of S (Kajiwara & Kaiho, 1992).
7.	Fullerenes (C_{60}, C_{70}) have been detected at various KTB sites with estimated mean global C^{60} concentration at the KTB to be 1.4ng/ cm^2 (Heymann *et al.*, 1996).
8.	^{187} Os/^{186} Os ratio is found to be ~ 1 in the K/T clay, similar to the value in meteorites or the Earth's mantle whereas the crustal value for this ratio is ~10 (Luck & Turekian, 1983).
9.	A 2.5 mm fragment separated from the K/T clay horizon of a mid-Pacific core shows high concentration of Fe, Cr and Ir, characteristic of chondrites and is suspected to be the fragment of the bolide responsible for K/T impact (Kyte, 1996). Schuraytz *et al.* (1996) have detected almost pure micron size iridium nuggets from Chicxulub impact melt.
Mineralogical and other features	
1.	Presence of shocked mineral grains such as shocked quartz, zircons and chromites (Bohor *et al.*, 1984; Bohor, 1990; Bostwick & Kyte, 1996). This is a strong evidence in favour of impact hypothesis.
2.	Spherules and microtektites have been reported from K/T sites. These include sanidine spherules (Smit & Klaver, 1981) and others having composition of potassium feldspar, glauconite, pyrite, etc. (Montanari *et al.*, 1983; Smit & Kyte, 1984; Brooks *et al.*, 1985). Glasses with shapes resembling those of microtektites have been found from Beloc section near Haiti (Hildebrand *et al.*, 1991; Kring & Boynton, 1991, 1993) which have been dated to be 65.01 ±0.08 Ma (Izett *et al.*, 1991).
3.	Discovery of nanometer sized diamonds favour impact hypothesis (Carlise, 1992, 1995). The authors found the Ir to nanometer size diamond ratio to be similar as observed in case of C2 type chondrites and further noticed that carbon isotopic ratio did not favour a terrestrial origin. The horizon containing the diamonds had fiftyone amino acids out of which 18 are found in carbonaceous chondrites only. Based on C and N isotopic ratio in diamonds, Gilmour *et al.* (1992) suggest an impact or plasma origin for these diamonds.
4.	Meteoric spinels (usually 2-10 microns), rich in nickel have been found at the KTB showing a prominent peak where the iridium enhancement is observed (Robin *et al.*, 1992). These are believed to be produced in the atmosphere during the entry of the bolide.
5.	Presence of soot in the boundary clay provides an evidence of large scale forest fires (Wolbach *et al.*, 1985, 1990; Ivany & Salawitch, 1993) which could have contributed to the loss of sunlight.
Environmental signatures	
1.	A severe temperature fluctuation; a slow cold wave (-6°c) followed by a severe heat pulse (+10°c). The cold wave is believed to be due to blanketing of sun light by soot, dust and sulphuric acid aerosols and the heat wave is due to green house effect resulting from release of large amounts of CO_2 as a consequence of impact on carbonate rocks (O'Keefe & Ahrens, 1989). Based on analysis of paleosol carbonates, it has been found that the $C0_2$ concentration of the atmosphere at the time of KTB was about 800-1200 ppm (Ghosh *et al.*, 1995; Berner, 1992)

of progressive fragmentation and destruction as it evolves through the phases of meteor streams to zodiacal cloud and is eventually blown away by the solar wind. The model predicts bombardment episodes of 10^4 - 10^5 year duration, separated by 10^5 - 10^6 year intervals, spread over a few millions years.

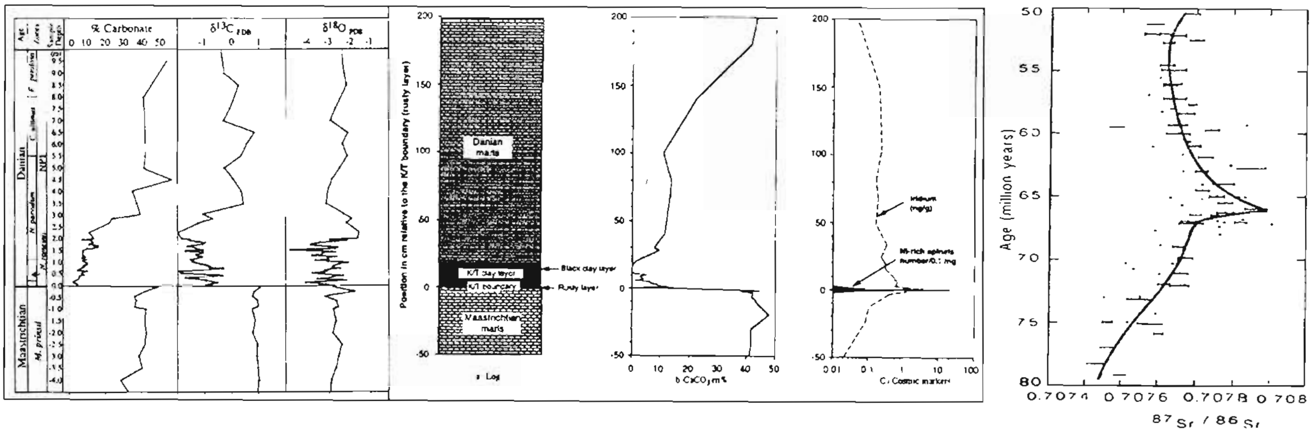
The spectacular celestial event of capture of the comet Shoemaker Levy 9 in circum-Jovian orbit, its breakup in orbit due to tidal forces and subsequent crash on Jupiter, witnessed in July 1994, has given much insight into the phenomenon of cometary impact on planets. Likelihood of a comet in circum-terrestrial orbit is negligibly small. However, there is evidence in form of crater chains (catenae) on satellites of Jupiter, e.g., Callisto and Ganymede and on Earth as well. Two terrestrial catenae have been identified recently. One is the American chain having a string of 8 or possibly 9 craters, identified from NASA's imaging radar space shuttle, ranging in size from 3 to 17 km and extending over a distance of 700 km (from southern Illinois to eastern Kansas), formed about 320 Ma ago. The other is the African chain having three craters including Aoroungan (12.7 km diameter) in northern Chad with two or three more companions, stretching over a 100 km, formed about 360 Ma ago (Rampino & Volk, 1996).

To test various mechanisms discussed above, two principal alternative scenarios depicting cometary impacts can be distinguished using terrestrial sedimentary and cratering records: (i) Impacts which are mainly stochastic in nature and occur due to occasional short-lived but intense comet showers, and (ii) impacts which are episodic and occur at regular intervals. Periodicity (26 Ma) of cratering and mass extinction events has been discussed but it appears that they are not statistically correlated in a significant way.

We first look at the sedimentary records and evidences which may allow us to identify processes responsible for extinctions.

Evidence from extinction horizons

Over ten geological boundaries have been studied for various physical and chemical markers such as the presence of tektites, shocked quartz, anomalously high concentration of platinum group and other diagnostic elements, isotopic changes of $\delta^{13}C$ and $\delta^{18}O$, etc. (Table 2). For understanding the physico-chemical processes responsible for extinction, it is important to distinguish between global and local effects. The results, briefly summarised in Table 2 indicates that every extinction is unique and the imprints of these markers at different boundaries are not identical. There are large craters formed on Earth without accompanying mass extinctions, and there are extinctions where it has not been possible to identify a crater of large enough size, responsible for the extinction. Kyte (1988) has mentioned that six



Text-figure 5—Profiles of some important physical and chemical indices, listed in Table 3, (carbonate content, $\delta^{13}C$, $\delta^{18}O$, occurring at and near the KTB horizon of the El Kef section and magnified profiles (between -50 and 200 cm of the KTB rusty layer) of carbonate and cosmic markers (iridium and nickel rich meteoric spinels) alongwith the litholog of the El Kef section are shown (compiled from Rocchia *et al.*, 1996 and Pospichal, 1996). The figure at the extreme right shows the profile of $^{87}Sr/^{86}Sr$ between 50 to 80 Ma (from Javoy & Courtillot, 1989).

stratigraphic boundaries (Cenomanian-Turonian, Callovian-Oxfordian, Early-Mid-Jurassic, Permian-Triassic, Frasnian-Famennian and Proterozoic-Cambrian) may possibly be of impact origin, whereas there are other boundaries where signatures of impact exists with negligible or no indication of extinction. Among the known (~130) impact craters listed by Grieve (1991) there are nine big craters (including Chicxulub) with their sizes ranging from 55 km to 200 km and ages varying between 36 to 1970 Ma. Among the 24 well-defined extinction peaks in the genus-level data (Sepkoski, 1992), impact signatures are found in case of five extinction boundaries (Pliocene, 2.3 Ma; Late Eocene, 36 Ma; K/T, 65 Ma; Triassic/Jurassic, 205 Ma and Frasnian/Famennian, 367 Ma) only (Rampino & Haggerty, 1996). Thus it is clear that large impacts are not responsible for all the observed extinctions. Similarly there are volcanic episodes accompanying extinctions and extinctions without concomitant volcanic activity. It is, therefore, unlikely that there is a general theory of extinction; rather it appears that there are several mechanisms capable of producing stress on life and some time they work in collusion to result in mass extinctions. The KTB is the most extensively studied horizon and large number of processes which occurred at this time have been documented. We therefore discuss the K/T event in detail.

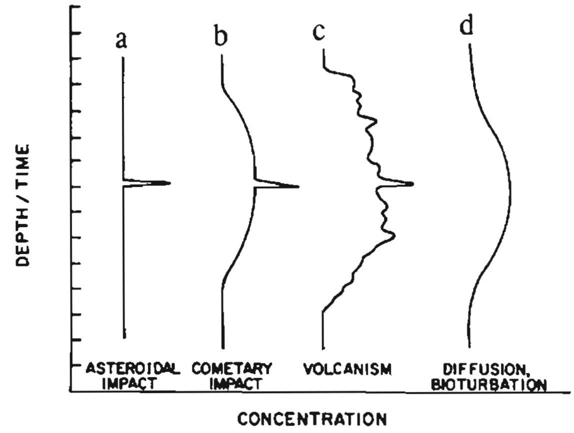
CRETACEOUS-TERTIARY BOUNDARY

Biological, geological, chemical, isotopic mineralogical and environmental signatures observed at the KTB are shown in Table 3. It is clear from this table that there is an overwhelming evidence that an impact took place at or close to the KTB while volcanism in Deccan was active. Krogh *et al*. (1993) on the basis of zircon ages from the KTB, showed that not only the Chicxulub crater was formed at the KTB but this was the only crater formed at the KTB. The argument is based on the bimodal distribution of ages of zircons collected from some KTB sections which have the 65 Ma age of KTB, superimposed upon the 545 Ma age of the Chicxulub platform, on which the impact occurred. The locations where high iridium has been observed is shown in Text-figure 2, indicating global distribution of iridium.

The questions which are now being debated in an impact scenario relate to (i) whether the bolide was a comet or an asteroid, and (ii) the role of impact on extinction. The answer rests on the evidence of extinction being in a single stage and sudden (years) or in multiple stages and gradual over prolonged period of time (million years). A sudden extinction will indicate an asteroidal impact and it would have played a dominant role in extinction. On the other hand, if the extinction is gradual or in several stages, then multiple impacts of cometary nuclei would be favoured. These alternatives and their bearings on tracer profile such as that of iridium are shown schematically in Text-figure 6. We therefore first investigate the nature of the iridium profile observed at KTB.

The Alvarez hypothesis (Alvarez *et al.*, 1980), that an extra-terrestrial object of the size ~10 km hit the Earth which caused the mass extinction at the Cretaceous-Tertiary boundary, was proposed to explain the presence of anomalously high concentration of iridium at the KTB. To settle the questions posed above, a high resolution study of KTB is required. Observed variations of some of the diagnostic markers of KTB, e.g., carbonate abundances, $\delta^{18}O$, $\delta^{13}C$, iridium concentration, population of meteoric spinels and change in $^{87}Sr/^{86}Sr$ are shown in Text-figure 5 for the El Kef section in Tunisia, considered to be the best preserved and stratotype section (Keller *et al.*, 1995). Kyte and Wasson (1986) looked for signatures of multiple cometary impacts in a marine sediment core but found only one peak of iridium and concluded that there were no impacts of a cometary shower on the Earth. The possibility of resolving multiple impacts, if they have occurred, depends on rates of sedimentation and time interval between different impacts. The fossil data on suddenness of extinction are controversial and favour step-wise extinction (Hut *et al.*, 1987). At the same time, role of other causes of extinction, such as multiple volcanic episodes, which is consistent with the iridium profile as well as fossil data can not be ruled out. If volcanism had a major role in gradual or step-wise extinction, then the suddenness of the final extinction may indicate that impact may be the last straw on camel's back.

A series of physico-chemical processes are triggered by the impact. These include aerosol loading of the atmosphere, blocking of Sun light, cessation of photosynthesis, significant temperature excursions, acid rain, destruction of O_3 layer, etc.



Text-figure 6—The expected depth profile of a tracer (e.g., Ir) in an asteroidal (a), cometary (b) and volcanic scenario (c). (d) shows effect of mixing of sediments based on plausible values of deposition and mixing in marine sediments on tracer profile from two sources, volcanic and asteroidal (Bhandari *et al.*, 1994).

which finally lead to mass extinction. The role of acid rain in bringing about extinction is very significant (Prinn & Fegley, 1987; Sigurdsson *et al.*, 1992). Firstly, during the impact, O_2 and N_2 in the atmosphere would combine to give rise to oxides of nitrogen which will be ultimately converted into nitric acid. The production of nitric acid is estimated to be over 1 g/cm^2. Over and above this devastating amount, it has been pointed out that the platform on which the impact occurred at Chicxulub was dominantly anhydrite and the impact would release a lot of sulphate ions in the atmosphere, which ultimately get converted into sulphuric acid. Combination of nitric and sulphuric acids can be even more fatal; Montanari has called it. *Acqua Morta*. If indeed it is the acid which killed the life, then it is difficult to distinguish between volcanism and impact, because both of them produce a lot of acid; volcanism through emission of SO_2 and CO_2, which are eventually converted into acids, and impact through the processes outlined above.

The role of aerosol loading can also be devastating. The Sun light, cut off by the ejecta debris of impact or through dust emanated in volcanism may lead to a dark Earth for at least a few years after the event. This would result in cessation of photosynthesis, leading to loss of the biosphere and consequently the life which depend on it, by mass starvation and other implied effects. The aerosol loading will result in a decrease in temperature over the globe by several degrees. The oxygen isotopic ratios ($\delta^{18}O$), which is a temperature indicator, bear a witness to this sudden cooling by several degrees (Text-figure 5). The green house gases released in impact on carbonate, particularly CO_2 (O'Keefe & Ahrens, 1989) released in volcanism will give rise to a heat wave shortly after the initial cold wave due to aerosol loading as observed. This increase is also expected to be several degrees, and may be another important factor in accelerating mass extinction.

Over and above the various processes mentioned above, there are some additional consequences like forest fires, whose evidence has been found in terms of fine soot at the KTB, which may further amplify the stress.

In summary, there are several evidences which favour impact at KTB (Table 3). Physical evidence for the impact exists in the form of shocked quartz (Bohor, 1990), meteoric spinels (Robin *et al.*, 1992), in addition to identification of the crater at Chicxulub, breccias and quickly quenched spheres around the impact site in the Yucatan peninsula. Chicxulub is a giant crater (diameter ~200 km) and has been dated at 64.98 ± 0.05 Ma, same as the KTB. From the geometry, magnetic and gravity anomalies and distribution of ejecta it has been inferred that the bolide came from south-east and ejecta cloud settled in north Pacific. Several cores raised from this region have provided definitive proof of the impact event (Kyte *et al.*, 1996). Although the processes following a large impact may be very effective in causing severe stress on life (Text-figure 4), its role in causing extinction still remains to be quantitatively established.

RESULTS FROM THE INDIAN SECTIONS

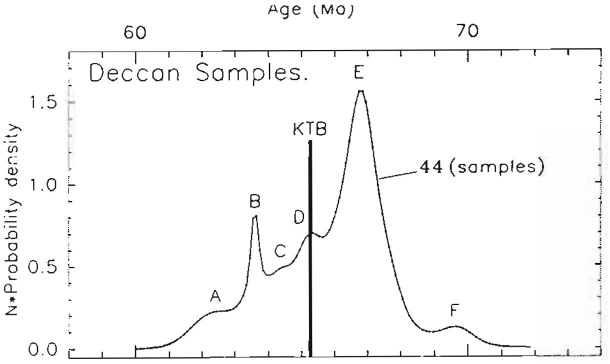
There are several evidences to show (Table 3) that an impact did take place ~65Ma ago at Chicxulub and around the same time, Deccan volcanism in central and western India was also active. However, the precise timing of initiation, peaking and duration of the volcanic episodes is still not established. It has been suggested that voluminous lava flow (<~10^{6}km^3) erupted in a short span of time (<~0.5 or 1 Ma) coinciding with the KTB age (Courtillot *et al.*, 1986; Vandamme *et al.*, 1991). Further, it has been suggested (Courtillot *et al.*, 1986) that the mantle material rich in Ir can emanate during volcanic episodes resulting in Ir rich layer at KTB, similar to those observed in air-borne particles emanating from Hawaiian (Olmez *et al.*, 1986) and Kamchataka (Felitzyn & Vaganov,

1988) volcanoes. Venkatesan *et al.* (1993) dated ($^{40}Ar/^{39}Ar$) stratigraphically controlled samples from 2.5 km section of Mahabaleshwar sequence belonging to the western margin of the Deccan basalts and found that Deccan volcanism pre-dated KTB by at least 1 Ma and emplacement of the whole section lasted at least 3 Ma. Distribution of all available ages of Deccan basalts, compiled by K. Pande (pers. commn., 1996) show a major peak in volcanic episodes at 67 Ma and only a minor one at 65 Ma (Text-figure 7).

To explain the near simultaneity of both impact and volcanic events it was suggested that Deccan volcanism was induced by an impact through pressure relief melting in the asthenosphere, as is believed to have occurred on the Moon which generated the lunar mare (Alt *et al.*, 1988; Rampino & Caldeira, 1993). In this context, it was realised that K/T sections from Indian subcontinent should provide useful clues in understanding the role of Deccan volcanism as its effects would be more pronounced in its proximity. Several intertrappean (IT) samples (lava ash, clay, marl, etc.), from various localities in the Deccan province, were therefore analysed to ascertain the Ir levels in these samples (Bhandari *et al.*, 1993a; Bhandari *et al.*, 1993b. The Ir levels in these samples, except for Anjar, discussed below are low and range from 8 pg/g to a maximum of 120 pg/g (Table 4). These values are short by several orders of magnitude to account for the high concentration of Ir observed at various KTB horizons (e.g., 5 ng/g to 187 ng/g Ir in Marine KTB sites) all over the globe. Further, the intertrappean samples do not show other chemical characteristics observed in case of Hawaiian volcanic particulates, for instance enhanced chalcophile element (Se, As, Sb, etc.) concentrations. If Deccan volcanism was contributing Ir and other elements similar to Hawaiian volcanic emissions, then these elements ought to be enriched in many IT samples contrary to our observation. Significant contribution of Deccan volcanism in giving rise to chemical anomalies seen at KTB can therefore be ruled out.

Anjar Intertrappean Section

The volcano-sedimentary sequence in coastal land section near Anjar, Kutch (Bhandari *et al.*, 1995, 1996; Hofmann *et al.*, 1997) is an exception to the low iridium concentration and shows three well-separated Ir-rich layers. These layers lie within the third intertrappean overlying three lava flows as shown in Text-figure 9. The flows above and below the Ir layer have been dated recently using $^{40}Ar/^{39}Ar$ method (Venkatesan *et al.*, 1996). The plateau ages of the two flows (FIII and FII) underlying the IT containing Ir-rich layer are found to be 65.2 ± 0.6 Ma and 64.9± 0.8 Ma, respectively whereas the overlying flow (FIV) gives a plateau-like age of 65.7 ± 0.1 Ma. These ages are similar to the age of KTB obtained from dating microtektites found in marine KTB sediments (Izett *et al.*, 1991) and 64.98 ± 0.1 Ma obtained by dating melt glass from Chicxulub (Swisher *et al.*, 1992). Furthermore, the flows IV, V, VI and VII all show reverse magnetic polarity (Kusumgar, pers. commn., 1996; Hofmann *et al.*, 1997), whereas the secondary magnetic imprints on FI, II and III are too intense to provide a reliable primary magnetic polarity of these lower flows. Considering the chronology of magnetic polarity, we place flows IV, V and VI in magnetic chron 29R, during which the KTB layer is known to have been emplaced. Whether Flows II and III also fall in this chron or not can only be decided when better data on remnant magnetism are available. FI appears to belong to the narrow reversed period of chron 30R. The three layers in the third intertrappean beds have an enhanced level of Ir and Os, the maximum values being 1.27 ng/g and 1.41 ng/g, respectively (Text-figure 9a), similar to those observed in case of various other continental K/T sections. The integrated amount of iridium in the Anjar section is comparable and not higher than fallout at any other place on the globe. Thus if the Ir-rich layer is taken to represent the KTB layer, then in



Text-figure 7 —Probability density of ages of Deccan flows (K. Pande, pers. com.) based on Ar-Ar plateau ages . The distribution shows a peak at 67 Ma, 2 Ma before the KTB age of 65 Ma. A, B, C, D, E represent regions from where samples were dated and their locations are shown in Text-figure 8.

Table 4—Estimates of atmospheric loading (g) at K/T and P/T boundaries

Source	CO_2	SO_4	HCI	NO	Soot from forest fires	Ejecta dust
a) K/T bcundary						
Impact Platform	$2.7\text{-}9\text{x}10^{18}$ (1)	$0.38\text{-}3\text{x}10^{19}$ (2)	-	$3.15\text{x}10^{18}$ (3)	10^{17}	10^{19}
Bolide	$1.4\text{x}10^{17}$ (4)	$3\text{-}300\text{x}10^{14}$ (5)		$2.7\text{x}10^{15}$ (4)		
Deccan volcanism	$2.2\text{x}\ 10^{19}$ (6)	$1.7\ \text{x}10^{19}$ (6)	$2.7\text{x}10^{17}$ (6)			
Total	$2.65\text{x}10^{19}$	$4.25\text{x}10^{19}$	$2.7\text{x}10^{17}$	$3.15\text{x}10^{19}$	10^{17}	10^{19}
g/cm 2	5.2	8.3	0.05	0.62	0.014	2
b) P/Tr boundary						
Siberian volcanism 8	$2.93\text{x}10^{19}$	$2.26\text{x}10^{19}$ --	?	$3.6\text{x}10^{19}$	?	

1. O'Keefe and Ahrens (1989) gave estimates for platform thickness of 1 and 4 km indicated by the range.
2. Sigurdsson *et al.* (1992).
3. Prinn and Fegley (1987).
4. The CO_2 and SO_2 values have been estimated assuming a 10 km C2 type of bolide (C=2.48%; N=802 ppm). The choice of C2 type bolide is based on similarity of amino acids found in KTB sections and C_2 meteorites (see Table 3).
5. Kring *et al.* (1996).
6. Caldeira and Rampino (1990).
7. Fires will also provide 10^{18}g CO, 10^{17}g CH_4, 10^{16}g N_2O etc. besides CO_2 and the atmosphere ozone layer will be depleted. This may have more devastating effect on life support system (Wolbach, Gilmour & Anders, 1990; Rampino & Haggerty, 1996; and other references therein).
8. Basaltic lava volume from Siberian volcanic episodes is estimated to be $2\text{x}10^6$ km^3. The aerosol estimates are scaled from Deccan which had a volume of $1.5\text{x}10^6$km^3 .

the light of observations summarised above, some conclusions can be drawn about relation between KTB and Deccan. Firstly, the results show that Deccan volcanism was active before, during and after the KTB transition. Secondly, the extra-terrestrial impact did not trigger Deccan volcanism. The location of the KTB layer within the Anjar intertrappeans provides a high resolution time sequence because of fast sedimentation rate, free from the uncertainties in absolute chronology and contradicts the models of impact induced volcanism proposed by Alt *et al.* (1988) as well as simultaneity of impact and Deccan volcanism (Rampino & Caldeira, 1993).

The Anjar section also provides important criteria to test some other hypotheses. Chatterjee (1990, 1992) proposed that there was another impact on the Earth at the KTB time near the Indo-Seychelles border. The slightly oval-shaped structure, named Shiva Crater, after the Indian God of Destruction, is about km in 600x450x12 km in size and the bolide which created it is estimated to be 40 km in diameter, much bigger than the Chicxulub impactor. The impact which occurred at India-Seychelles border created the Carlsberg Ridge and triggered the rifting of the Indian Plate. The Carlsberg Ridge splitted the crater into two halves which drifted away from each other. At present the boundary of the western half of the crater is identified as the Amirante Arc and the eastern half is concealed under Deccan lava but discernible in the Panvel flexure. From the shape of the crater, Chatterjee (1990, 1992) suggested that the bolide came from south-west. If it is indeed so, Anjar, being not far from the point of impact, and placed in the immediate ejecta fallout zone, should have some evidence of the impact debris. We have not found any evidence of breccias, or other ejecta debris at Anjar, as has been found around Chicxulub crater or in the Pacific sediments where the Chicxulub ejecta cloud settle. If the sediments around the iridium layers at Anjar were deposited at the KTB time, as appears likely, than absence of these markers at Anjar rules out another impact of a larger magnitude at the proposed site of the Shiva crater. The same argument can be extended to the crater near Bombay high, proposed by Negi *et al.* (1993) based on a gravitational anomaly, although its dimensions are much smaller and thus large ejecta debris is not expected.

Table 5 — Ir concentration (pg/g) in Deccan basalts and in K-T boundary sections, India

I.		**Deccan basalts**	
	1	Takli	≤ 0.027
	2	Lonar Crater	0.004-0.006*
	3	Anjar FIII	<0.01
II.		**Continental K-T sections**	
A.		Takli section, Nagpur	
	1	Volcanic ash	0.05-0.12
	2	Marl	0.032-0.067
	3	Green clay	0.041-0.099
	4	Lower contact with trap	0.081
B.		Lameta Section, Jabalpur	
	1	Brown layer, Chui Hill	0.026
	2	Coal Seam, Padwar	0.015
C.		Bargi Canal section	
	1	Clay	0.008-0.015
D.		Jirabad	
	1	Trap contact	
E.		Mahabaleshwar section	<0.2
F.		Anjar	
	1	Boundary clay	0.69 -1..33
	2	Below and above boundary clay	0.1
III.		**Marine K-T sections**	
A.		Um Sohryngkew River section	
	1	Boundary clay	7.8
	2	Brown separate	12.1
	3	Cretaceous shales (-70 cm)	0.019
	4	Tertiary shales (+50 cm)	0.04
B.		Gongma section	<0.2

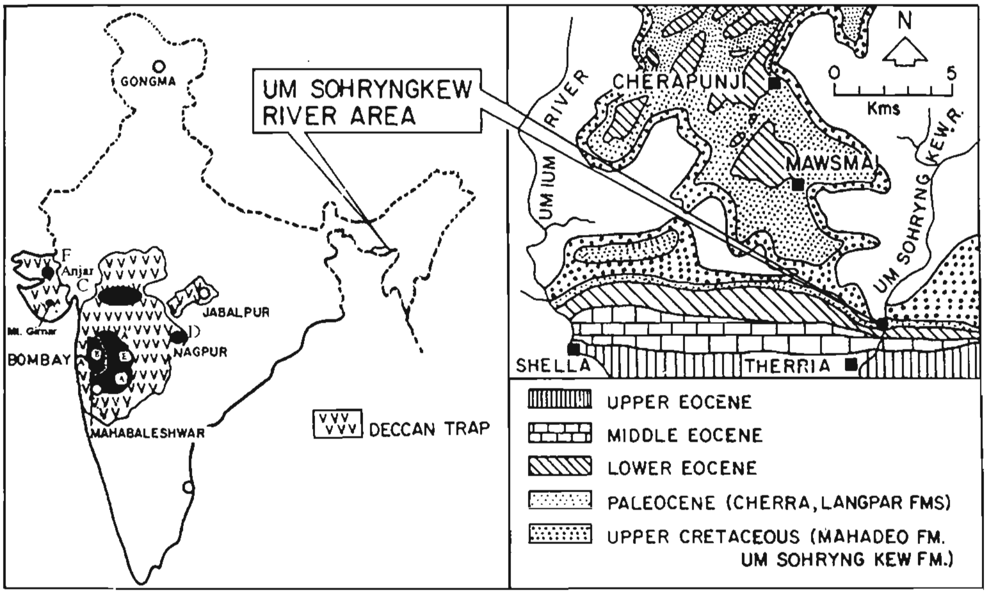
*Morgan (1978)

Um Sohryngkew River Section

A marine K/T section was studied from Um Sohryngkew River Basin, Meghalaya in eastern India (Text-figure 9) where the Maastrichtian-Danian sequence is continuous and a 1.5 cm thick limonitic layer enriched in Ir, Os and the other siderophile elements, characteristic of the KTB, is observed (Bhandari *et al.*, 1994 and references therein). The Ir profile in this section (Text-figure 9) shows a broad (30 to 70 cm) band on modest Ir concentration (~100pg/g), ten times higher than the background levels (10 pg/g) both below and above the KTB. The main sharp Ir peak (1200 pg/g) coincident with KTB is superimposed on this broad band.

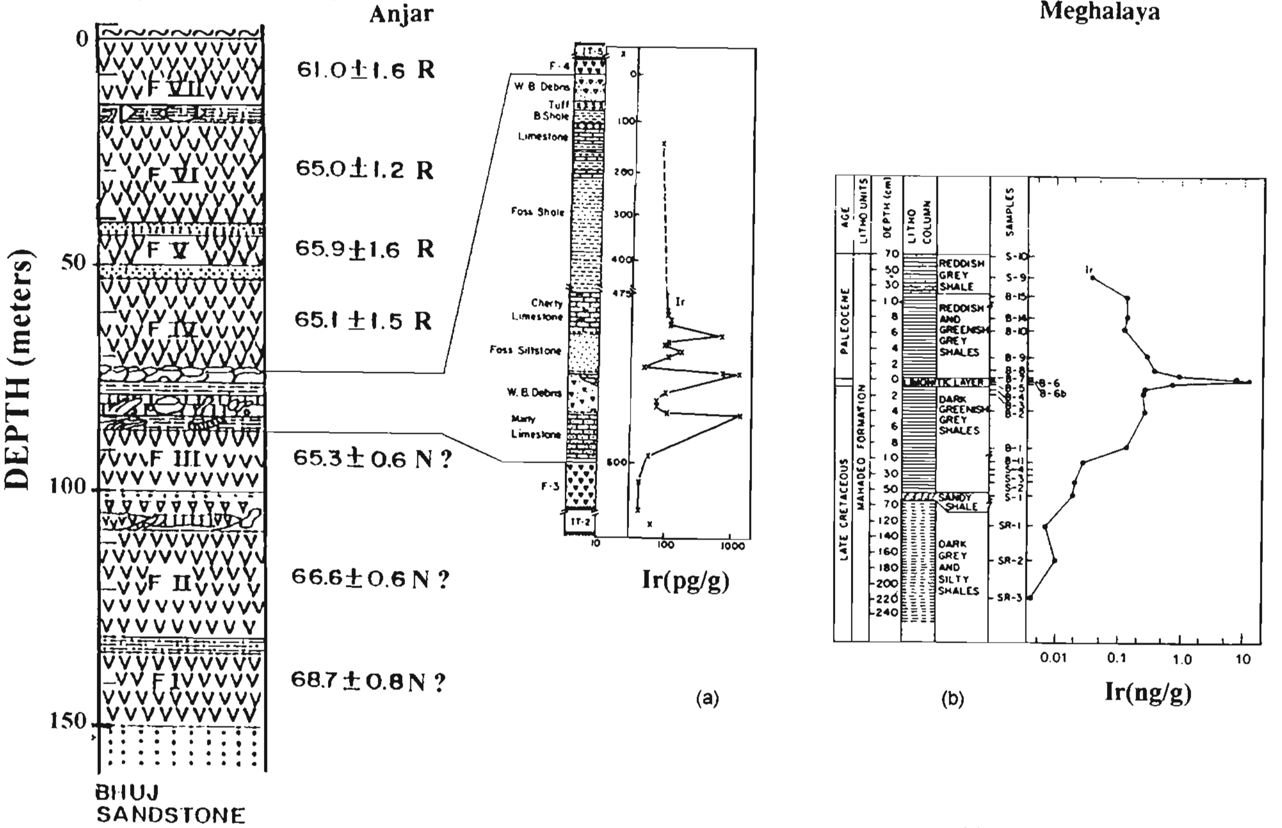
The extended Ir profile of Meghalaya section may be compared with Ir profiles in other marine KTB sections, e.g., Stevens Klint; El Kef, Caravaca; Hole 761 shown in Text-figure10. In all these sections, the main Ir peak at KTB is situated on a broad hump although the shape of the profile which depends on sedimentation rate is quite different in each of them. The broadening of the profiles is usually dismissed as due to post-depositional migration of Ir and other elements (Colodner *et al.*, 1992) although, at least in Meghalaya there is absence of significant bioturbation, mixing and post-depositional movement (Bhandari *et al.*, 1994). If this indeed is the case then it should be possible to test various hypotheses, i.e., volcanic, an asteroidal and multiple cometary impacts. It can be seen that Ir profile in a single asteroidal impact (Text-figure 6a) does not match with the observed Ir profiles in various sections (Text-figures 9, 10). Also a single asteroidal impact hypothesis does not explain the step-wise extinction pattern observed around the KTB (Hut *et al.*, 1987). The best match is obtained with tracer profiles shown in Text-figure 6b, or with combination of different profiles.

The other two scenarios, viz., volcanic eruptions and multiple cometary collisions are essentially episodic in nature and are also consistent with the observed gradual or step-wise extinction pattern. In case a comet fragments into a number of km-sized nuclei and a large amount of debris in a heliocentric earth-crossing orbit, all of it may eventually fall on the Earth, preceding and succeeding the impact of various nuclei. This scenario is shown in Text-figure11. In this model the main Ir peak could be due to the impacts of different nuclei as observed at Anjar, whereas the hump structure in the elevated Ir profile could be due to smaller debris. Similarly, in a volcanic scenario one could observe multiple Ir peaks corresponding to each volcanic episode. Graup and Spettel (1989) have reported three Ir enriched layers in the Lattengebirge section from Bavarian Alps and suggested volcanism as a cause for these enhancements. In this section, Ir resides in sulphide phases and is accompanied by enrichment in chalcophile trace elements as well. As mentioned earlier, Ir and chalcophile trace element enrichment in particulates from Hawaiian volcanoes also favour such a scenario. However, our extensive measurements of intertrappean sediments at various Deccan localities (Table 5) neither show adequate level of Ir nor there is any enrichment of chalcophile elements (Bhandari *et al.*, 1993a, 1993b, 1995, 1996).



Text-figure 8 —Sites of Indian K/T boundary sections and the Deccan Plateau showing regions A, B, C, D, E and F for which the distribution of ages is shown in Text-figure 7. Anjar intertrappean (IT III) in Kutch and Um Sohryngkew River section in Meghalaya shows anomalously high iridium concentration.

In conclusion, there is mounting evidence summarised earlier (Table 3) that Deccan volcanism was active around the K/T time and that a large impact took place ~65 Ma ago. Some authors (Alt *et al.*, 1988; Rampino & Caldeira, 1993) argue that a bolide impact triggered volcanism whereas others opine that impact and volcanic eruptions at KTB are independent events with no causal link, having



Text-figure 9 — Ir profiles observed in two Indian K/T sections. Anjar is a continental section from Kutch (a) and Um Sohryngkew River section is a marine section from Meghalaya (b). The composite section of Anjar volcano-sedimentary sequence is shown on the left some sample locations are marked.

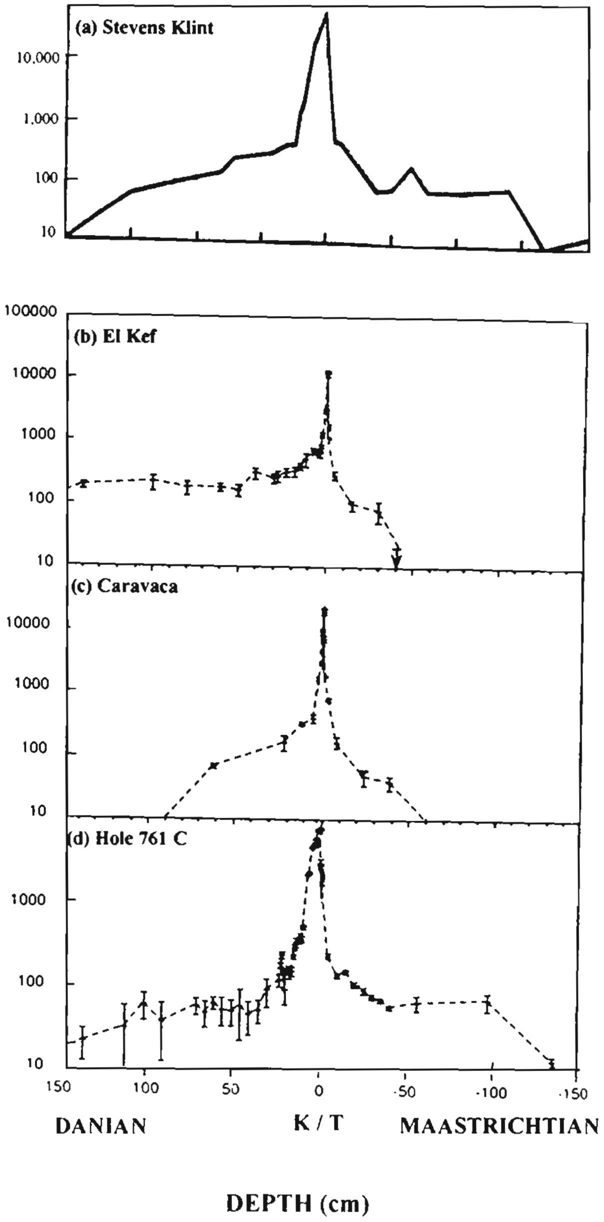
Table 6— Major observations at Permo-Triassic boundary

Biological signatures	
1.	**Global extinction of about 90% of marine fauna and 70% of terrestrial vertebrates (Sepkoski, 1992):** This is the most severe extinction event in the Phanerozoic.
2.	**Near disappearance of Permian flora (Retallack, 1995)**
Geological signatures	
1.	**Siberian flood basalts, timing and duration**: ^{40}Ar/^{39} Ar ages range between 253 Ma to 247 Ma. The volume is estimated to be (2x10^{6} km^{3}). It has been suggested that bulk of the basalts erupted within a short interval of time of less than 1 Ma around P/TB (Renne & Basu, 1991).
2.	Pyroclastic volcanism in south China (1000 to 4000 km^{3})
3.	**Sea level changes**: Rapid regression and transgression. About 280 m fall in sea level is estimated. The scenario envisages two regressions followed by a rapid transgression in the Early Triassic.
Chemical and isotopic signatures	
1.	Two small peaks of iridium ($\leq$ 120 pg/g) have been found at several locations (Holser *et al.*, 1989; Bhandari *et al.*, 1992)
2.	A positive europium anomaly has been found in Lalung and Guling sections in Spiti India (Bhandari *et al.*, 1992)
3.	A sharp decrease in δ^{13}C at and above the P/TB
4.	Excursions in δ^{18}O values indicating changes in sea water temperature of several degrees before and after the P/T event.
5.	Enrichment in S isotopic ratios (^{34}S/^{32}S) attributed to an anoxic event.
6.	A marked shift in Sr isotopes.
7.	Strong anoxia in the world oceans, both at high and low palaeolatitudes in the Late Permian (Erwin 1996; Wignell and Twichett, 1996). Records from the deep sea sections indicate a totally stratific ocean for a period of about 20 Ma which included a 12 Ma super anoxic period (Isozaki, 1997).
Mineralogical and other features	
1	Presence of quartz with planar deformation features in Australia and Antarctica P/TB sections (Retallack, 1996)

occurred by chance at the same time (Sutherland, 1994). The results on the Anjar and Meghalaya sections support the latter view as discussed above. Both of these events are highly energetic and their relative roles in mass extinction remains to be quantitatively evaluated.

The presence of excess Ir in the limonitic layer in the Um Sohryngkew River section in Meghalaya led Bhandari *et al.* (1994) to conclude that this layer represents the KTB. Further work on this section has been controversial in spite of the reported presence of the characteristic faunal break (Pandey, 1978, 1980) concomitant with iridium enrichment (12.1 ng/g) in the limonitic layer, by more than an order of magnitude (Bhandari *et al.*, 1987) above the normal level. Lahiri *et al.* (1988) reported absence of such a faunal break and contended that the KTB is about 30 m above the iridium rich limonitic layer. Subsequently, Jafar and Singh (1992) reported that latest Maastrichtian planktonic foraminifer and nannoplankton assemblages are absent in this section and argued that this section might be incomplete and without KTB. On the other hand, evidence for presence of KTB within this layer has come from a detailed study of foraminifera (Pandey, 1978, 1990) and from the occurrence of the diagnostic calcareous nannoplankton assemblages containing *Micula prinsii* just below the iridium layer (Garg & Jain, 1995). As it is important to ascertain if the KTB indeed occurs in this section, a search for meteoric spinels in the limonitic clay was made. Ni-rich spinels are believed to provide an unequivocal imprint of a cosmic bolide (Robin *et al.*, 1992). Simultaneous occurrence of Ni-rich spinels and high Ir concentration in the Meghalaya section (Robin *et al.*, 1997) has now settled this controversy and confirmed the existence of KTB in this section.

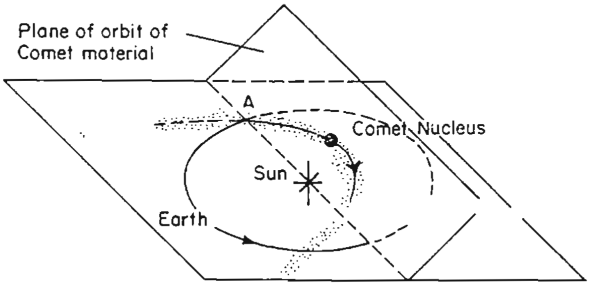
Recently, Alvarez (1996) modelled the fallout ejecta debris from the geometry of impact (angle, velocity, palaeogeographic locations) and concluded that impact ejecta did not reach India, which was located in the "forbidden zone". Although iridium and meteoric spinels have been found in Meghalaya section, there is as yet no evidence of the presence of shocked quartz which is a physical marker of the ejecta debris. Their presence in Anjar or Um Sohryngkew River sections may provide a test of the models of distribution of ejecta material.



Text-figure 10—Ir profile in some selected K/T boundary sections (Stevns Klint, El Kef, Caravaca and Hole 761C). Occurrence of a major Ir peak located on a broad extended hump above and below KTB, can be seen.

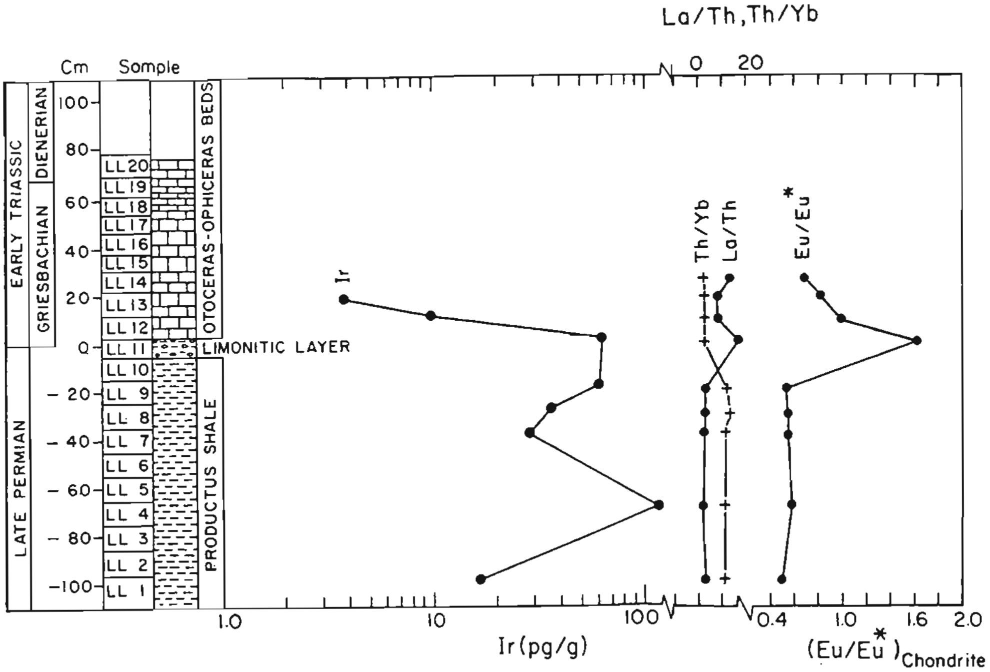
PERMIAN-TRIASSIC BOUNDARY

The Permian-Triassic (P-T) mass extinction was the most catastrophic in the geological record where as many as 90 per cent of the marine fauna and 70 per cent of the terrestrial vertebrates became extinct (Raup & Şepkoski, 1986; Erwin, 1994a, 1994b). Significant floral extinctions are also observed around this boundary (Retallack, 1995). The PTB is quite complex and palaeontological controls as well as preservation of evidence is relatively poor. Several P/T sections have been studied, but in most of them some horizons are missing (Sweet *et al.,* 1992; Kapoor, 1992). Some of these sections are shown in Text-figure14. Claystone, mudstone or pyrite bands have been found at the PTB at many locations (Nakazawa *et al.,* 1992). Geochemical, isotopic and palaeontological studies have been carried out on Carnic Alps section in Austria (Holser *et al.*, 1989); China (Clark *et al.,* 1986; Zhou & Kyte, 1988), India (Bhandari *et al.*, 1992); Italy (Wignall & Twitchett, 1996); Russia (Alekseev *et al.*, 1983), etc. Although earlier reports indicated that P-T extinctions took place over about 8 to 10 million years (Stanley, 1987; Teichert, 1990), a recent re-examination of the palaeontological data by Erwin (1994a, 1994b,1996) suggests a shorter duration, about 2 Ma or less, for this extinction. Important biological, geological, chemical and isotopic signatures found at PTB are summarised in Table 6. Search of a chemical marker having a global nature has not yielded any definitive clues. The range of Ir values observed across the boundary in various sections range from a few pg/g to hundreds of pg/g as listed in Table 6. In their detailed study of Gartnerkofel section in Carnic Alps Holser *et al.* (1989) found two minor Ir peaks, one occurring at the base of a pyrite zone at the boundary and the other about 40 m above it. Both the Ir peaks are associated with $\delta^{13}C$ minima. Though the peak Ir concentrations at the boundary are marginally higher than the background values, these minor Ir enhancements could result from some terrestrial processes (Colodner *et al.,* 1992).



Text-figure 11—Schematic diagram showing orbits of cometary debris and the earth-crossing each other which may explain the iridium profiles observed in KTB sections shown in Text-figures 9 and 10.

Before we discuss the scenario emerging for P/T transition, the results obtained from Indian sections (Bhandari *et al.*, 1992) are briefly described here. In view of the geographical proximity of these sections



Text-figure 12—Ir and Eu profiles in a P/T section from Lalung, Spiti, showing a large positive europium anomaly in the limonitic layer. Th/Yb and La/Th profiles are also shown which indicate basaltic volcanic contribution above the limonitic layer (Bhandari *et al.*, 1992).

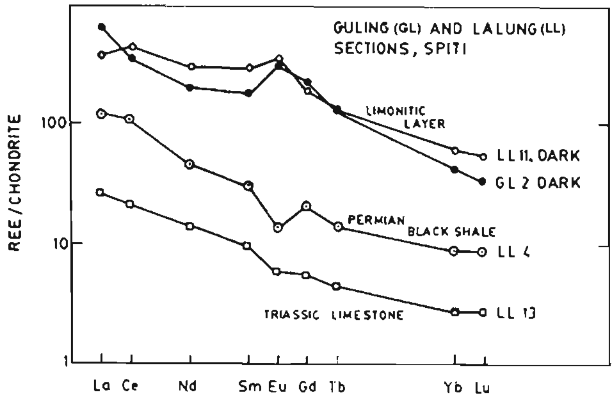
to Siberian volcanic region (Text-figure 2) during the end-Permian period, it can only be expected that the large volcanic episode will overwhelm the chemistry of sedimentary deposits at that time. If indeed there was another event of global significance, such as an impact, its signatures can best be seen far away from the volcanic regime.

CLUES FROM THE INDIAN SECTIONS AT GULING AND LALUNG, SPITI VALLEY

During the Permian-Triassic time Australia, Antarctica and India were located in the southern hemisphere (Text-figure 2b). Chemical analysis of Lalung and Guling sections in Spiti by Bhandari *et al.* (1992), where a limonitic layer exists at the Permian-Triassic interface, shows a small Ir enhancement at the boundary (70 pg/g) and another minor Ir peak (~114 pg/g) about 70 cm below the boundary (Text-figure 12). These Ir levels are similar to those observed in Carnic Alps by Holser *et al.* (1989) and in Chinese sections by Zhou and Kyte (1988), both located in the northern hemisphere (Text-figure 2b). However, the boundary sample of the limonitic layer at Spiti shows a very high Eu concentration and the chondrite normalised REE patterns (Text-figure 13) shows a positive Eu anomaly of $(Eu/Eu^*)_{max}$ equal to 1.9 (Eu* is the interpolated concentration based on its neighbouring elements Sm and Gd). The Eu anomaly is also associated with high value of Sb and Zn. Some of these geochemical features like high Fe, Zn and Sb are also observed in boundary samples from Meishan section in China (Zhou & Kyte, 1988). Bhandari *et al.* (1992) have discussed various terrestrial and extra-terrestrial causes which can give rise to the positive Eu anomaly observed at the PTB. Among the terrestrial sources, it has been pointed out that volcanogenic sediments and interaction of hydrothermal solutions with felsic volcanic rocks could give rise to a positive Eu anomaly. Among the extra-terrestrial objects, differentiated meteorites like eucrites and lunar anorthosites exhibit high positive Eu anomaly and have very low Ir values. Thus if an impact were responsible for the P/T event, the observations would be consistent with a bolide of a differentiated achondritic body.

Recently, Retallack (1996) found some quartz grains having planar deformation features (PDF) in the P/T section near Sydney, Australia which can possibly be due to impact. Similar damaged quartz were found in the P/T section of Victorialand, Antarctica. These PDF quartz are associated with $\delta^{13}C$ anomaly indicative of P/T extinction. The search for shocked quartz at PTB in sections located in the northern hemisphere has not yielded positive results.

If an impact occurred in the southern hemisphere, some northern hemisphere sections may be excluded from the ejecta debris and this may explain their absence in Chinese and European sections. Whether an impact occurred or not at the PTB the extinction may be a result of cumulative stress created by several physico-chemical processes. Some of these are schematically shown in Text-figure 14 (after Erwin, 1996) and these possibilities are briefly discussed below.



Text-figure 13 — Chondrite normalized REE patterns from Guling and Lalung PTB sections, Spiti. A positive Eu anomaly is observed at the boundary (Bhandari *et al.*, 1992).

EFFECT OF SIBERIAN VOLCANISM

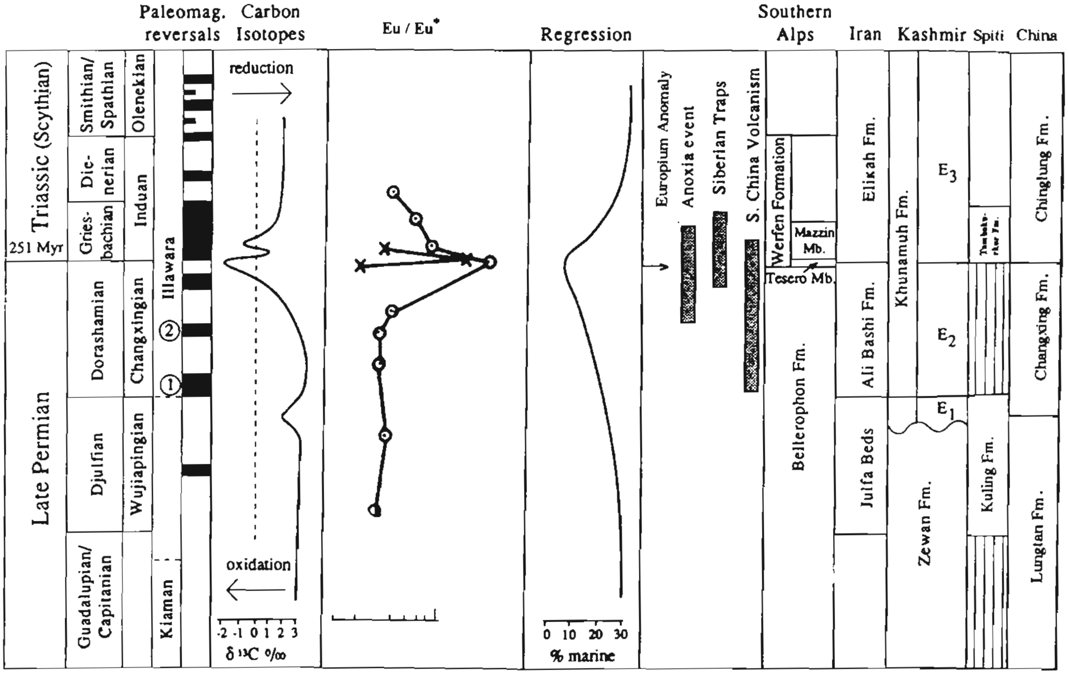
The available geochronological data on Siberian traps suggest that it was synchronous with the P-T extinction. Renne *et al.* (1995) estimated the age of the PTB by dating two tuff samples from southern Chinese sections, Shangsi and Meishan, located just above and below the boundary. The plateau ages 249.91±0.51 Ma (Meishan, Sanidine sample) and 250.04±0.36 Ma (Shangsi, Plagioclase sample) are indistinguishable from each other. The mean value of 249.98±0.2 Ma is comparable to the PTB age of 251.2±3.4 Ma obtained by U-Pb analysis of zircons from the Meishan section (Cloue-Long *et al.*, 1991).

The best estimate of initiation time of the Siberian trap volcanism as indicated by main stage of the tholeiitic magma is 250.0±1.6 Ma (Renne *et al.*, 1995) same as the estimated age of the PTB. The volcanism lasted for a short duration, ~1Ma (Renne & Basu, 1991; Renne *et al.*, 1995; Basu *et al.* 1995; Venkatesan *et al.*, 1997). Prior to this main pulse of tholeiitic magma, an alkaline volcanism from the north eastern part of the Siberian flood basalt province has been observed by Basu *et al.* (1995) around 253.3±2.6 Ma. Siberian flood basalts have the largest subaerial exposure of ~$3x10^6$ km^3 in the Phanerozoic and are associated with mafic intrusions which contain sulphide ores. The eruptions were both explosive and sulphur rich which would have injected large amount of SO_2 and volcanic dust in the atmosphere causing acid rain and global cooling. The estimated sulphate loading of the atmosphere is given in Table 4. Campbell *et al.* (1992) mention several features of Siberian volcanism which could bring about global cooling through SO_2 emissions and have argued in favour of Siberian volcanism as the main cause of P-T extinction through climatic stress. This scenario is supported by Courtillot *et al.* (1996) who also believes Siberian volcanism to be dominantly responsible for the P-T extinction. The isotopic and geochemical studies of Alpine and the Chinese sections (Holser *et al.*, 1989; Clark *et al.*, 1986; Zhou & Kyte, 1988) suggest a strong regression-transgression event occurring with mass extinction at the PTB and also favour a volcanic scenario based on geochemical arguments.

In the scenario that is emerging, various observations could be visualized as follows. Siberian traps produced sufficient sulphate aerosols in the stratosphere which resulted in rapid cooling. This initiated ice cap accumulation causing a marine regression leading to sub-aerial exposure of the continental shelves. It also explains the observed excursions in C, S and Sr isotopes. Mantle derived CO_2 and SO_2 being light in C and S contributed to the negative anomalies in $\delta^{13}C$ and $\delta^{34}S$. When the Siberian volcanism ceased, a rapid transgression followed and climate recovery took place due to green house effect of volcanic gases like CO_2. Thus anoxia, volcanism and sea level regression, all three may have played an important role in P/T extinction as shown in Text-figure 14. Search of impact signature and a detailed study of claystones, mudstones, pyrite bands and limonitic layers found at various P/T boundaries may provide some clues to other significant processes occurring at the PTB.

SUMMARY

We have described the main features of the two most severe extinction events in the geologic history of the Earth. The debate between impact and volcanic



Text-figure 14 — Schematic scenario for extinction at the PTB (modified from Erwin, 1994a, 1994b, 1996). Periods of global anoxia, Siberian volcanism and south Chinese volcanism are shown together with the event of positive europium anomaly, observed in Spiti. Palaeomagnetic polarity, carbon isotope and Europium (Eu/Eu*) profiles and sea level changes are shown. Some of the P/T sections (Southern Alps, Iran, Kashmir, Spiti and China) are shown at the right.

hypotheses is far from resolved. From the evidences summarised in this article, it is clear that there are very few similarities in physical, chemical and biological markers observed at P/T and K/T boundaries. The situation is even more exclusive when other boundaries are taken into consideration. It therefore appears unlikely that there is a single mechanism which could explain the extinctions. Hypotheses involving multiple causes, therefore, appear more plausible although McLaren and Goodfellow (1990) and Rampino and Haggerty (1996) have argued for an impact theory of extinction whereas Courtillot *et al.* (1986) and McLean (1985) have advanced the volcanic hypothesis. It may be that sometimes volcanism and impact occur together increasing the severity of climatic stress (Sutherland, 1994). In Text-figure 14, we reproduce a likely scenario, developed by Erwin (1994a, 1994b, 1996), where anoxia, aerosol loading, sea-level regression, etc. can contribute to extinction in some measures. Whatever may be the primary cause that triggered the sequence of event(s) that resulted in mass extinctions, it is clear that at the time of mass extinctions, the days were cold, pitch dark and dry and climate was not conducive for the survival of fauna and flora.

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REFERENCES

Abbas S & Abbas A 1996. Comments on biological effects of stellar collapse neutrinos. astro-ph 9612003 preprint, University of Bhuvaneshwar, India.

Alekseev AS, Barsukova LD, Kolesov GM, Nazarov MA & Grigoyan AG 1983. Permian-Triassic boundary event : geochemical investigation of the Trans Caucasia (abstract). *Lunar Planet. Sci.* **14**: 7-8.

Alt D, Sears JM & Hyndmann DW 1988. Terrestrial Maria : the origins of large basalt plateaus, hot spot tracks and spreading ridges. *J. Geol.* **96**: 647-662.

Alvarez LW, Alvarez W, Asaro F & Michel HV 1980. Extraterrestrial cause of the Cretaceous/Tertiary extinction. *Science* **208**: 1095-1108.

Alvarez W 1996. Trajectories of ballistic ejecta from the Chicxulub Crater. *Geol. Soc. Am. Spec. Pap.* **307**: 141-150.

Basu AR, Poreda RJ, Renne PR, Teichmann F, Vasiliev YR, Sobolev NV & Turrin BD 1995. High ^{3}He plume origin and temporal spatial evolution of the Siberian flood basalts. *Science* **269**: 822-825.

Berner AR 1992. Palaeo-CO_2 and climate. *Nature* **358**: 114.

Bhandari N 1991. Collisions with Earth over geologic times and their consequences to the terrestrial environment. *Curr. Sci.* **61**: 97-104.

Bhandari N, Gupta M, Pandey J & Shukla PN 1994. Chemical profiles in K/T boundary section of Meghalaya, India : Cometary, asteroidal or volcanic. *Chem. Geol.* **113**: 45-60.

Bhandari N, Gupta M & Shukla PN 1993a. Deccan volcanic contribution of Ir and other trace elements near the K/T boundary. *Chem. Geol.* **103:** 129-139.

Bhandari N, Shukla PN & Azmi RJ 1992. Positive europium anomaly at the Permo-Triassic boundary, Spiti, India. *Geophys. Res. Letts* **19**: 1531-1534.

Bhandari N, Shukla PN & Castagnoli GC 1993. Geochemistry of some K/T sections in India. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **104**: 199-211.

Bhandari N, Shukla PN, Ghevariya ZG & Sundaram SM 1995. Impact did not trigger Deccán volcanism : evidence from Anjar K/T boundary intertrappean sediments. *Geophys. Res. Letts.* **22:** 433-436.

Bhandari N, Shukla PN, Ghevariya ZG & Sundaram SM 1996. K/T boundary layer. in Deccan intertrappeans at Anjar, Kutch. *Geol. Soc. Am. Spec. Pap.* **307**: 417-424.

Bhandari N, Shukla PN & Pandey J 1987. Iridium enrichment at Cretaceous-Tertiary boundary in Meghalaya. *Curr. Sci*. **56**: 1003-1005.

Bohor BF 1990. Shocked quartz and more : Impact signatures in Cretaceous/Tertiary boundary clays. *Geol. Soc. Am. Spec. Pap.* **247**: 335-342.

Bohor BF, Betterton WJ & Krogh TE 1993. Impact-shocked zircons : discovery of shock induced textures reflecting increasing degrees of shock metamorphism. *Earth Planet. Sci. Letts* **119**: 419-424.

Bohor BF, Foord EE, Modreski PJ & Triplehorn DM 1984. Mineralogic evidence for an impact event at the Cretaceous-Tertiary boundary. *Science* **224**: 867-869.

Bostwick JA & Kyte FT 1996. Size and abundance of shocked quartz in Cretaceous-Tertiary boundary sediments from the Pacific basin. *Geol. Soc. Am. Spec. Pap.* **307**: 403-415.

Brooks RR, Hock PL, Reeves RD, Wallace RC, Johnston JH, Ryan DE, Holzbechee J & Collen JD 1985. Weathered spheroids in a Cretaceous/Tertiary boundary shale at Woodside Greek, New Zealand. *Geology* **13**: 738-740.

Caldeira KG & Rampino MR 1990. Deccan volcanism, green house warming and the Cretaceous/Tertiary boundary.*Geol. Soc. Am. Spec. Pap.* **247**: 117-123.

Campbell IH, Czamanske K, Fédorenko VA, Hill RI & Stepanov V 1992. Synchronism of the Siberian traps and the Permian-Triassic boundary. *Science* **258**: 1760-1763.

Carlise DB 1992. Diamonds at the K/T boundary. *Nature* **357**: 119-120.

Carlise DB 1995. *Dinosaurs, diamonds and things from outer space : the great extinctions. Stanford University Press.*

Chatterjee S 1990. A possible K-T impact site at the India-Seychelles boundary. (abstract). *Lunar Planet. Sci. XXI*: 182-183.

Chatterjee S 1992. A kinematic model for the evolution of the Indian Plate since the Late Jurassic. *In* : Chatterjee S & Hotton N III (Editors) — *New concepts in global tectonics* : 33-62. Texas Univ. Press, Lubbock.

Cloue-Long JC, Zichao Z, Guogan M & Shaohua D 1991. The age of the Permian-Triassic boundary. *Earth Planet. Sci. Letts* **105:** 182-186.

Clark DL, Wang CY, Orth CJ & Gilmore JS 1986. Conodont survival and low iridium abundance across the Permian-Triassic boundary in South China. *Science* **233**: 984-986.

Clube SVM & Napier WM 1986. Giant comets and the galaxy : Implications of the terrestrial record. *In* : Smoluchowski R, Bahcall JN & Matthews MS (Editors) — *The galaxy and the solar system.*: 260-285. The University of Arizona Press, Tucson, Arizona,

Colodner DC, Boyle EA, Edmond JM & Thompson J 1992. Post-depositional mobility of platinum, iridium and rhenium in marine sediments. *Nature* **358:** 402-404.

Courtillot V 1995. La Vie en Catastrophes, Feyard (Editor).

Courtillot V, Besse J, Vandamme D, Montigny R, Jaeger JJ & Cappetta H 1986. Deccan flood basalts at the Cretaceous-Tertiary boundary. *Earth Planet. Sci. Letts* **80**: 361-374.

Courtillot V, Jaeger JJ, Yang Z, Feraud G & Hofmann C 1996. The influence of continental flood basalts on mass extinctions : where do we stand? *Geol. Soc. Am. Spec. Pap.* **307:** 513-525.

Davis M, Hut P & Muller RA 1984. Extinction of species by periodic comet showers. *Nature* **308**: 715-717.

Ellis J & Schramm D 1995. Could a supernova explosion have caused a mass extinction. *Proc. natn. Acad. Sci. Washington* **92**: 235-238.

Erwin DH 1994a. The Permo-Triassic extinction. *Nature* **367**: 231-236.

Erwin DH 1994b. The end-Permian mass extinction : a complex multicaused extinction : In new developments regarding the KT event and other catastrophes in Earth history. LPI Contribution No. 825, Houston, p.33 (abstract).

Erwin DH 1996. The mother of mass extinctions. *Scient. Am.* **275**: 56-62.

Felitzyn SB & Vaganov PA 1988. Iridium in the ash of Kamchatkan volcanoes. *Int. Geol. Rev.* **30**: 1288-1291.

Garg R & Jain KP 1995. Significance of terminal Cretaceous calcareous nanoplankton marker *Micula prinsii* at the K/T boundary in Um Sohryngkew section, Meghalaya, India. *Curr. Sci.* **60**: 1012-1017.

Gardener A, Hildebrand A & Gilmour I 1992. Isotopic composition and organic geochemistry of nitrogen at the Cretaceous-Tertiary boundary. *Meteoritics* **27**: 221-223.

Ghosh P, Bhattacharya SK & Jani RA 1995. Palaeoclimate and palaeovegetation in central India during the Upper Cretaceous based on stable isotope composition of the palaeosol carbonates. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **114**:285-296.

Gilmour I, Russell SS, Arden JW, Lee MR, Franchi IA & Pillinger C 1992. Terrestrial carbon and nitrogen isotopic ratios from Cretaceous-Tertiary boundary nanodiamonds. *Science* **258 :** 1624-1626.

Graup G & Spettel B 1989. Mineralogy and phase chemistry of an Ir-enriched pre-K/T layer from the Lattengebirge, Bavarian Alps, and significance for the KTB problem. *Earth Planet. Sci. Letts* **95**: 271-290.

Grieve RAF 1991. Terrestrial impact : the record in the rocks. *Meteoritics* **26:** 175-194.

Hallam A 1992. *Phanerozoic sea-level changes.* Columbia University Press, New York.

Haq BU, Hardenbol J & Vail PR 1987. Chronology of fluctuating sea levels since the Triassic. *Science* **235:** 1156-1167.

Heymann D, Chibante LPF, Brooks RR, Wolbach WS, Smit J, Korochantsev A, Nazarov MA & Smalley RE 1996. Fullerenes of possible wildfire origin in Cretaceous-Tertiary boundary sediments. *Geol. Soc. Am. Spec. Pap.* **307**: 453-464.

Hildebrand AR, Penfield GT, Kring DA, Pilkington M, Camargo A, Jacobsen SB & Boynton WV 1991. Chicxulub Crater : a possible Cretaceous/Tertiary boundary impact crater on the Yucatan Peninsula, Mexico. *Geology* **19:** 867-871.

Hills J 1981. Comet showers and the steady state infall of comets from the Oorts' cloud. *Astron. J.* **86:** 1730-1740.

Hills J 1986. Deflection of comets and other long-period solar companions into the planetary system by passing stars. *In* : Smoluchowski R, Bahcall JN & Matthews MS (Editors)—*The galaxy and the solar system*: 397-408. The University of Arizona Press, Tucson, Arizona.

Hofmann C, Courtillot V, Bhandari N, Shukla PN, Kusumgar S, Ghevariya ZG, Gallet V, Fraud G & Rocchia R 1997. Timing of bolide impact and flood basalt volcanism at the K/T boundary based on the study of Kutch sections. Abstract, 21/3 A06, E.G.S. Meeting, Strasbourgh.

Hollander DJ, McKenzie JA & Hsu KJ 1993. Carbon isotope evidence for unusual plankton blooms and fluctuations of surface water CO_2 "Strangelove Ocean" after terminal Cretaceous event. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **104**: 229-237.

Holser WT & Magaritz M 1992. Cretaceous/Tertiary and Permian/Triassic boundary events compared. *Geochim. Cosmochim. Acta* **56**: 3297-3309.

Holser WT, Schonlaub HP, Attrep M, Boeckelmann K, Klein P, Magaritz M, Orth CJ, Feninger A, Jenny C, Kralik M, Mauritsch H, Pak E, Schramm JM, Stattegger K & Schmoller R 1989. A unique geochemical record at the Permian-Triassic boundary. *Nature* **337**: 39-44.

Hoyt WG 1980. *Planet X and Pluto.* The University of Arizona Press, Tucson, Arizona.

Hsu KJ & Mckenzie JA 1990. Carbon isotope anomalies at era boundaries : global catastrophes and their ultimate cause. *Geol. Soc. Am Spec. Pap.* **247**: 61-70.

Hut P, Alvarez W, Elder WP, Hansen T, Kauffman EG, Keller G, Shoemaker EM & Weissman PR 1987. Comet showers as a cause of mass extinctions. *Nature* **329**: 118-126.

Isozaki Y 1997. Permo-Triassic boundary superanoxia and stratified Superocean : records from lost deep sea. *Science* **276**:235-238.

Ivany LC & Salawitch RJ 1993. Carbon isotope evidence for biomass burning at the K-T boundary. *Geology* **21**: 487-490.

Izett GA, Dalrymple GB & Snee LW 1991. ^{40}Ar- ^{39}Ar age of Cretaceous-Tertiary boundary tektites from Haiti. *Science* **252:** 1539-1542.

Jafar SA & Singh OP 1992. K/T boundary species with Early Eocene nanofossils discovered from Subathu Formation, Shimla Himalaya, India. *Curr. Sci.* **62:** 409-413.

Javoy M & Courtillot V 1989. Intense acidic volcanism and the Cretaceous-Tertiary boundary. *Earth Planet. Sci. Letts* **94:** 409-416.

Kaiho K 1994. Planktonic and benthic foraminiferal extinction events during the last hundred m.y. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **111**: 45-71.

Kajiwara Y & Kaiho K 1992. Oceanic anoxia at the Cretaceous/Tertiary boundary supported by the sulfur isotope record. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **99**: 159-162.

Kamo SL & Krogh TE 1995. Chicxulub crater source for shocked zircon crystals from the Cretaceous-Tertiary boundary layer, Saskatchewan: evidence from new U-Pb data. *Geology* **23:** 281-284.

Kapoor HM 1992. Permo-Triassic boundary of the Indian subcontinent and its intercontinental correlation. *In* : Sweet, WC, Zunyi Y & Dickins Yin H (Editors) — *Permo-Triassic events in the eastern Tethys:* 21-36. Cambridge University Press.

Keller G 1994. Global biotic effects of the K/T boundary event: Mass extinction restricted to low latitudes. *Lunar Planet. Inst. Contrib.* **825:** 57-58.

Keller G, Li L & Mac Leod 1995. The Cretaceous/Tertiary boundary stratotype section of El Kef, Tunisia : how catastrophic was mass extinction. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **119:** 221-254.

Kring DA & Boynton WV 1991. Altered spherules of impact melt and associated relic glass from K/T boundary sediments in Haiti. *Geochim. Cosmochim. Acta* **55**: 1737-1742.

Kring DA & Boynton WV 1993. K/T melt glasses. *Nature* **363**: 503-504.

Kring DA, Melosh HJ & Hunten DM. 1996. Impact-induced perturbations of atmospheric sulfur. *Earth Planet. Sci. Letts* **140**: 201-212.

Krogh TE, Kamo SL, Sharpton VL, Marin LE & Hildebrand AR 1993. U-Pb ages of single shocked zircons linking distal K/T ejecta to the Chicxulub crater. *Nature* **366**: 731-734.

Kuiper GP 1951. On the origin of the solar system. *In*: Hynek A (Editors) — *"Astrophysics: a topical symposium"*: 357-424. McGraw Hill, New York.

Kyte FT 1988.The extra terrestrial component in marine sediments : description and interpretation. *Palaeoceanography* **3**: 235-247.

Kyte FT 1996. A piece of the K/T bolide? (abstract). *Lunar Planet. Sci.* **XXVII :** 717-718.

Kyte FT, Bostwick JA & Zhou L 1996. The Cretaceous-Tertiary boundary on the Pacific plate : composition and distribution of impact debris. *Geol. Soc. Am. Spec. Pap.* **307**: 389-401.

Kyte FT & Wasson JT 1986. Accretion rate of extraterrestrial matter : Iridium deposited 33 to 67 million years ago. *Science* **232:** 1225-1229.

Lahiri TC, Sen MK, Raychaudhuri AK & Acharyya SK 1988. Observations on Cretaceous/Tertiary boundary and reported iridium enrichment, Khasi Hills, Meghalaya. *Curr. Sci.* **20**: 1335-1336.

Luck JM & Turekian KK 1983. Osmium-187/Osmium-186 in manganese nodules and the Cretaceous-Tertiary boundary. *Science* **222**: 613-615.

Martin EE & McDougall JD 1991. Sea water Sr isotopes at the Cretaceous/Tertiary boundary. *Earth Planet. Sci. Letts* **104**: 166-180.

Matese JJ & Whitmire DP 1986. Planet X as the source of the periodic and steady-state flux of short period comets. *In* : Smoluchowski, Bahcall JN & Matthews MS (Editors) — *The galaxy and the solar system*: 297-312. The University of Arizona Press, Tucson, Arizona.

McLaren DJ & Goodfellow WD 1990. Geological and biological consequences of giant impacts. *Annl. Rev. Earth Planet. Sci.* **18**:123-171.

McLean DM 1985. Deccan traps mantle degassing in the terminal Cretaceous marine extinction. *Cretaceous Res.* **6**:235-259.

Montanari A, Hay RL, Alvarez W, Asaro F, Michel HV, Alvarez LW & Smit J 1983. Spheroids at the Cretaceous-Tertiary are altered droplets of basaltic composition. *Geology* **11**:668-671.

Morgan JW 1978. Lonar crater glasses and high-magnesium australites: trace element volatilisation and meteoritic contamination. *Proc. Lunar Sci. Conf. IX* : 2713-2730.

Nakazawa K, Okimura Y & Tokuoka T 1992. Permian and Triassic problems in the Tethys. *Abst. Symp. Himalayan Geology, Shimane*.: 32.

Napier WM 1985. Dynamical interactions of the solar system with massive nebula. *In* : Carusi A & Valsecchi GB (Editors) - *Dynamics of comets : their origin and evolution* : 41-31 D.Reidel.

Negi JG, Agrawal PK, Pandey OP & Singh AP 1993. A possible K-T boundary bolide impact site offshore near Bombay and triggering of rapid Deccan volcanism. *Phys. Earth Planet. Inter.* **76**: 189-197.

Nelson BK, Macleod GK & Ward PD 1991. Rapid change in strontium isotopic composition of sea water before the Cretaceous-Tertiary boundary. *Nature* **351:** 644-647.

O'Keefe JD & Ahrens TJ 1989. Impact production of CO_2 by the Cretaceous-Tertiary extinction bolide and the resultant heating of the earth. *Nature* **338**: 247-249.

Olmez I, Finnegan DL & Zoller WH 1986. Iridium emissions from Kilauea volcanoes. *J. geophys. Res.* **91**: 653-662.

Pandey J 1978. Palaeocene smaller foraminifera of Um Sohryngkew River section, Meghalaya. *In:* Rasheed RDA (Editor) — *Proc. 7th Indian Colloq. Micropaleont. Stratgr., Madras Univ., Madras* : 70-152.

Pandey J 1980. Cretaceous foraminifera of Um Sohryngkew River section, Meghalaya. *J. palaeont. Soc. India* **25**: 53-75.

Pandey J 1990. Cretaceous/Tertiary boundary, iridium anomaly and foraminifer breaks in the Um Sohryngkew River section, Meghalaya. *Curr. Sci.* **59**: 570-575.

Pospichal JJ 1996. Calcareous nannoplankton mass extinction at the Cretaceous/Tertiary boundary : An update. *Geol. Soc. Am. Spec. Pap.* **307:** 335-360.

Prinn RG & Fegley B 1987. Bolide impacts, acid rain, and biospheric traumas at the Cretaceous-Tertiary boundary. *Earth Planet. Sci. Letts* **83**: 1-15.

Rampino MR & Caldeira KG 1993. Major episodes of geological change: correlations, time structure and possible causes. *Earth Planet. Sci. Letts* **114:** 215-227.

Rampino MR & Haggerty BM 1996. Impact crises and mass extinctions: a working hypothesis *Geol. Soc. Am.. Spec. Pap.* **307**: 11-30.

Rampino MR & Volk T 1996. Multiple impact event in Paleozoic : collision with a string of comets or asteroids? *Geophys. Res. Letts* **23:** 49-52.

Raup DM 1972. Taxonomic diversity during the Phanerozoic. *Science* **177:** 1065-1071.

Raup DM & Sepkoski JJ 1986. Periodic extinction of families and genera. *Science* **231**: 833-836.

Renne PR & Basu AR 1991. Rapid eruption of the Siberian trap flood basalts at the Permo-Triassic boundary. *Science* **253**: 176-179.

Renne PR, Zichao Z, Richards MA, Black MT & Basu AR 1995. Synchroneity and causal relations between Permian-Triassic boundary crises and Siberian flood volcanism. *Science* **269**: 141-1416.

Retallack GJ 1995. Permian-Triassic crisis on land. *Science* **267**: 77-80.

Retallack GJ 1996. Paper presented at the Geological Society of America Meeting.

Robin E, Bonte P, Forget L, Jehanno C & Rocchia R 1992. Formation of spinels in cosmic objects during atmospheric entry : a clue to the Cretaceous-Tertiary boundary event. *Earth Planet. Sci. Letts* **108**: 181-190.

Robin E, Rocchia R, Bhandari N & Shukla PN 1997. Imprints of cosmic bolide in the Meghalaya K/T section (in preparation).

Rocchia R, Robin E, Froget L & Gayraud J 1996. Stratigraphic distribution of extraterrestrial markers at the Cretaceous-Tertiary boundary in the Gulf of Mexico area : implications for the temporal complexity of the event. *Geol. Soc. Am. Spec. Pap.* **307**: 279-286.

Sarkar A, Bhattacharya SK, Shukla PN, Bhandari N & Naidin DP 1992. High-resolution profile of stable isotopes and iridium across a K/T boundary section from Koshak Hill, Mangyshlak, Kazakhstan. *Terra Nova* **4:** 485-590.

Schmitz B, Keller G & Stenvall O 1992. Stable isotope and foraminiferal changes across the Cretaceous-Tertiary boundary at Stevns Klint, Denmark : arguments for long-term oceanic instability before and after bolide impact event. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **96:** 233-260.

Schuraytz BC, Lindstrom DJ , Marin LE, Martinez RR, Mittlefehldt DW, Sharpton VL & Wentworth SJ 1996. Iridium metal in Chicxulub impact melt : forensic chemistry on the K-T smoking gun. *Science* **271:** 1573-1576.

Sepkoski JJ 1982. A compendium of marine fossil families. *Milwaukee Public Mus.: Contrib. Biol. Geol.* **51** : 1-125.

Sepkoski JJ 1992. Ten years in the library : new data confirm paleontological patterns. *Paleobiology* **19**: 43-51.

Sharpton VL, Marin LE, Carney JL, Lee S, Ryder G, Schuraytz BC, Sikora P & Spudis PD 1996. A model of the Chicxulub impact basin based on evaluation of geophysical data, Well logs, and drill core samples. *Geol. Soc. Am. Spec.Pap.* **307**: 55-74.

Signor PW & Lipps JH 1982. Sampling bias, gradual extinction patterns and catastrophes in the fossil record. *Geol. Soc. Am. Spec. Pap.* **190**: 291-296.

Sigurdsson H, D'Hondt S & Carey S 1992. The impact of Cretaceous/Tertiary bolide on evaporite terrain and generation of major sulphuric acid aerosol. *Earth Planet. Sci. Letts* **109:** 543-559.

Smit J & Klaver G 1981. Sanidine spherules at the Cretaceous-Tertiary boundary indicate a large impact event. *Nature* **292:** 47-49.

Smit J & Kyte FT 1984. Siderophile-rich magnetic spheroids from the Cretaceous-Tertiary boundary in Umbria, Italy. *Nature* **310**: 403-405.

Stanley SM 1987. *Extinction*. Scientific American Books, San Francisco.

Sweet WC, Zunyi Y, Dickins JM & Yin H (Editors) 1992. *Permo-Triassic events in the eastern Tethys* : 1-8. Cambridge University Press.

Swisher CC, Nishimura JMG, Montanari A, Margolis SV, Claeys P, Alvarez W, Renne P, Pardo EC, Maurrasse FGMR, Curtis GH, Smit J & Williams MO 1992. Coeval Ar/Ar ages of 65 million years ago from Chicxulub crater melt rock and Cretaceous-Tertiary boundary tektites. *Science* **257:** 954-958.

Sutherland FL 1994. Volcanism around K/T boundary time - its role in an impact scenario from the K/T extinction events. *Earth Sci. Rev.* **36:** 1-26.

Teichert C 1990. The Permian-Triassic boundary revisited. *In:* Kauffman E & Walliser G (Editors) - *Extinction events in Earth history, Lecture Notes in Earth Sciences* **30:**199-237.

Valentine JW & Moores EM 1970. Plate-tectonic regulation of faunal diversity and sea level : a model. *Nature* **228**: 657-659.

Vandamme D, Courtillot V, Besse J & Montigny R 1991. Palaeomagnetism and age determinations of Deccan traps : results of a Nagpur-Bombay traverse and review of earlier work. *Rev. Geophys.* **29**: 159-190.

Van Den Bergh S 1994. Astronomical catastrophes in Earth history. *Astronom. Soc. Pacific.* **106**: 689-695.

Van Valen LM 1984. A resetting of Phanerozoic community evolution. *Nature* **307**: 50-52.

Venkatesan TR, Kumar A, Gopalan K, Al'Mukhamedov AI 1997. Of Siberian volcanism and Permo-Triassic boundary changes. *Chemical Geology* (in press).

Venkatesan TR, Pande K & Ghevariya ZG 1996. ^{40}Ar/^{39}Ar ages of Anjar Traps, Western Deccan Province (India) and its relation to Cretaceous-Tertiary boundary events. *Curr. Sci.* **70**: 990-996.

Venkatesan TR, Pande K & Gopalan K 1993. Did Deccan volcanism pre-date the K/T transition? *Earth Planet. Sci. Letts* **119**: 181-189.

Weissman PR 1982. Terrestrial impact rates for long and short period comets. *Geol. Soc. Am. Spec. Pap.* **190**: 15-24.

Wetherill GW & Shoemaker E 1982. Collision of astronomically observable bodies with the Earth. *Geol. Soc. Am. Spec. Pap.* **190:** 1-13.

Wignall PB & Twitchett RJ 1996. Oceanic anoxia and the end Permian mass extinction. *Science* **272**: 1155-1158.

Wolbach WS, Gilmour I & Anders E 1990. Major wild fires at the Cretaceous-Tertiary boundary. *Geol. Soc. Am. Spec. Pap.* **247**: 391-399.

Wolbach WS, Lewis RS & Anders E 1985. Cretaceous extinctions : evidence for wild fires and search for meteoric material. *Science* **230**: 167-170.

Yayanos AA 1983. Thermal neutrons could be a cause of biological extinctions 65 Myr ago. *Nature* **303**: 797-800.

Zahnle K & Grinspoon D 1990. Comet dust as a source of amino acids at the Cretaceous/Tertiary boundary. *Nature* **348**: 157-160.

Zhao M & Bada JL 1989. Extraterrestrial amino acids in Cretaceous/Tertiary boundary sediments at Stevns Klint, Denmark. *Nature* **339:** 463-465.

Zhou L & Kyte FT 1988. The Permian-Triassic boundary event : a geochemical study of three Chinese sections. *Earth Planet. Sci. Letts* **90**: 411-421.

Permian-Triassic Boundary : a tyro's view

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The major stratigraphic divisions of the Phanerozoic are based on "mass extinction events", a concept that is gradually loosing followers. These divisions are called as systems, and the boundaries between the different systems are often arbitrarily drawn. In continuous sequences it is usually possible to clearly draw the system boundaries, but in case of global stratigraphic gaps, as between the Permian and the Triassic, the placement of the system boundary becomes a difficult task. This paper discusses and analyses information available on the Permian-Triassic transition, both in marine and non-marine sequences, and brings out gaps in information. It has been suggested that the system boundaries are not natural boundaries, and hence instead of focusing on a static PTB, that is, on an abrupt change from Permian to Triassic, more emphasis should be placed on the transition from Permian to Triassic which may be referred to as the PTB Interval.

Key-words—Permian-Triassic Boundary, Global Stratotype Section and Point, Geological Time Boundaries.

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साराँश

परमियन-ट्रायॅसिक सीमा : एक नौसिखिये का दृष्टिकोण

हरिकृष्ण माहेश्वरी

.फेनरोज़ोइक के मुख्य स्तरिक प्रभाग ''व्यापक विलोपी घटनाओं '' की अवधारणा पर आधारित हैं। इस संकल्पना के अनुसरण करने वालों की संख्या में क्रमशः कमी हो रही है। इन मुख्य स्तरिक प्रभागों को सिस्टम कहते हैं। विभिन्न सिस्टमों के मध्य सीमाऐं प्रायः मनमाने रूप से निर्धारित की गई है। जो अनुक्रम निरन्तर है उनमें सिस्टम सीमाओं को स्पष्टतः निर्धारित करना प्रायः सम्भव होता है पर उन दशाओं में जब कि विश्वव्यापी स्तरिकीय क्रमभंग हों, जैसे कि परमियन व ट्रायॅसिक सिस्टमों के बीच है, सिस्टम सीमा का निर्धारण एक कठिन समस्या बन जाता है। प्रस्तुत समीक्षा में समुद्री एवं असमुद्री दोनों अनुक्रमों में परमियन-ट्रायॅसिक संक्रमणकालीन अवधि पर उपलब्ध जानकारी का आंकलन किया गया है तथा जानकारी में जो कमियां हैं उनको उभारा गया है। सिस्टम सीमाऐं प्राकृतिक सीमाऐं न होने के कारण यह सुझाव दिया गया है कि एक नियत परमियन-ट्रायॅसिक सीमा के स्थान पर एक परमियन-ट्रायॅसिक अंतरावधि की परिकल्पना की जाये जो कि परमियन-ट्रायॅसिक संक्रमणकालीन अवधि से सम्बन्धित हो।

BOUNDARIES, be it a political boundary or a geological boundary, are so uncertain a concept that no amount of persuasion or data seems to settle once and for all their limits. I have always been fascinated by the movement of both these boundaries; the only difference between the two is that the political boundaries are moved laterally and usually by brute force whereas the geological boundaries are moved vertically, through seemingly unending arguments. So when the BSIP Golden Jubilee Conference on "Physical and biological changes across the major geological boundaries" was announced, I thought I will initiate a discussion on whether the geological boundaries are or can ever be *Lakshman Rekhas*[1]. But then the Convener of the conference proposed that I give an overview of status of the Permian-

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[1] *Lakshman Rekha* is derived from the Indian Epic Ramayana. The epic's hero Prince Ram of Ayodhya, his wife Princess Sita, and brother Prince Lakshman are living in the forest. Sita sites a "golden" deer and asks Ram to get her its skin. Ram goes after it and after a long pursuit is able to put an arrow into it. The deer, which in fact was the demon Maricha in disguise, dies after uttering O'Lakshman, O'Sita. Its cries are heard by Sita who presumes that Ram is hurt and asks Lakshman to go and help Ram. Lakshman pleads that nothing can harm his brother, but Sita is adamant. Lakshman knowing fully well that it may be a ruse of the demons who abounded in that forest, draws a line with his arrow around her hut and requests her not to cross that line so as to remain safe from any mishap. Nothing and nobody will be able to cross the line and enter the encircled area. Outside could be trouble. This line is known as *Lakshman Rekha*.

Triassic Boundary. I accepted the proposal thinking that preparation for this presentation should present no difficulties. After all, I had talked about the Raniganj-Panchet Boundary (in relation to the Permian-Triassic Boundary) way back in 1971 in the Kodaikanal Autumn School, on the occasion of the Silver Jubilee of the Birbal Sahni Institute of Palaeobotany (Maheshwari, 1974). So may be, on the occasion of the Golden Jubilee of the BSIP, another visit to the Permian-Triassic Boundary was in order.

But soon I became disillusioned. Though much literature has poured in on this subject during the past 25 years, yet the final placement of this very important boundary is nowhere in sight. In fact, several new problems have cropped up. I have tried to organise as much data as possible but I am afraid I have been lost in a dark chamber illuminated by infra-red light. I find myself to be a tyro in this respect. Hence, in spite of all my attempts at organisation, this presentation has remained very disorganised.

What actually is a boundary? Webster defines the boundary as "anything marking a limit". So when we talk of a boundary between two geological systems, we actually mean delimitation of upper and lower limits of the older and younger systems, respectively, naturally expecting a sharp line.

GEOLOGICAL SYSTEMS

The Phanerozoic sedimentary sequence is divided into a number of major stratigraphic units on the basis of distinctive lithologies or distinctive fossil contents. Each such unit represents an important time-slice of earth's history and is known as a 'System'. These units as we know today evolved through time not through the efforts of a person or a group, but through independent proposals from a large number of geoscientists, and hence their definitions are being consistently updated. Regardless of how the systems were conceived originally, subsequently they have been recognised in widely separated areas almost entirely on the basis of distinctive fossils, either animal, or plant, or both. Most system boundaries were chosen at apparent breaks in the geological record of the fossils.

The systems of the Phanerozoic are grouped in three eras, namely, the Palaeozoic, the Mesozoic and the Cenozoic, based on the concept of "mass extinction". Thus the boundary between the Palaeozoic and Mesozoic Erathems, consequently the boundary between the Permian and Triassic Systems, should reflect a mass extinction of extraordinary severity. Yang *et alii* (1991) suggest that the mass extinction across the PTB was a result of a number of causes. They have found evidence of frequent volcanic activity across the PTB. One cause commonly mentioned to explain the mass extinction of Permian and Triassic times is an eustatic sea-level drop during which epi-continental seas withdrew from the continents thus leading to large scale loss of ecological niches causing death of most marine life forms. Recently some evidence has come to light about the occurrence of an anoxic event around the PTB (Wignall & Twitchett, 1996). But not every body is enamoured of the idea of mass extinction (Hills & Logan, 1973). As Ager (1987) said in another context 'I find very little evidence for such "mass extinctions" on earth.....In every case I know, there are clear signs of gradual decline in every group of organisms concerned,..... If there was a major break in fossil record.....I would far rather blame it on a gap in the record than on.....'. According to Teichert (1990) "Many authors who fill international journals with papers on "mass extinctions" have little knowledge of fossils and are, therefore, unable to ask simple, pertinent questions: ..... what it was that actually became extinct, and exactly when, and where, and in what order.". According to another view the Permian regression was accompanied by a global climatic change from an Early Permian glacial-maximum condition to a latest Permian-Triassic evaporite-maximum condition. As a consequence to this, the vegetation changed considerably, thus drastically reducing food supply for many herbivorous tetrapods feeding on this vegetation. There was a comparable reduction in both land animals and land plants, which, however, was a far cry from "mass extinction". It is interesting to note that most of the shallow water groups that apparently disappeared around the PTB, reappeared in the Olenekian or in the Middle Triassic. "They all seemingly survived in insular relict areas within the tropical part of Panthalassa" (Kozur, 1996).

Permian System

Before we consider the placement of the Permian-Triassic Boundary, it is important to examine what constitutes the two systems. In Germany, a copper-bearing "Zechstein" group rests on "Red Underlayer" (Rotliegende) of conglomerates, shales and sandstones. In 1808, d'Halloy described the strata between the "Red Underlayer" and the Muschelkalk as *Terrain peneén,* rocks with few fossils (Sherlock, 1947). The term was later (d'Halloy, 1834) restricted to "Red Underlayer", copper shales and Zechstein, only. Murchison (1841) recognised equivalent strata in eastern Russia, near the town of Perm, and named these as Permian, ignoring d'Halloy's term. For long the Permian remained one of the most ill-defined systems. The deliberations of the Subcommission on Permian Stratigraphy (IUGS) during the last two decades have gradually resulted in the establishment of a global time scale for the marine component of the Permian System. Consensus has emerged for a three-fold division of the Permian System. The present position about the divisions and subdivisions of the Permian System is summarised in Table 1 (modified from Jin Yugan, 1996). Such a global time scale is yet to be agreed upon for the Permian System in the non-marine domain.

Triassic System

The term Trias was introduced by Friedrich August von Alberti, the noted salt mining engineer, in 1834 for all the rock units, that is, Bunter Sandstone, Muschelkalk and Keuper, stratigraphically located between the Zechstein and the Lias in Germany. His *"Beitrag zu einer Monographie des Bunten Sandsteins, Muschelkalks und Keupers, und die Verbindung dieser Gebilde zu einer Formation"* deals in detail with the three units. This 'Germanic' system and its classification gradually gained general acceptance, more so in Europe. Later, it was realised that the 'Germanic' classification is not suited for equivalent marine sequences in the Alps and other Tethyan regions. Ammonoid biostratigraphy was found to be a satisfactory criterion for classification of the marine Triassic. Presently, three series, namely, Lower, Middle and Upper, are recognised in the Triassic System. However, as yet there is no agreement on the number of stages, there being no objective absolute criteria for recognition of a stage (Ager, 1987). The Subcommission for Triassic Stratigraphy by a majority decision approved recognition of seven stages, but Tozer (1993) vehemently disagrees with this proposal. The main area of disagreement is the subdivision of Early Triassic. The two views are

Table 1

Series	Stage	Conodonts	Ammonoids	Fusulinids
LOPINGIAN	Changhsingian	*Clarkina subcarinata*	*Paratirolites-Shevrevites*	*Palaeofusulina sinensis*
	Wuchiapingian	*Clarkina postbitteri*	*Roadoceras-Doulingoceras*	*Codonofusiella kwangsiana*
GUADLUPIAN	Capitanian	*Jinogondolella postserrata*	*Timorites*	*Polydiexodina shumardii*
	Wordian	*Jinogondolella aserrata*	*Waagenoceras*	*Neoschwagerina craticalifera*
	Roadian	*Jinogondolella nankingensis*	*Stacheoceras discoedale*	*Cancellina cutalensis*
CISURALIAN	Kungurian	*Neostreptognathodus pnevi* *N. exculptus*	*Propinacoceras busterense*	*Brevaxina dyhrenfurthi*
	Artinskian	*Sweetognathus whitei* *Streptognathodus florensis*	*Uraloceras fedorowii* *Artinskia artiensis*	*Charaloschwagerina vulgaris*
	Sakmarian	*Sweetognathus merrillii* *Svetlanoceras strigosum*	*Streptognathodus barskovii* *Sphaeroschwagerina*	*Sakmarites inflatus* *sphaerica*
	Asselian	*Sweetognathus expansus* *Streptognathodus isolatus*	*Svetlanoceras serpentinum* *Svetlanoceras primore*	*Sphaeroschwagerina vulgaris*

shown in Table 2. According to Kozur (1992) the lower stage in the two-fold classification of the Early Triassic should be named as Brahmanian and not Induan. For reasons not enumerated Lucas (1992, fig. 2) considers Olenekian to be a stage older than the Induan.

Table 2

UPPER	Rhaetian	Rhaetian	
	Norian	Norian	
	Karnian	Carnian	
MIDDLE	Ladinian	Ladinian	
	Anisian	Anisian	
LOWER	Spathian	Olenekian	SCYTHIAN
	Smithian		
	Dienerian	Induan	
	Griesbachian		
	Tozer, 1993	STS, 1984	

PERMIAN-TRIASSIC BOUNDARY PROBLEM

The contact between the Buntsandstein and the underlying Zechstein should normally define the Permian-Triassic Boundary. However, the Buntsandstein, which is non-marine, does not have typical fauna or flora that could be used for global recognition of equivalent strata. In fact on the basis of occurrence of elements of Late Permian palynoflora in the Buntsandstein of the Iberian peninsula, it has been suggested "that Buntsandstein sedimentation began before the end of the Permian in many parts of Spain" (Cassinis *et alti,* 1992). Further, it is now generally agreed that the chronostratigraphic boundaries are best defined in marine sequences.

The Bellerophon/Werfen succession in Dolomite Alps north of Italy, an equivalent of Zechstein-Buntsandstein, was initially used as a supplement. Sedimentologically the contact between the Bellerophon and Werfen Formations is considered to be transitional, though the occurrence of a sedimentary gap at the Bellerophon/Werfen Boundary was suggested (Broglio Loriga *et alti,* 1988). Later, this gap has been found at this level in almost all the areas; this probably could be the result of a major regression.

For the recognition of the PTB a detailed database is needed on the complete succession of biological events at the end of the Permian and beginning of the Triassic, both in the Tethyan and Boreal Realms. However, there is evidence to suggest a regression of the sea from the continental areas during Late Permian culminating at the PTB. At the latter level the hiatus may have been global (Dickins, 1988). The solution of the PTB thus seems to lie with the determination of the base of Triassic.

The sedimentary gap at the Permian-Triassic level is present even in the Gondwanic areas, for example, in Australia (Dickins & Campbell, 1992), Antarctica (Collinson *et alti,* 1994), and India (Fox, 1931; Krishnan, 1960). This naturally has necessitated searching a section where there is virtually no sedimentary gap at the Permian-Triassic boundary level. Many candidates have been proposed, namely,

Meishan Section, south-east China;
Shangsi Section, Sichuan Province, China;
Selong Xishan Section, Xizang; and
Guryul Ravine Section, Kashmir Valley, India

POTENTIAL GSSPS FOR PTB

The arguments advanced in favour of selection of the Meishan Section as GSSP are (Yin, 1996):

1. The section is easily accessible, well exposed, and records continuous marine sedimentation from the Changxingian into the Early Triassic;
2. The base of bed 27c in D Section is characterised by first appearance of conodont *Hindeodus parvus* in the evolutionary lineage of *H. latidentatus — H. parvus—Isarcicella isarcica.* [Ammonoid *Otoceras,* however, is not known].

The Shangsi Section located in Guangyuan County of Sichuan Province is also easily accessible. The section is about 500 m long and is reported to represent a continuous Late Permian-Early Triassic sedimentation. The PTB is drawn just above the 'Black Clay' (Li *et alti,* 1989). The absence of both *Otoceras* and *Hindeodus parvus* in the basal Triassic beds is a major drawback.

In the Selong Section, the first and simultaneous appearance of *Otoceras latilobatum, Hindeodus parvus* and *Neospathodus primitivus* is coincident with the beginning of an anoxic event. This level is proposed as a potential GSSP (Mei, 1996).

The Guryul Ravine Section is located near Khunamuh Village, about 10 km southeast of Srinagar, and is easily accessible. The Permian-Triassic transition is represented by Member D (Zewan Formation) and Member E (Khunamuh Formation). Member E is composed of alternating shale and subordinate limestone and is divided into three units, namely, E_1, E_2 and E_3. E_2 is characterised by the presence of *Otoceras woodwardii* which makes its appearance in Bed 52. *Hindeodus parvus* appears in Bed 56 and *Isarcicella isarcica* in Bed 58. E_1/E_2 contact may be a potential GSSP (Kapoor, 1992).

In most of these areas the Permian and Triassic consist of very different facies and hence a hypostratotype section has also been proposed. Zakharov (1988) reasons that the Permian and Triassic at Meishan consist of very different facies, that is, limestones, clay and mudstones, and as such problems are faced in recognition of continuous succession in marine fauna. He therefore suggests the stratotype section of Dorashamian Stage in the Trans-Caucasia as a Hypostratotype for the PTB interval. In this section the Upper Permian and Lower Triassic strata both comprise similar carbonaceous facies, except for an about 5 m thick clay at the boundary.

EVIDENCES

Several evidences have been used by different workers for deciding the base of the Triassic System, for example:

Ammonoid evidence,
Conodont evidence,
Palynological evidence, and
Geochemical evidences.

Ammonoid evidence

During the 1870s, ammonoids were discovered in certain marine beds in the Himalaya. The most peculiar form was *Otoceras,* and Griesbach (1880) considered the *Otoceras*-Bed as Triassic. Noetling (1905) maintained that all the *Otoceras*-Beds were Permian because similar forms *(Ceratites/Protoceras)* were found in the Permian of Armenia. Diener (1912) reviewed the data and convincingly putforth the argument suggesting a Triassic age for the *Otoceras*-Bed in the Himalaya; which since then has been accepted as forming the base of the Triassic and thus delineating the PTB. *Otoceras* has been reported from the Himalayan region (Spiti, Pahlgam, Guryul Ravine, Barus, Selong, and Nepal), and the Arctic (East Greenland, Axel Heiberg Island, Ellesmere Island, Spitzbergen and North America). Further, the appearance of *Otoceras* coincides with a major transgression. However, there have been a few hiccups, and it has sometimes been suggested to place the PTB at the top of the *Otoceras*-Bed.

Tozer (1988) has reviewed the evidence pertaining to this question. He has concluded that "The most suitable level for defining the base of the Triassic System is the base of the *Otoceras woodwardi* Zone of the Himalayas, with which the base of the *Otoceras concavum* Zone of Arctic Canada and Siberia is correlative.". Type locality for the *O. woodwardii* Zone is the Shalshal Cliff in the Himalaya. Tozer further opines that these zones correlate, albeit only approximately, with the base of the Werfen Formation which is correlatable with the base of Buntsandstein that defines the base of the Triassic. However, at most places the latest Permian (Dorashamian/Changxingian) is absent (Dagys & Dagys, 1988) indicating a global Late Permian regression that may have been the cause of change over from a Palaeozoic to a Mesozoic fauna.

In the Tethyan sequences, *Otoceras woodwardii* and *Ophiceras* Zones have been established in the Lower Griesbachian of Kashmir in the Perigondwana Province. *Otoceras*-Beds have also been reported from central Himalaya and northern slope of Mount Everest in Xizang. In the Boreal Region, the first biological event of significance in the earliest Triassic is the appearance of *Otoceras concavum* followed by the appearance of *Otoceras boreale.* Subsequent event relates to the appearance of the genus *Ophiceras* followed by extinction of the genus *Otoceras* (Dagys & Dagys, 1988). Thus the *Otoceras* Zones (Lower Griesbachian) may be taken as datum for marking the PTB interval.

Newell (1988), however, argues that *Otoceras* and *Ophiceras,* which are relatively rare, belong to a line of Permian ammonoids, and are associated with invertebrate taxa nearly all of which originated in the Permian. He suggests that the PTB be drawn at the top of the Griesbachian Stage which level marks the beginning of a new group of ammonoids, the Meekoceratids, and conodonts *(Neospathodus).*

Conodont evidence

Conodonts are the second group that is used for zonal subdivision and global correlation of the Triassic sequences. Yin *et alii* (1988, see also Yin,

1994) have recommended replacement of *Otoceras* with *Hindeodus parvus* (Kozur & Pjatakova) Matsuda for drawing the base of the Triassic. The main reasons advanced by them include:

1. The superposition of *Otoceras* Zone upon the *Pseudotirolites* or *Paratirolites* Zone (undoubted uppermost Permian) is possibly known only from Changxing, south-east China;
2. The lower part of *Otoceras woodwardii* Zone in western Himalaya probably overlaps the *Paratirolites* Zone of Iran (Sweet, 1979);
3. Conodonts from the *Otoceras*-Beds of the Spiti Valley include *Gondolella subcarinata* and *G. orientalis*, both index fossils of Late Permian (Bhatt *et alii*, 1981), [a report rejected by Matsuda, 1984];
4. In the Guryul Ravine Section of Kashmir Valley, conodont *Hindeodus parvus* occurs in the upper *Otoceras* Zone, and predates first appearance of *Isarcicella isarcica* (Matsuda, 1985);
5. *Hindeodus parvus* Zone is always superjacent to the latest Permian horizons, for example, in sections at Selong, Meishan and Shangsi (China), Gurvul Ravine (India), Salt Range (Pakistan), Dorasham (Trans-Caucasia), and Hambast Valley (Iran);
6. In China the succession of first appearance of conodont taxa is *Hindeodus minutus*—*H. parvus* — *Isarcicella isarcica* (Yin, 1993);
7. *Hindeodus parvus* has a much wider distribution than *Otoceras;* and
8. *Hindeodus parvus* is also known from basal Griesbachian (Dinwoody Formation) of western United States of America (Paull & Paull, 1983).

In south-east China, the *Hindeodus parvus* Zone is delineated from the Permian by a basal boundary clay. It is towards the base of this clay that the biggest mass extinction (trilobites, fusulinids, corals, productids, Permian ammonoids, etc.) is presumed to have taken place. Evidence of catastrophic events (Iridium anomaly, sphaerules, carbon isotopic anomalies, tuffaceous materials, etc.) is also found in this clay. Thus, according to Yin *et alii* (1988), the lower limit of *Hindeodus parvus* Zone coincides with event boundary. Yin (1996) recommends the base of bed 27c in the Meishan Section, south-east China as GSSP for the basal boundary of the Triassic System. This bed is marked by the first appearance of *Hindeodus parvus* in the evolutionary lineage of *H. latilobatus* — *H. parvus* — *Isarcicella isarcica*.

Li *et alii* (1996), on the other hand, point out that *Hindeodus parvus* Zone is a Range Zone, and its lower boundary is not defined by the lineage or biotic evolution. The first appearance of the species is in the *Otoceras*-Bed in the Tethyan Realm (Perigondwana), and in the *Ophiceras*-Bed in the Boreal Realm (Greenland). First appearance of the conodont *Isarcicella isarcica* is therefore suggested to mark the PTB. *I. isarcica*, however, made its first appearance only in the upper Griesbachian. Does it mean that the *Otoceras woodwardii* Zone actually lies in the latest Permian? *I. isarcica* is not yet known from the Boreal Realm. In the Guryul Ravine Section, the base of Griesbachian is represented by Bed 52 of Khunamuh E_2 (Nakazawa *et alii*, 1975). This horizon has *Otoceras woodwardii*, *Hindeodus minutus* and many Permian fossils. *H. parvus* first appears only in Bed 56.

There are some problems even with the conodont evidences, for example,

- Stratigraphical distribution of certain conodont species varies considerably in local sections;
- It is difficult to recognise changes related with evolution from those caused by facies variations and degree of investigation;
- In the Boreal Realm, there are two long ranging species—*Anchignathus typicalis* and *Neogondolella carinata;*
- In the Tethyan Realm, three events, namely, first appearance of *Hindeodus parvus*, first appearance of *Isarcicella isarcica* and extinction of *I. isarcica* have been proposed as candidates for defining the PTB; and
- In the Selong Section of Xizang co-occurrence of *Otoceras*, *Hindeodus parvus* and *Isarcicella isarcica* has been noticed (Wang *et alii*, 1989).

According to Dagys and Dagys (1988), present knowledge on conodonts is not sufficient for effectively determining the base of the Triassic or for correlating with the Griesbachian ammonoid zones. Stratigraphic distribution of certain conodont species is not uniform laterally; it may be due to variations in facies investigated as well as due to the degree of investigation. Some authors (for example, Sweet, 1992) recommend *Isarcicella isarcica—Ophiceras—Claraia* Assemblage as index for the basal Triassic, thus putting the PTB between lower and upper Griesbachian. Paull and Paull (1994), however, are of the opinion that this assemblage has little value in North America because of the limited distribution of the zone's conodont component, the scarcity of ammonoid specimens, and the long range of *Claraia*. Kotlyar (1991) suggests that the PTB be associated with a complete replacement of Permian biota by the Triassic one.

Palynological evidence

Three better known examples, namely, Bellerophon/Werfen sequence of Italy, marine and non-marine of Hungary, and sub-surface of Israel, are discussed.

In Italy, palynofossils have been recorded from the Bellerophon/Werfen sequence of the southern Alps (Visscher & Brugman, 1988). The silty intercalations in the Bellerophon Formation have yielded palynodebris which, besides pieces of tracheids and cuticles, contain diversified gymnosperm pollen assemblages and a few marine palynofossils. Typical palynotaxa are *Lueckisporites virkkiae, Jugasporites delasaucei* and *Klausipollenites schaubergeri*. Towards the top of the formation, fungal remains appear in relatively high frequencies, and most of the characteristic Late Permian pollen virtually disappear. In the basal part of the Tesero Horizon of the Werfen Formation, *Protohaploxypinus*-type pollen is common, and fungal remains are sometimes overwhelmingly dominant. From the lower part of the Mazzin Member upwards the palynodebris have preponderance of marine acritarchs *Scythiana* Goczan *et alii* and the *Veryhachium—Micrhystridium*-complex. This data is interpreted to indicate that in northern Italy, the PTB interval witnessed replacement of land-derived organic matter by organic matter of marine origin. A 'practical' PTB is drawn at the top of fungi-dominated assemblage which coincides approximately with the disappearance of typical Late Permian pollen taxa *Lueckisporites virkkiae* and *Jugasporites delasaucei*. The "fungal event", reportedly known from latest Permian and/or earliest Triassic sediments of various parts of the Tethyan Realm, the Zechstein Basin of Europe, and various parts of the Boreal Realm, is interpreted to mark "the dramatic collapse of the stable Late Permian ecosystem" (Visscher & Brugman, 1988).

In Hungary, palynofossil assemblages are known from the Permian-Triassic transition both from the marine and non-marine sequences (Haas *et alii*, 1988). In the marine sequences, the PTB is drawn at the level at which characteristic Permian algae and foraminifera disappear and typical Triassic palynofossils appear. The latter include *Lapposisporites villosus* Visscher, *Kraeuselisporites apiculatus* Jansonius, *Anaplanosporites stipulatus* Jansonius, *Endosporites papillatus* Jansonius, *Densoisporites variabilis* (Jansonius), *Lunatisporites novimundii* (Jansonius) and *Spheripollenites elphinstonei* Jansonius. In the continental facies, the PTB is drawn at the level at which the Late Permian palynoflora acquires some so-called Early Triassic palynofossils, such as, *Lueckisporites virkkiae* var. C and *Densoisporites playfordii*.

In Israel, Late Permian-Early Triassic strata are represented by 'Arqov, Yamin and Zafir Formations. The lower part of the 'Arqov Formation contains fusulinids *Codonofusiella, Pseudovermiporella* and *Sargentina* indicating a Dzhulfian (lower Changxingian) age. The uppermost part of the Yamin Formation is unequivocally assigned to the Olenekian Stage on the basis of conodonts *Pachycladina* and *Hadrodontina*, but in Zohar-8 bore-hole this level also has *Lueckisporites virkkiae*, a Late Permian pollen. Elsewhere this taxon does not occur higher than the 'Arqov Formation, and hence the Zohar-8 occurrence may be due to reworking. The Early Triassic *Endosporites papillatus* appears only above the lower third of the Yamin Formation. Thus the PTB interval is presumed to lie within the lower part of the Yamin, slightly above the base of the Formation (Eshet, 1992).

Geochemical evidences

Iridium contents have been recognised at the PTB at Sovetachen in Trans-Caucasia (Alekseev *et alii*, 1983). Iridium anomaly has also been observed at this level at Changxing (Sun *et alii*, 1984; see also Xu & Yan, 1993). Zakharov (1988) reports a high concentration of Iridium in a specimen collected from the base of Triassic at San Antonio, Italy. A relatively high concentration of Iridium (114 ppb) has been reported from a horizon, within the

Productus Shale and 70 cm below the limonitic layer at PTB, in the Lalung section at Spiti, India (Bhandari *et alii*, 1992). Thus, it is possible to speculate on a global Iridium anomaly at or near the PTB.

Oberhänsli *et alii* (1989) have reported a negative $\delta^{13}C$ shift by 2-3‰ in selected bulk samples of finely ground carbonaceous mudstones and siltstones from apparently continuous PTB sections (i) on the east edge of the Schuchert Dal, north of Major Paars Dal on Jameson Land (Greenland) and (ii) at San Antonio (Cadore) in the southern Alps. A similar drop in values of $\delta^{13}C$ has been reported near the PTB in Changxing, south China (Chen *et alii*, 1984). According to Oberhänsli *et alii* (1989) "The carbon isotopic change, which we observe world-wide at the Permian-Triassic boundary, occurs within a few thousand years and may be related to a change in the global carbon cycle".

PTB IN THE NON-MARINE REALM

At the Beijing International Geological Congress 1996 it was proposed to identify GSSP for the PTB in the non-marine sequences also. Some of the candidate sections are (Lozovsky, 1996):

> Germanic Basin, west European Platform,
> Moscow Syneclise, east European Platform,
> Tungusikai Syneclise, Siberian Platform,
> Dalongkou Anticline near Jimusar, western China,
> Noyon Soon Depression, Mongolia, and
> Gondwana Basins, India

In most non-marine sequences too there is a sedimentary gap at the PTB. In the continental series of Eurasia the PTB interval is marked by:

- change of the Upper Permian tetrapod *(Dicynodon)* communities;
- dominance of striate-bisaccate pollen assemblages in the Upper Permian;
- presence of cavate triletes *(Lundbladispora, Densoisporites)*, nonstriate-bisaccate pollen *(Lunatisporites, Klausipollenites)* and taeniate pollen *(Taeniaesporites)* in the Lower Triassic;
- presence of *Lystrosaurus* in the Lower Triassic; and
- distinctive conchostracans in the Lower Triassic.

In the Moscow Syneclise, the most complete section comprising the PTB transition in the Vetluga River Basin too shows a gap in sedimentation at the PTB. Here the Molomskian Member of the Vjaatskian Horizon (latest Permian) has a palynoflora comprising *Brevitriletes* sp., *Apiculatisporites* sp., *Anaplanisporites stipulatus, Densoisporites complicatus, Indotriradites* sp., *Lundbladispora* sp., *Klausipollenites schaubergeri, Ephedripites* spp., and the fungal *Tympanicysta stochiana*. The overlying Vokhmian Horizon (Lower Triassic) contains *Lystrosaurus georgii* (Kalandadze, 1975, in Astschichian Member) and a rich palynoflora comprising *Anaplanisporites stipulatus, Leptolepidites jonkeri, Lycospora imperialis, Propertisporites pocockii, Nevesisporites limatulus, Naumovaspora striata, Densoisporites playfordii, Lundbladispora* sp., *Aratrisporites* sp., *Rewanispora* sp., *Protohaploxypinus jacobii, P. pantii, P. samoilovichii, Striatoabieites richteri, S. multistriatus, Lunatisporites hexagonalis, L. pellucidus, L. noviaulensis, L. transversundatus, Striatopodocarpites* spp., *Ephedripites extensus, E. multistriatus, E. scottii, E. steevesii*, etc. It has been suggested that the palynoflora of the Molomskian Member is transitional from the Permian to the Triassic (Lozovsky & Yaroshenko, 1994).

The Dalongkou Section near Jimusar, Xinjiang (Junggar Basin), China that has been proposed as GSSP for the PTB in non-marine sequences, apparently comprises a continuous deposition across the PTB. A diversity of fossils—vertebrates, conchostracans, ostracods, bivalves, plant megafossils, palynofossils—is known from the section. Distribution of different biotic groups is shown in Table 3 (derived from Zhou *et alii*, 1996).

Table 3

GROUP	FORMATION	
		Lystrosaurus vertebrate assemblage
	Shaofanggou	*Lundbladispora-Taeniaesporites* assemblage Conchostraca
	Jiucaiyuan	Ostracods
		Lystrosaurus-Jimusaria vertebrate assemblage *Limatulasporites-Lundbladispora* assemblage *Falsisca-Cyclotunguzites* conchostracan assemblage
		———PTB below 50 m top of formation———
Cangfanggou	Guodikeng	*Striodon magnus*, bivalves, conchostracans *Limatulasporites-Lueckisporites* assemblage *Zamiopteris-Viatsheslavia* assemblage
	Wutonggou	*Callipteris-Comia-Iniopteris* assemblage *Dicynodontia* vertebrate assemblage
	Quanzije	Palynofossils

The PTB in the Dalongkou Anticline is drawn 50 m below the top of the Guodikeng Formation mainly on the basis of ostracods and bivalves. For reasons not specified Esaulova (1995) places the Guodikeng Formation in the upper Kazanian Stage. Though palynofossils are reported from several layers straddling across the PTB, yet these do not provide indubitable evidence for the placement of the boundary. In fact, the palynoassemblages from the northern and southern limbs of the anticline show appreciable differences. The Late Permian sediments contain following palynotaxa: _Cyclogranisporites aureus_, _Calamospora pallida_, *_Alisporites sublevis_, *_A. australis_, *_Vitreisporites pallidus_, _Decussatisporites multistriatus_, *_Treilites_ sp., *_Triangulatisporites_ sp. cf. _T. triangulatus_, *_Cordaitina rotata_, _Vesicaspora fusi_, _Platysaccus alatus_, *_Limatulasporites fossulatus_, _Protohaploxypinus ovaticorpus_ and _P. samoilovichii_. The taxa marked with an asterisk (*) continue into the Early Triassic beds of the Guodikeng Formation which on the southern limb of the anticline contain: +_Apiculatisporites spinifer_, _Klausipollenites schaubergeri_, +_Alisporites australis_, +_A. sublevis_, _Vitreisporites pallidus_, _Pteruchipollenites reticorpus_, +_Lueckisporites virkkiae_, +_Limatulasporites fossulatus_, +_Protohaploxypinus limpidus_, +_Striatoabieites richteri_, _Taeniaesporites pellucidus_, and _Hamiapollenites limbatus_. Taxa marked with a plus (+) sign are also present in the Early Triassic on the northern limb along with _Punctatisporties_ sp., _Apiculatisporites xiolongouensis_, _A. decorus_, _Lundbladispora wantangensis_, _Kraeuselisporites disparilis_, _Equisetosporites_ sp., _Triangulisaccus_ sp., _Treilites_ sp., _Triangulatisporites_ sp. cf. _T. triangulatus_, _T. vermiculatus_, _Verrutriletes_ sp., _Maexisporites_ sp., _Limatulasporites limatulus_, _Taeniaesporites noviaulensis_, etc. Among the known plant megafossils from the Early Triassic are _Paracalamites_ sp., _Zamiopteris_ sp. cf. _Z. glossopteroides_, _Walchia_ sp. and _Samaropsis_ sp.

In India, the task is to find in the non-marine deposits, the stratigraphic analogues of the base of _Otoceras—Hindeodus parvus_ Zone, the level "accepted" as the PTB in international geological time frame. The transition from marine to non-marine strata of PTB interval can not be traced from the Himalayan basins to the Gondwanan basins. Therefore, correlation can only be made on the basis of palaeontological, palaeomagnetic and geochemical data; and hardly any useful information is available. The best areas to look for the PTB interval are the Damodar and Godavari Grabens. In the Damodar Graben, the PTB is presumed to be astride the Raniganj-Panchet formational boundary (Ghosh _et alii_, 1996) and in the Godavari Graben within the "Kamthi" Formation. An analysis of the available data shows that:

i) there is no marine control for precisely demarcating the PTB interval in basins on peninsular India;

ii) the PTB interval is located somewhere across the Raniganj-Maitur (lower Panchet) transition in the Damodar Graben (Maheshwari, 1974), and within the Kamthi Formation in the Godavari Graben (Srivastava & Jha, 1995);

iii) in most of the sections in the Damodar Graben, possibly except for the Banespati stream section, there is a gap or a pebbly/conglomeratic horizon between the Raniganj and Panchet Formations (Ghosh _et alii_, 1996);

iv) Permian plant taxa, such as, _Schizoneura_ and _Glossopteris_, and striate-bisaccate pollen continue into the Maitur Formation (Maheshwari & Banerji, 1975); _Playfordiaspora_ and _Lunatisporites_ which are characteristic of the Maitur palynoflora are known from the Permian of Salt Range, Pakistan (Balme, 1970); palynological transition from Late Permian into Early Triassic is often gradual;

v) _Dicroidium_ and _Lystrosaurus_ which mark the advent of the Triassic elsewhere are both absent in the Maitur Formation; the latter is, however, present in the younger Hirapur (upper Panchet) Formation (Tripathi & Satsangi, 1963);

vi) presence of "dicroidia" in the Nidhpuri beds (?Permian) of South Rewa Basin needs verification (Maheshwari & Chandra, 1994), no dicroidia are known from the Panchet Group, definite dicroidia are known only from the Parsora Formation of Rhaetian age (Lele, 1962) and possibly also from the Tiki Formation of Carnian-Norian age; and

vii) the exact horizon where the Triassic conchostracans make their first appearance in the Maitur Formation has yet to be clearly specified;

If the _Lystrosaurus_ Zone represents the oldest interval of the Early Triassic (Lucas, 1992), the PTB does not exactly coincide with any lithological boundary; it possibly lies somewhere above the Maitur Formation. The main problem in non-marine sequences is that a definite biota has not emerged as a marker of the base of the Triassic, in spite of the claim that the *Lystrosaurus* Zone represents oldest Triassic. Often the appearance of the genus *Dicroidium* was taken to mark the beginning of the Triassic on the Gondwana Supercontinent at least. However, Dobruskina (1995, chart 1) has come out with a synthesis which shows that the genus *Dicroidium* appeared only in the Olenekian Stage coincident with the changeover from Palaeophytic to Mesophytic on the Gondwana Supercontinent. Then all leaves with forked rachides are not necessarily dicroidia, for example, *Callipteridium changii, Comia* and *Supaia*, all Permian taxa. Even otherwise it should be very difficult to find a fossil plant as a common global denominator for identification of the base of Triassic.

Table 4—Various levels of Permian-Triassic Boundary in southern Israel. Extracted from Hirsch and Weissbrod (1988, figure 1).

FORMATION		
RA'AF	*Balatonites balatonicus* *Noetlingites arifensis* *Noelingites kockeli*	
ZAFIR	*Palynofossils* *Pachycladina*	
YAMIN	*Hadrodontina* Palynofossils	---- PTB (Hirsch, 1975) ---- PTB (Hirsch, 1988) ---- PTB (Hirsch, 1976)
ARQOV	Palynofossils *Codonofusiella*	

IN THE END

I suggest that we seriously ponder over if a sharp Permian-Triassic Boundary, that is, a *Lakshman Rekha* can actually be marked in the global perspective, particularly so when the criteria needed to identify/recognise such a boundary are yet to be agreed upon. With so many imponderables, the available data are subject to differing interpretations. It is too much to expect that with all the climatic zones, different ecological niches and habitats, the biota ever had an uniform global distribution at any given point of time. Taxa of higher metazoans and metaphytes could not have had originated simultaneously all over the globe. Some time lapse must be allowed for their migration to places other than locale of their origin. Similarly such taxa could not have died at the same point of time all over the globe. The genus *Glossopteris* is one such example. While elsewhere on the Gondwana Supercontinent it became extinct by the end-Permian, on the Indian peninsula it continued into the Early Triassic, and possibly even into the Rhaetian (Parsora Formation; Maheshwari, 1992). Bisaccate-striate pollen appeared on the Gondwana Supercontinent in the earliest Permian whereas elsewhere it is mostly known from late Early Permian onwards only. Thus FADs and LADs of different taxa may vary in different regions. It should greatly relieve the confusion if one talks of a Permian-Triassic Boundary Interval rather than of a fixed boundary level, a concept which so far seems to be a mirage and is likely to remain so for long. Alternatively, we consider fixing boundaries in terms of absolute ages; but even these are not that absolute (Claoué-Long *et alii*, 1991). Let us be pragmatic. An objective look at the PTB problem shows that the delimitation of the boundary is so subjective, and that is why the PTB "has been placed by different authors at several stratigraphic levels between the base of the Changxingian.....and at, or close to, the top of the Griesbachian" (Teichert, 1990). Sometimes, even the same author has placed the boundary at different levels in different publications (Table 4). PTB is our invention, not a discovery. He did not say "let there be a PTB" and there it was!

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REFERENCES

Ager DV 1987. A defence of the Rhaetian Stage. *Albertiana* **6**: 4-13.

Alekseev AS, Barsukova LD & Kolesov GM 1983. The Permian-Triassic Boundary event: geochemical investigation of the Transcaucasia section. *14th Cong. Lunar planet. Sci. Abstracts* :7-8.

Balme BE 1970. Palynology of Permian and Triassic strata in the Salt Range and Surghar Range, West Pakistan. *In*: Kummel B & Teichert C (Editors) — *Stratigraphic boundary problems: Permian and*

Triassic of West Pakistan, Univ. Kansas Dept. Geol. Spec. Publ. (4):305-453.

Bhandari NN, Shukla PN & Azmi RJ 1992. Geochemical clues to the origin of limonitic layer at Permo-Triassic Boundary, Spiti. *Symp. Himalayan Geol. Shimane Abstracts :6.*

Bhatt DK, Joshi VK & Arora RK 1981. Conodonts of the *Otoceras* Bed of Spiti. *J. palaeont. Soc. India* **25**: 130-134.

Broglio Loriga C, Neri C, Pasini M & Posenato R 1988. Marine fossil assemblages from Upper Permian to lowermost Triassic in the western Dolomites (Italy). *In:* Cassinis G (Editor) — *Proceedings of the field conference on Permian and Permian-Triassic Boundary in the south Alpine segment of the western Tethys, and additional regional reports. Mem. Soc. Geol. Italiana* **34**: 5-44.

Cassinis G, Toutin-Morin N & Virgili C 1992. Permian and Triassic events in the continental domains of Mediterranean Europe. *In:* Sweet WC, Yang Z, Dickins JM & Yin H (Editors) — *Permo-Triassic events in the eastern Tethys: stratigraphy, classification and relations with the western Tethys :* 60-77. Cambridge University Press, Cambridge.

Chen Jinshi, Shao Maorong, Huo Weiguo & Yao Yuyuan 1984. Carbon isotopes of carbonate strata at Permian-Triassic Boundary in Changxing, Zhejiang. *Scient. geol. sinica* (1):88-93. (in Chinese with English abstract).

Claoué-Long JC, Zhang Zichao, Ma Guogan & Du Shaohua 1991. The age of the Permian-Triassic Boundary. *Earth planet. Sci. Lettrs* **105**:182-190.

Collinson JW, Isbell JL, Elliot DH, Miller MF & Miller JMG 1994. Permian-Triassic Transantarctic Basin. *Geol. Soc. Am. Mem.* **184**:173-222.

Dagys AS & Dagys AA 1988. Biostratigraphy of the lowermost Triassic and the boundary between Paleozoic and Mesozoic. *Mem. Soc. Geol. Italiana* **34**:313-320.

Dickins JM 1988. The world significance of the Hunter/Bowen (Indosinian) mid-Permian to Triassic folding phase. *Mem. Soc. Geol. Italiana* **34**:345-352.

Dickins JM & Campbell HJ 1992. Permo-Triassic boundary in Australia and New Zealand. *In:* Sweet WC, Yang Z, Dickins JM & Yin H (Editors)—*Permo-Triassic events in the eastern Tethys: stratigraphy classification and relations with the western Tethys:* 169-174. Cambridge University Press, Cambridge.

Diener C 1912. The Trias of the Himalayas. *Mem. geol. Surv. India* **36**(3): 1-176.

Dobruskina I 1995. Triassic plants and Pangea. *Palaeobotanist* **44**:116-127.

Esaulova NK 1995. Correlation of the Upper Permian floristic complexes of the Volga-Urals region of Russia with Dalongkou Section of China. *Permophiles* (27):34-38.

Eshet Y 1992. The palynofloral succession and palynological events in the Permo-Triassic boundary interval in Israel. *In:* Sweet WC, Yang Z, Dickins JM & Yin H (Editors) — *Permo-Triassic events in the eastern Tethys: stratigraphy, classification and relations with the western Tethys:* 134-145. Cambridge University Press, Cambridge.

Fox CS 1931. The Gondwana system and related formations. *Mem. geol. Surv. India* **58**:1-241.

Ghosh SC, Nandi A, Ahmed G & Roy DK 1996. Study of Permo-Triassic Boundary in Gondwana sequence of Raniganj Basin, India. *In:* Guha PKS *et alii* (Editors) — *Gondwana Nine* **1**: 179-193. Oxford & IBH Publ. Co. Ltd., New Delhi.

d'Halloy O 1834. *Elemente der Geologie,* 2nd Ed.

Hills LV & Logan A (editors) 1973. *Permian and Triassic Systems and their mutual boundary. Canadian Soc. Petroleum Geols Mem. 2.*

Hirsch F & Weissbrod T 1988. The Permian-Triassic Boundary in Israel. *Mem. Soc. Geol. Italiana* **34**:253-255.

Jin Yugan 1996. A global chronostratigraphic scheme for the Permian System. *Permophiles* (28):4-9.

Kalandadze NN 1975. The first discovery of *Lystrosaurus* in the European regions of the USSR. *Palaeont. Zh.* (4):140-142. (In Russian).

Kapoor HM 1992. Permo-Triassic Boundary of the Indian subcontinent and its intercontinental correlation. *In:* Sweet WC, Yang Z, Dickins JM & Yin H (Editors) — *Permo-Triassic events in the eastern Tethys: stratigraphy, classification and relations with the western Tethys:* 21-36. Cambridge University Press, Cambridge.

Kotlyar GV 1991. Permian-Triassic boundary in Tethys and Pacific belt and its correlation. *Proc. Shallow Tethys 3, Saito Ho-on Kai Spec. Publ.* (3):387-391.

Kozur H 1992. The problem of the Lower Triassic subdivision. *Albertiana* **10**: 21-22.

Kozur H 1996. The Permian-Triassic Boundary (PTB) in marine and continental beds - possible causes for the PTB biotic crisis. *30 Int. geol. Congr. Beijing, Abstract* **2**: 55.

Krishnan MS 1960. *Geology of India and Burma.* 4th Edn. Higginbothams, Madras.

Lele KM 1962. Studies in the Middle Gondwana Flora - 1. On *Dicroidium* from the South Rewa Gondwana Basin. *Palaeobotanist* **10**: 48-67.

Li Zishun, Zhan Lipei, Dai Jinye, Jin Ruogu, Zhu Xiufang, Zhang Jinghua, Huang Hengquan, Xu Daoyi, Yan Zheng & Li Huamei 1989. Study on the Permian-Triassic biostratigraphy and event stratigraphy of northern Sichuan and southern Shangshi. *Geol. Mem. Min. Geol. Min. Res.* ser. 2 (9):1-435. (in Chinese with English summary).

Li Zishun, Zhan Lipei & Zhang Shunxin 1996. Definition of the Permian-Triassic Boundary. *30 Int. geol. Congr. Beijing Abstracts* **2**: 60.

Liu Shuwen 1994. The nonmarine Permian-Triassic Boundary and Triassic conchostracan fossils in China. *Albertiana* **13**: 12-24.

Lozovsky VR 1996. The Permian-Triassic boundary in the continental series of Eurasia. *30th Int. geol. Congr. Beijing Abstracts* **2**: 59.

Lozovsky VR & Yaroshenko DP 1994. The Permian/Triassic Boundary in the continental series of the Moscow Syneclise: recent achievement. *Permophiles* (24):54-59.

Lucas SG 1992. Nonmarine standards for Triassic times. *Albertiana* **10:** 35-40.

Maheshwari HK 1974. Raniganj-Panchet Boundary. *In:* Surange KR, Lakhanpal RN & Bharadwaj DC (Editors) — *Aspects and appraisal of Indian Palaeobotany* : 408-420. Birbal Sahni Institute of Palaeobotany, Lucknow.

Maheshwari HK 1992. Provincialism in Gondwana floras. *In:* Venkatachala BS & Singh HP (Editors) — *Four decades of Indian Palaeobotany, Palaeobotanist* **40**: 101-127.

Maheshwari HK & Banerji J 1975. Lower Triassic palynomorphs from the Maitur Formation, West Bengal, India. *Palaeontographica* **B152**: 149-190.

Maheshwari HK & Chandra S 1994. The Nidhpuri magic pit: revisited. *9th Int. Gondwana Symp. Abstracts :* 21-22.

Matsuda T 1984. Early Triassic conodonts from Kashmir, India. Part 4, *Gondolella* and *Platyvillosus. Jl Geosci. Osaka Univ.* **27**(4):119-141.

Matsuda T 1985. Late Permian to Early Triassic conodont paleobiogeography in the Tethys Realm. *In:* Nakazawa K & Dickins JM (Editors) — *The Tethys, her paleogeography and paleobiogeography from Paleozoic to Mesozoic:* 57-70. Tokai University Press.

Mei Shilong 1996. Conodont succession around the Permian-Triassic Boundary and the natural Permian-Triassic Boundary. *30 Int. geol. Congr. Beijing Abstracts* **2**: 57.

Nakazawa K, Kapoor HM, Ishii K, Bando Y, Okimura Y & Tokuoka T 1975. The Upper Permian and Lower Triassic in Kashmir, India. *Mem. Fac. Sci. Kyoto Univ.,* Ser. *Geol. Mineral.* **42**(1): 1-106.

Newell ND 1988. The Paleozoic-Mesozoic Erathem Boundary. *Mem. Soc. Geol. Italiana* **34**: 303-311.

Noetling F 1905. Die Asiatische Trias. *Lethaea Geognostica 2, Lethaea Mesozoica* **1**(3): 107-221.

Oberhänsli H, Hsü KJ, Piasecki S & Weissert H 1989. Permian-Triassic carbon-isotope anomaly in Greenland and in the southern Alps. *Historical Geol.* **2**: 37-49.

Paull RK & Paull RA 1983. Revision of type lower Triassic Dinwoody Formation, Wyoming and designation of principal reference section. *Contrib. Geol. Univ. Wyoming* **22**(2):83-90.

Paull RK & Paull RA 1994. *Hindeodus parvus* as the index fossil for the Permian-Triassic boundary: a response to the Chinese Working Group. *Albertiana* **13**:3-7.

Sherlock PL 1947. *The Permo-Triassic formations: a world review.* Hutchinson's Scientific and Technical Publications, London.

Srivastava SC & Jha N 1995. Palynostratigraphy and correlation of Permian-Triassic sediments in Budharam area, Godavari Graben, India. *J. geol. Soc. India* **46**: 647-653,

Sun Yiyin, Xu Daoyi, Zhang Qinwen, Yang Zhengzhong, Sheng Jinzhang, Chen Chuzhen, Rui Lin, Liang Xiluo, Zhao Jiaming & He Jinwen 1984. The discovery of Iridium anomaly in the Permian-Triassic Boundary clay in Changxing, Zhejiang, China and its significance. *In*: Tu Guangzhi (Editor) — *Developments in geoscience* : 235-245 Beijing Science Press. (in Chinese with English abstract).

Sweet WC 1992. A conodont-based high-resolution biostratigraphy for the Permo-Triassic Boundary Interval. *In*: Sweet WC, Yang Z, Dickins JM & Yin H (Editors) — *Permo-Triassic events in the eastern Tethys: stratigraphy, classification and relations with the western Tethys* :121-133. Cambridge University Press, Cambridge.

Teichert C 1990. The Permian-Triassic Boundary revisited. *In*: Kauffman EG & Walliser OH (Editors) — *Extinction events in earth history, Lecture Notes in Earth Sciences* **30**: 199-238.

Tozer ET 1988. Definition of the Permian-Triassic (P-T) Boundary: the question of the age of the *Otoceras* beds. *Mem. Soc. Geol. Italiana* **34**: 291-301.

Tozer ET 1993. Triassic chronostratigraphic divisions considered again. *Albertiana* **11**: 32-37.

Tripathi C & Satsangi PP 1963. *Lystrosaurus* fauna of the Panchet series of the Raniganj Coalfield. *Mem. geol. Surv. India, Palaeont. indica*, new series, **37.**

Visscher H & Brugman WA 1988. The Permian-Triassic Boundary in the southern Alps: a palynological approach. *Mem. Soc. Geol. Italiana* **34**: 121-128.

Wang Yigang, Chen Chuzhen & Rui Lin 1989. A potential global stratotype of Permian-Triassic Boundary. *Developments in Geoscience*: 221-228. Science Press, Beijing. (in Chinese).

Wignall PB & Twitchett RJ 1996. Oceanic anoxia and the end Permian mass extinction. *Science* **272**: 1155-1158.

Xu Dao-yi & Yan Zheng 1993. Carbon isotope and Iridium event markers near the Permian/Triassic boundary in the Meishan section, Zhejiang Province, China. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **104**: 171-175.

Yang Zunyi, Wu Shunbao, Yin Hongfu, Xu Guirong & Zhang Kexin 1991. *Permo-Triassic events of south China.* Geological Publishing House, Beijing. (in Chinese with English summary).

Yin Hongfu 1993. A proposal for the global stratotype section and point (GSSP) of the Permian-Triassic Boundary by the Chinese Working Group on the Permian-Triassic Boundary. *Albertiana* **11**:4-30.

Yin Hongfu 1994. Reassessment of the index fossils at the Paleozoic-Mesozoic Boundary. *In*: Jin Yugan, John Utting & Wardlaw RM (Editors) — *Permian stratigraphy, environments and resources* **1**: *Palaeontology & Stratigraphy*: 153-171. Nanjing Univ. Press.

Yin Hongfu 1996. Recommendation of Meishan section as the Global Stratotype section and Point (GSSP) of Permian-Triassic Boundary (PTB). *30 Int. geol. Congr. Beijing Abstracts* **2**: 57.

Zakharov YD 1988. Type and hypotype of the Permian-Triassic Boundary. *Mem. Soc. Geol. Italiana* **34**: 277-289.

Zhou Tongshun, Li Peixian, Yang Jiduan, Hou Jingpeng, Liu Shuwen & Cheng Zhengwu 1996. Research on the non-marine Permian-Triassic Boundary stratotype in China. *30 Int. geol. Congr. Beijing Abstracts* **2**: 60.

Palynology of Permian-Triassic sequence in Iria Nala, Tatapani-Ramkola Coalfield, India

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Srivastava Suresh C, Anand-Prakash & Kar Ratan 1997. Palynology of Permian-Triassic sequence in Iria Nala, Tatapani-Ramkola Coalfield. *Palaeobotanist* **46** (1,2): 75-80.

The Permian-Triassic sediments exposed along Iria Nala in the northern part of Tatapani-Ramkola Coalfield have been palynologically analysed. The palynological assemblage includes 42 genera and on the basis of quantitative dominance three assemblage zones have been distinguished in ascending order : (i) *Densipollenites magnicorpus* zone, (ii) *Crescentipollenites fuscus* zone and (iii) *Falcisporites stabilis* zone. The first two palynoassemblage zones are restricted to the coal, carbonaceous shale, sandstone sequence (= Raniganj Formation) which is overlain by a khaki shale bed rich in *Schizoneura gondwanensis*. The lithological succession above this bed contains greyish/khaki green splintery shale and sandstone (=Panchet Formation). These shales have yielded the third palynoassemblage zone marked by *Falcisporites stabilis, Playfordiaspora cancellosa* and *Klausipollenites schaubergeri*. The Permian - Triassic boundary lies above the *Schizoneura gondwanensis* bed between the second and third palynozones. The transition is marked by the decline in the frequency of *Crescentipollenites* followed with the increase of non-striate group represented by *Falcisporites*. The onset of Triassic sedimentation is also marked by the presence of khaki shales which closely compares with the Panchet (Lower Triassic) sediments of the type area. Thus, the transition of palynoflora from Late Permian to Early Triassic is gradual and broadly conforms with the lithological changes. There appears to be a continuous sedimentation between the Permian and Triassic periods in this part of Tatapani-Ramkola Basin.

Key-words—Palynology, Tatapani-Ramkola Coalfield, Gondwana, Permian, Triassic, India.

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सारांश

भारत में तातापानी-रामकोला कोयला-क्षेत्र में इरिया नाला में परमियन-ट्रायॅसिक अनुक्रम का परागाणविक अध्ययन

सुरेश चन्द्र श्रीवास्तव, आनन्द प्रकाश एवं रतन कर

तातापानी-रामकोला कोयला-क्षेत्र के उत्तरी भाग में स्थित इरिया नाला के संग-संग अनावरित परमियन-ट्रायॅसिक अवसादों का परागाणविक अध्ययन किया गया। उपलब्ध परागाणविक समुच्चय में 42 प्रजातियाँ हैं तथा परिमाणात्मक विश्लेषण के आधार पर (i) *डेन्सीपोलिनाइटिस मैग्नीकॉर्पस* मंडल (ii) *क्रीसेन्टीपोलिनाइटिस फस्कस* मंडल एवं (iii) *फाल्सीस्पोराइटिस स्टेबिलिस* मंडल आरोही क्रम में बनाये गये हैं। पहले दो मंडल कोयला, कार्बनी शैल, बालुपत्थर अनुक्रम (रानीगंज शैल-समूह), जो कि खाकी शैलों के नीचे हैं, से सम्बद्ध हैं। इस संस्तर के ऊपर स्थित अनुक्रम से तृतीय परागाणविक मंडल उपलब्ध हुआ है। यह मंडल *फ़ाल्सीस्पोराइटिस स्टेबिलिस, प्लेफ़ोर्डियास्पोरा कैन्सेलोसा* एवं *क्लॉसीपोलिनाइटिस शॉबर्जेराई* से लक्षणित है। परमियन-ट्रायॅसिक सीमा *शाइज़ोन्यूरा गोंडवानेन्सिस* संस्तर के ऊपर दूसरे और तीसरे परागाणविक मंडलों के मध्य स्थित है। वनस्पतिक परिवर्तन *क्रीसेन्टीपोलिनाइटिस* की संख्या में कमी तथा धारीदार विहीन समूह में वृद्धि प्रदर्शित करता है। ट्रायॅसिक अवसादन का प्रारम्भ खाकी रंग की शैलों से जाना जा सकता है जो कि इसी क्षेत्र के पंचेत अवसादों से तुलनीय है। इस प्रकार ऐसा पाया गया है कि अनंतिम परमियन से प्रारम्भिक ट्रायॅसिक तक परागाणुवनस्पतिजात में परिवर्तन शनैः शनैः हुआ है। तातापानी-रामकोला द्रोणी में इस क्षेत्र में परमियन और ट्रायॅसिक कल्पों के बीच निरन्तर क्रमबद्ध अवसादन हुआ है।

THE Permian-Triassic boundary in the Indian continental deposits has been traced *vis-à-vis* the transition between Raniganj and Panchet Formations of the Gondwana Sequence. The contact between the Raniganj and Panchet sediments is not well defined. At most of the places, the boundary between these two formations is difficult to mark as the succession is mostly gradational and devoid of diagnostic fossil content. This problem has drawn the attention of many workers in the past and also forms the main theme of the present communication.

Palynology is best suited for biostratigraphic studies of the Gondwana sediments because of the predominantly continental nature of deposits. On the basis of palynological studies, delineation of Permian-Triassic boundary from different Indian Gondwana basins have been attempted by several workers (Bharadwaj, 1970; Tiwari, 1979; Tiwari & Singh, 1982, 1983, 1986; Tiwari & Tripathi, 1992; Srivastava & Jha, 1990, 1995; Jha & Srivastava, 1996; Ram-Awatar, 1996; Srivastava & Bhattacharyya, 1996). However, most of the above studies are based on bore-core samples and only a few attempts have been made to demarcate the actual boundary in outcrop sections (Banerji & Maheshwari, 1974; Bharadwaj *et al.*, 1979; Kumar, 1996; Pal *et al.*, 1996). A continuous sequence of Raniganj-Panchet sediments is exposed in the Iria Nala and it is thus possible to observe the changing palynofloral pattern across Raniganj-Panchet transition and thereby demarcate the Permian-Triassic boundary in this section.

Tatapani-Ramkola Coalfield—The Tatapani-Ramkola Coalfield is considered to be the western extension of the Damodar-Koel Valley Basin. It is a composite basin, comprising a northern strip of coal-bearing rocks referred to as Tatapani Coalfield and a southern one called the Ramkola Coalfield. The basin is situated between latitudes 23°30'-23°55'N and longitudes 83°00'-83°40'E (Raja Rao, 1983). Not much is known about the stratigraphy, structure, tectonic framework and subsurface succession of rocks as detailed mapping is still under progress. Palaeobotanical knowledge is limited only to a few megafossils described from the Raniganj and Panchet Formations (Bose *et al.*, 1977).

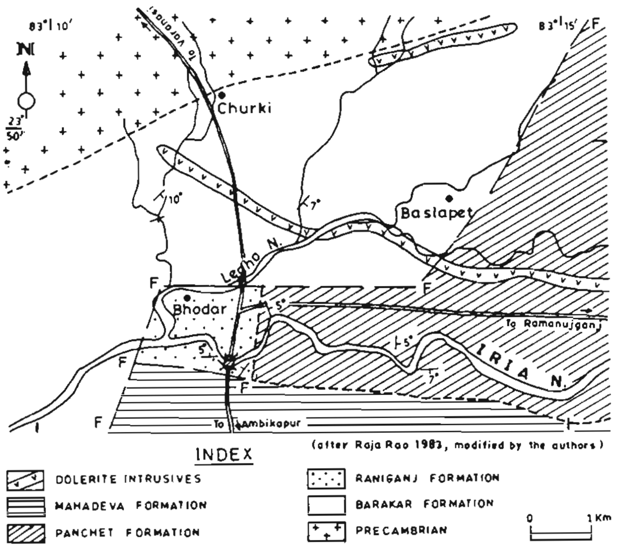
The coalfield is characterised mostly by a plain area with some undulations at places. The central part is occupied by a wide expanse of Supra Panchet sediments, which shows uneven topography and forms ridges and low hills. The Gondwana sediments are preserved in the form of an inlier flanked on either sides by hillocks of Precambrian rocks. The Gondwana sequence is represented by the sediments of Talchir, Barakar, Barren Measures, Raniganj, Panchet and Mahadeva Formations (Table 1).

Table 1—Generalised stratigraphic sequence in Tatapani-Ramkola Coalfield (modified after Raja Rao, 1993)

AGE	FORMATION	LITHOLOGY
Recent	Alluvium	
Cretaceous?	Basic Intrusives	Dolerite dykes
Upper Triassic ?	Mahadeva	Thick, cross-bedded coarse-grained ferruginous sandstones
Lower	Panchet	Yellowish, fine-grained sand stone with alternating red and Triassic green silt-stones, shales and clays
Upper Permian	Raniganj	Micaceous fine-grained ripple laminated sandstones, grey and carbonaceous shales and shaly coal bands
Middle Permian	Barren Measures	Ironstone shales showing box structure, fine-grained sandstone, shales and argillaceous sandstones
Lower Permian	Barakar	Medium to coarse-grained pebbly arkosic sandstone, grey and carbonaceous shales and coal seams
Lower Permian	Talchir	Diamictite, khaki-green needle shales, siltstone, fine-grained sandstone and varves
	-----------------Unconformity---------------	
Archean		Granites, gneisses, mica and talc schists, phyllites and quartz veins

Iria Nala section—An excellent outcrop of Raniganj - Panchet sediments can be observed on the right bank of Iria Nala, 5 km before Wadrafnagar, below the road bridge on Varanasi-Ambikapur road (Text-figure 1). The area east of Bhodar Village, between Ledho and Iria nalas, was earlier shown to have sediments belonging to the Barakar Formation (see the geological map of Tatapani-Ramkola Coalfield in Raja Rao, 1983). However, during field investigations we observed that no Barakar sediments exist in this section. In fact, these sediments rather have closer affinity with the Panchet sediments. Therefore, these sediments are placed in the Panchet Formation instead of the Barakar Formation (Text-figure 1). Palynological results bear testimony to the above observations.

The basal portion of the section consists of Raniganj sediments and begins with a dark grey clayey shale, followed by interbedded sandstone and shale units. The sandstone is characterised by a pale white colour, micaceous content, fine-grain size and well-marked ripple laminations with thin intercalations of grey shales. One such shale bed contains abundant *Schizoneura gondwanensis* im-



(after Raja Rao 1983, modified by the authors)

Text-figure 1—Geological map of a part of Tatapani-Ramkola Coalfield, Madhya Pradesh, India (modified after Raja Rao, 1983).

pressions. Above the *Schizoneura* bed a sandstone-shale sequence is again exposed. This sandstone is dirty white in colour and slightly coarser in nature than the underlying sandstone. It also has comparatively less mica content. The overlying shale beds are khaki-green in colour and compare closely with the Panchet shales exposed in the type area. Further upstream coarse-grained ferruginous sandstones are exposed and thereafter the outcrops are covered with alluvium. The details of the samples investigated are given in Table 2.

Table 2—List of samples investigated from Iria Nala section in Tatapani- Ramkola Coalfield

Sample No.	Lithology	Palynomorphs
INP-1	Limonitic micaceous shale	-
INP-2	Khaki micaceous shale	-
INP-3	Khaki-grey shale	+
INP-4	Grey clayey shale	-
INP-5	Khaki shale	-
INP-6	Khaki-grey shale	+
INP-7	Grey shale	+
INP-8	Grey clayey shale	+

Present (+); Absent (-)

PALYNOZONES

The palynoflora comprising 42 genera, in general, shows the dominance of striate disaccate pollen amongst which *Faunipollenites* and *Striatopodocarpites* form the dominant association. However, the quantitative association of other taxa differentiates three palynozones. Along with these, the first appearance of some important pollen and spores also characterise the assemblages (Text-figure 2).

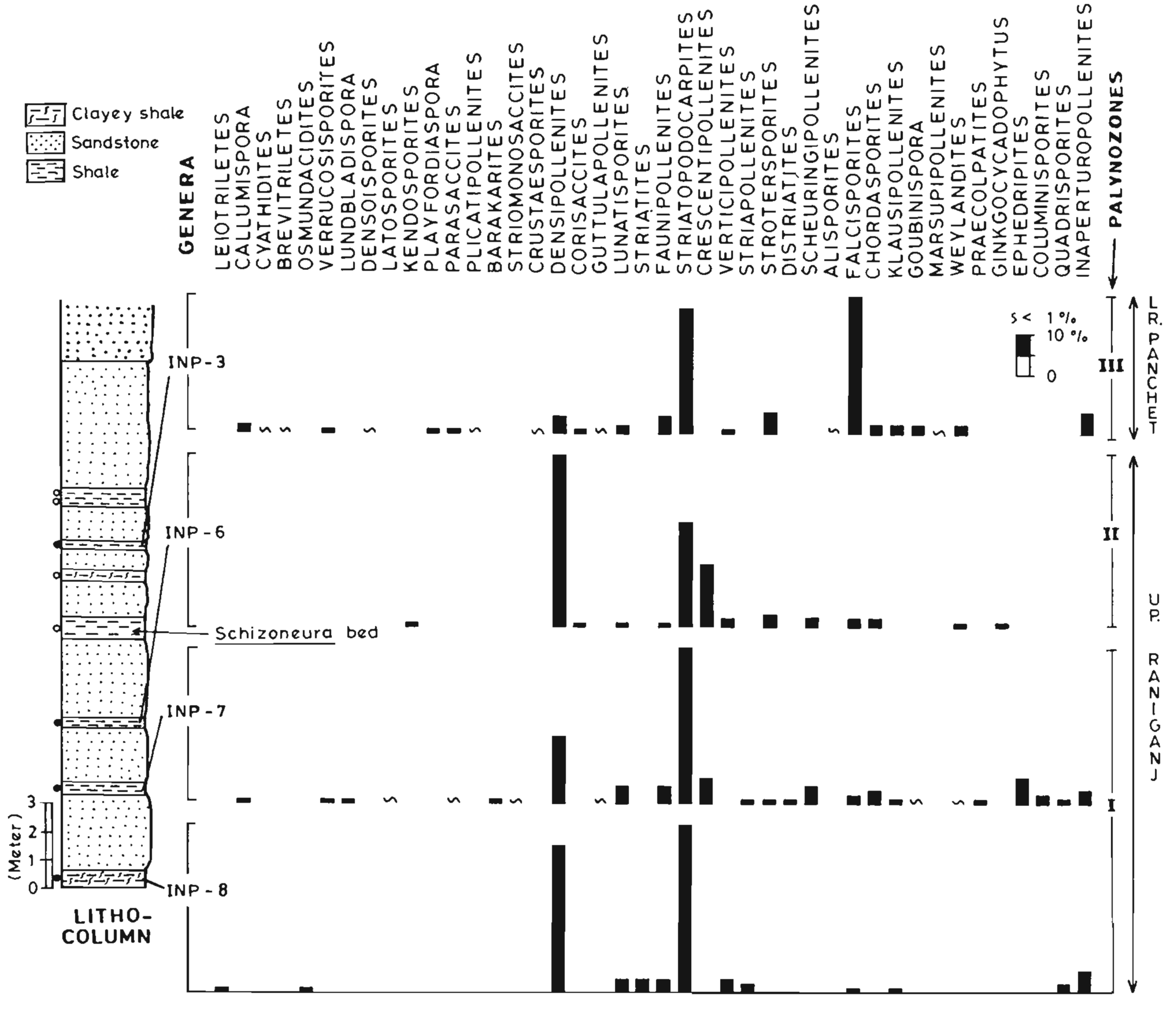
Palynozone I—The grey clayey-shales present at the basal part of the sequence contain 16 - 35 per cent *Densipollenites* in addition to equally significant numbers of striate disaccate pollen. *Densipollenites magnicorpus* is characteristic of this assemblage. *Praecolpatites sinuosus* and *Columinisporites* are restricted to this palynozone, whereas, *Lundbladispora, Falcisporites, Chordasporites, Klausipollenites* and *Goubinispora* make their first appearance in the sequence.

Palynozone II—This palynozone is marked by the subdominance of *Crescentipollenites* (15%), mainly represented by *Crescentipollenites fuscus*. *Densipollenites* attains maximum percentage (41%), while striate pollen are mainly represented by *Striatopodocarpites* (25%). *Kendosporites, Corisaccites, Lunatisporites, Falcisporites, Chordasporites* and *Weylandites* are present in rare amount.

Palynozone III—The total percentage of striate disaccate pollen remains similar to Palynozone II, but the percentage of non-striate disaccate pollen rises almost equal to that of striate disaccates. *Falcisporites* alone rises to 33 per cent. This palynozone is further characterised by the presence of *Playfordiaspora, Densoisporites, Alisporites, Chordasporites, Klausipollenites, Goubinispora, Callumispora, Cyathidites* and *Verrucosisporites*, though they occur in rare amount.

DISCUSSION

Palynozone I (*Densipollenites magnicorpus* Zone) of the Iria Nala section compares well with Assemblage III (Tiwari & Singh, 1982) and Assemblage R-1A (Tiwari & Singh, 1986) of Raniganj Coalfield. Similar palynoassemblage has been described from the Talcher Coalfield (Tiwari *et al.*, 1991). In Son Valley, similar palynoassemblages have been recorded from the Gopat River section (Maheshwari, 1967) and Nidpur beds (Tiwari & Ram-Awatar, 1990). Palynozone I also compares with the



Text-figure 2—Showing quantitative distribution of various taxa in Iria Nala, Tatapani-Ramkola Coalfield, Madhya Pradesh, India.

palynoflora described from the Bijori Formation of Satpura Basin (Bharadwaj *et al.*, 1978), Wardha Valley (Palynozone 1, Srivastava & Bhattacharyya, 1996) and Mailaram and Budharam areas of Godavari Graben (Assemblage III, Srivastava & Jha, 1990 and Palynozone 8, Srivastava & Jha, 1995).

Palynozone II (*Crescentipollenites fuscus* Zone) of the present investigation is comparable to similar assemblages reported from the Raniganj Coalfield (Assemblage III, Bharadwaj & Tiwari, 1977; Assemblage IV, Tiwari & Singh, 1982; Assemblage R-1A, Tiwari & Singh, 1986), Talcher Coalfield (Tiwari *et al.*, 1991), Nidpur beds of Son Valley (Tiwari & Ram-Awatar, 1990), Bijori sediments of Satpura Basin (Sarate & Patil, 1994), Wardha Valley (Palynozone 2, Srivastava & Bhattacharyya, 1996) and from Godavari Graben (Assemblage III, Srivastava & Jha, 1990; Palynozone 9, Srivastava & Jha, 1995). Palynozones I and II represent the younger assemblages of the Raniganj palynozones (Late Permian).

Palynozone III (*Falcisporites stabilis* Zone) is representative of the oldest assemblage of Panchet Formation in Tatapani-Ramkola Coalfield. Similar palynoassemblages have been reported from Bazargaon area of Wardha Valley (Palynozone 3, Srivastava & Bhattacharyya, 1996) and Tamia Ghat section in Satpura Basin (Palynoassemblage B, Kumar, 1996). The present palynozone differs from the *Striatopodocarpites-Klausipollenites* assemblage (P-1A Assemblage, Tiwari & Singh, 1986) from Raniganj Coalfield, and the assemblage described from the Sukri River, Auranga Coalfield (Banerji & Maheshwari, 1975) in having a dominance of *Falcisporites* and relatively lesser amounts of zonate triletes. Palynozone III of the Iria Nala also differs from the *Lunatisporites -Verrucosisporites* assemblage of Mailaram area (Srivastava & Jha, 1990) and *Densoisporites-Lundbladispora* assemblage of Budharam area (Srivastava & Jha, 1995), Godavari Graben, in having dominance of *Falcisporites* and rare percentage of trilete spores.

The Permian-Triassic boundary is located somewhere above the *Schizoneura gondwanensis* bed between palynozones II and III. The transition is marked by the decline in the frequency of *Crescentipollenites* followed with the increase in frequency of non-striate pollen represented by *Falcisporites.* The beds below the boundary are marked by the presence of carbonaceous matter indicative of upper part of Raniganj Formation (Late Permian), while a marked change in lithology to khaki-green shales points to the beginning of Panchet sedimentation (Early Triassic). Similar lithological changes have also been reported from other Indian Gondwana basins (Gee, 1932; Fox, 1934; Bharadwaj *et al.,* 1978, 1979). Striate disaccate pollen with typical Raniganj forms transgress the lithological boundary. Although, striate disaccates retain their dominance, it is the other constituents of the mioflora, as well as the rare forms signifying the younger aspect which reflect the basic change between Permian and Triassic miofloras. The continuously changing pattern of the mioflora without a sudden break, the conformable sequence of Raniganj and Panchet sediments with gradual change in lithology and the incoming of characteristic Triassic miospores, suggest that the Permian-Triassic transition is represented by a 'zone' rather than a 'sharp-line' in the Iria Nala section in Tatapani-Ramkola Coalfield.

REFERENCES

Banerji J & Maheshwari HK 1974. Palynology of the Panchet Group exposed in the Nonia nala near Asansol, West Bengal. *Palaeobotanist* **21**: 368-372.

Banerji J & Maheshwari HK 1975. Palhynomorphs from the Panchet Group exposed in Sukri River, Auranga Coalfield, Bihar. *Palaeobotanist* **22**: 158-170.

Bharadwaj DC 1970. Palynological subdivision of the Gondwana Sequence in India. *In* : Haughtan SH *et al.* (Editors)—*Proc. 2nd Int. Gondw. Symp., Univ. Cape Town, S. Africa (1970)* : 531-536.

Bharadwaj DC & Tiwari RS 1977. Permian-Triassic miofloras from the Raniganj Coalfield, India. *Palaeobotanist* **24**: 26-49.

Bharadwaj DC, Tiwari RS & Anand-Prakash 1978. Palynology of Bijori Formation (Upper Permian) in Satpura Gondwana Basin, India. *Palaeobotanist* **25**: 72-78.

Bharadwaj DC, Tiwari RS & Anand-Prakash 1979. Permo-Triassic palynostratigraphy and lithological characteristics in Damodar Basin, India. *Biol. Mem.* **4**: 49-82.

Bose MN, Banerji J & Maithy PK 1977. Some fossil plant remains from Ramkola-Tatapani coalfields, Madhya Pradesh. *Palaeobotanist* **24**: 108-117.

Fox CS 1934. The Lower Gondwana coalfields of India. *Mem. geol. Surv. India* **59** : 19.

Gee ER 1932. The geology and coal resources of the Raniganj Coalfield. *Mem. geol. Surv. India* **61** : 54.

Jha N & Srivastava SC 1996. Kamthi Formation - Palynofloral diversity. *In* : Guha PKS *et al.* (Editors)—*Gondwana Nine* **1** : 355-368. Oxford & IBH Publ. Co. Ltd., New Delhi.

Kumar P 1996. Permo-Triassic palynofossils and depositional environment in Satpura Basin, Madhya Pradesh. *Geophytology* **25**:47-54.

Maheshwari HK 1967. Note on a miospore assemblage from Gopat River Valley, M.P. *Curr. Sci.* **36**(7):181.

Pal PK, Shome D, Sannigrahi A & Ghosh AK 1996. Raniganj-Panchet transition *vis-a-vis* Permo-Triassic transition in the Raniganj coalfield, India (abst.). *In* : *Golden Jubilee Conference on Physical and biological changes across the major geological boundaries,* Nov. 15-17, 1996 :26. Birbal Sahni Institute of Palaeobotany, Lucknow.

Raja Rao CS 1983. Coalfields of India Vol. III : Coal resources of Madhya Pradesh, Jammu and Kashmir. *Bull. geol. Surv. India,* ser. A **45**: 75-80.

Ram-Awatar 1996. Palynostratigraphy of Supra-Barakar sediments (Pali, Tiki and Parsora formations) and their stratigraphic positions in South Rewa Basin, M.P., India. *In* : Guha PKS *et al.* (Editors)—*Gondwana Nine* **1**: 439-454. Oxford & IBH Publ. Co. Ltd., New Delhi.

Sarate OS & Patil GV 1994. Palynostratigraphy of Bijori sediments, Satpura Basin, India. *Geophytology* **23**: 197-201.

Srivastava SC & Bhattacharyya AP 1996. Permian-Triassic palynofloral succession in subsurface from Bazargaon, Nagpur District, Maharashtra. *Palaeobotanist* **43**: 10-15.

Srivastava SC & Jha N 1990. Permian-Triassic palynofloral transition in Godavari Graben, Andhra Pradesh. *Palaeobotanist* **38**: 92-97.

Srivastava SC & Jha N 1995. Palynostratigraphy and correlation of Permian - Triassic sediments in Budharam area, Godavari Graben, India. *J. geol. Soc. India* **46** : 647-653.

Tiwari RS 1979. Palynostratigraphy of Permo-Triassic transition in India. *Proc. IV Int. palynol. Conf., Lucknow* **2**: 199-207. Birbal Sahni Institute of Palaeobotany, Lucknow.

Tiwari RS & Singh V 1982. Pattern of miofloras through Permo-Triassic transition in bore-hole RAD-2, East Raniganj Coalfield, W. Bengal. *Geophytology* **12**: 181-186.

Tiwari RS & Singh V 1983. Miofloral transition at Raniganj-Panchet boundary in East Raniganj Coalfield and its implication on Permo-Triassic time boundary. *Geophytology* **13**: 227-234.

Tiwari RS & Singh V 1986. Palynological evidences for Permo-Triassic boundary in Raniganj Coalfield, Damodar Basin, India. *Bull. geol. Min. metall. Soc. India* **54**: 256-264.

Tiwari RS & Ram-Awatar 1990. Palynodating of Nidpur beds, Son Graben, Madhya Pradesh. *Palaeobotanist* **38**: 105-121.

Tiwari RS & Tripathi A 1992. Marker assemblage-zones of spores and pollen species through Gondwana Palaeozoic and Mesozoic sequence in India. *Palaeobotanist* **40**: 194-236.

Tiwari RS, Tripathi A & Jana BN 1991. Palynological evidence for Late Permian Raniganj coals in western part of Talchir Coalfield, Orissa, India. *Curr. Sci.* **61**(6): 407-410.

Megafloral zonation of Permian-Triassic sequence in the Kamthi Formation, Talcher Coalfield, Orissa

Pankaj K. Pal & Amit K. Ghosh

Pal PK & Ghosh AK 1997. Megafloral zonation of Permian-Triassic sequence in the Kamthi Formation, Talcher Coalfield, Orissa. *Palaeobotanist* 46 (1, 2) : 81-87.

The Kamthi Formation exposed in the west-central part of Talcher Coalfield is divisible into a Lower and an Upper Member. Megafloral assemblage (Assemblage Zone-I) of the Lower Member is dominated by *Glossopteris* in association with *Trizygia, Vertebraria* and *Pseudoctenis.* The Upper Member consists of two distinct sets of lithounits, viz., lower and upper beds. Assemblage Zone-II found in the lower beds of Upper Member is characterised by preponderance of *Glossopteris*; associated elements are : *Cyclodendron, Phyllotheca, Stellotheca, Trizygia, Sphenophyllum, Raniganjia, Schizoneura, Dizeugotheca, Neomariopteris, Damudopteris, Surangephyllum, Handapaphyllum,* various glossopterid fructifications, scale leaves, etc. The Assemblage Zone-III also from the lower beds of Upper Member is dominated by *Glossopteris*; associated elements are equisetaceous stems and *Neomariopteris.* However, presence of *Lepidopteris* and *?Dicroidium* distinguishes Assemblage Zone-III. Assemblage Zone-IV from the upper beds of Upper Member is characterised by abundance of *Dicroidium,* in association with *Lepidopteris, Elatocladus, Yabiella* and *Desmiophyllum.* On the basis of megafloral assemblages it has been derived that Permian-Triassic Boundary (PTB) in the Talcher Coalfield lies somewhere in the lower beds of the Upper Member of Kamthi Formation.

Key-words—Megafloral zonation, Kamthi Formation, Permian-Triassic Boundary, Talcher Coalfield, India.

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सारांश

उड़ीसा में तलचीर कोयला-क्षेत्र में कामथी शैल-समूह के परमियन-ट्रायॅसिक अनुक्रम में गुरुवनस्पतिजातीय मंडलन

पंकज कुमार पाल एवं अमित कुमार घोष

तलचीर कोयला-क्षेत्र के पश्चिमी केन्द्रीय भाग में अनावरित कामथी शैल-समूह उपरि एवं अधरि सदस्यों में विभाजित किया गया है। अधरि सदस्य का समुच्चय मंडल-1 *ट्राइजीजिया, वर्टीब्रेरिया* एवं *स्यूडोटीनिस* सहित *ग्लॉसॉप्टेरिस* से प्रभावी है। उपरि सदस्य में दो विभिन्न शैल इकाईयाँ हैं। इससे प्राप्त समुच्चय मंडल-2 भी *ग्लॉसॉप्टेरिस* से प्रभावी है। इसके अतिरिक्त इसमें *साइक्लोडेन्ड्रॉन, फिल्लोथीका, स्टीलोथीका, ट्राइजीजिया, स्फीनोफिल्लम्, रानीगंजिआ, शाइजोन्यूरा, डाइज्यूगोथीका, हंडपाफिल्लम्, निओमेरिऑप्टेरिस* आदि सहयुक्त अवयव भी पाये गये हैं। इसके अलावा उपरि सदस्य के निचले संस्तरों से प्राप्त समुच्चय मंडल-3 में *ग्लॉसॉप्टेरिस* की बाहुल्यता है। साथ ही इक्वीसिटेली तने और *निओमारिऑप्टेरिस* नामक अन्य सहयुक्त अवयव भी मिलते हैं। समुच्चय मंडल-4 *लेपिडोप्टेरिस, इलेटोक्लेडस, याबियॅल्ला* एवं *डेस्मिओफिल्लम्* के साहचर्य में *डाइक्रोइडियम* से प्रभावी है। उपलब्ध गुरुवनस्पतिजातीय समुच्चय के आधार पर यह निष्कर्ष निकाला गया है कि तलचीर कोयला-क्षेत्र में परमियन-ट्रायॅसिक सीमा कामथी शैल-समूह के उपरि सदस्य की अधरि संस्तरों में कहीं विद्यमान है।

THE Gondwana rocks in the Talcher Coalfield are represented by a sequence of fluvial sedimentary deposits belonging to the Talchir, Karharbari, Barakar and post-Barakar Formations. The stratigraphic position of the post-Barakar deposits in this coalfield has long been a matter of controversy. Subramanian (1962) and Chakraborty, Das and Banerjee (1967) classified the post-Barakar sequence into Raniganj, Panchet and Mahadeva Formations on the basis of lithological and palaeontological attributes. However, Raja Rao (1982) considered the entire sequence as a single lithounit, the Kamthi Formation. Chakraborty (1989) mapped the Kamthi Formation exposed in the west-central part of Talcher Coalfield and classified it into a Lower Member and an Upper Member. The Lower Member is about 200 m thick, comprising mainly medium- to coarse-grained, pebbly, cross-bedded, ferruginous sandstones alternating with and containing clasts of greenish-white shales. The Upper Member is also more or less 200 m thick; two distinct sets of lithologies have been recognised. The lower beds of the Upper Member are represented by medium-grained buff or white, cross-bedded, ferruginous sandstones alternating with thick bands of red and grey shales. The upper beds of the Upper Member are characterised by highly ferruginous, hard and quartzitic sandstones, bands of hard, compact, brown to yellow shales, bands and clasts of lavender and creamy white shales.

From the well-known Hinjrida Ghati locality (near Handapa Village), belonging to the lower beds of Upper Member of Kamthi Formation, a rich assemblage of plant megafossils dominated by *Glossopteris* has been recorded (Subramanian & Rao, 1960; Khan, 1969; Surange & Maheshwari, 1970; Surange & Chandra, 1973a, 1973b, 1973c, 1974a, 1974b, 1974c, 1974d; Maithy, 1977; Chandra & Rigby, 1981; Singh & Chandra, 1987; Ghosh, 1992; and others). Subramanian and Rao (1960) considered these beds as equivalent to Panchet Formation (Lower Triassic). On the other hand, Khan (1969) and Chandra and Rigby (1981) considered those as homotaxial with Raniganj Formation.

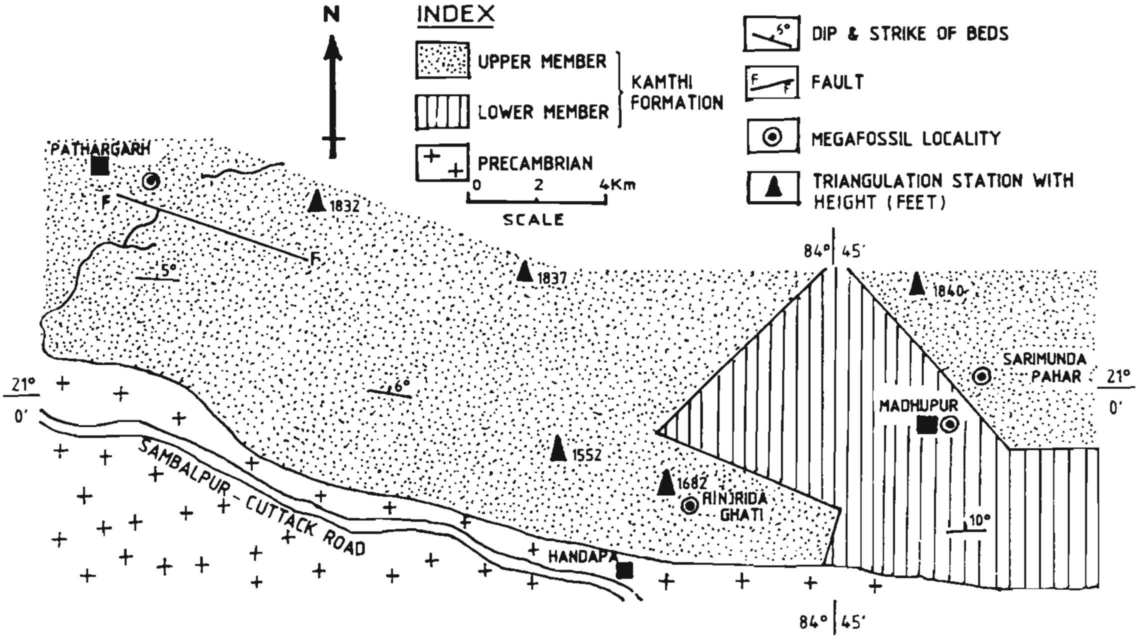
Plant fossils from the Lower Member and upper beds of Upper Member of Kamthi Formation were recorded by Pal *et al.* (1991) and Ghosh (1992). They reported plant megafossils from three new localities viz., (i) about 1 km south-east of Madhupur Village (Lower Member), (ii) southern slope of Sarimunda Hill (lower beds of Upper Member), (iii) about 1.5 km east of Pathargarh Village (upper beds of Upper Member) in addition to the well-known Hinjrida Ghati locality (Map 1).

In the present paper an attempt has been made to establish the overall lithological and megafloral successions in the Kamthi Formation of Talcher Coalfield with special reference to demarcate the PTB (Permian-Triassic Boundary) interval.

MEGAFLORAL ASSEMBLAGES

Assemblage Zone-I (Madhupur locality)

The assemblage is rich in *Glossopteris* leaves along with *Vertebraria indica.* Other associated forms are : *Trizygia speciosa, Neomariopteris hughesii, Glossopteris communis* (Pl. 1, fig. 2; Text-figure 1A), *G. tenuifolia, G. gigas* (Pl. 1, fig. 3; Text-figure 1D),



Map 1—Geological map of part of Talcher Coalfield showing megafossil localities.

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Text-figure 1-A— *Glossopteris communi* from Madhupur locality. X 1; **B.** *Eretmonia* - type scale leaf from Madhupur locality. X 2; **C.** *Pseudoctenis ballii* from Madhupur locality. X 1; **D.** *Glossopteris gigas* from Madhupur locality. X 1; **E.** *Lepidopteris* sp. from Sarimunda Hill locality. X 2; **F.** ?*Dicroidium* sp. from Sarimunda Hill locality. X 2; **G.** *Lepidopteris* sp. cf. *L. stormbergensis* from Pathargarh locality. X 2; **H.** *Elatocladus* sp. from Pathargarh locality. X 2; **I.** *Dicroidium giarens* from Pathargarh locality. X 1; **J.** *Dicroidium zuber* from Pathargarh locality. X 2; **K.** *Dicroidium superbum* from Pathargarh locality. X 2; and **L.** *Yabiella* sp. from Pathargarh locality. X 2.

Text-figure 1

Eretmonia-type scale leaf (Text-figure 1B) and *Pseudoctenis ballii* (Pl. 1, fig. 4; Text-figure 1C).

Assemblage Zone-II (Hinjrida Ghati locality)

The assemblage is characterised by the preponderance of glossopterid leaves and fructifications as has already mentioned by Chandra and Rigby (1981) and Singh and Chandra (1987). The other elements known from the Hinjrida Ghati beds are : *Cyclodendron leslii, Phyllotheca indica, Stellotheca robusta, Sphenophyllum crenulatum, S. churulianum, Trizygia speciosa, Raniganjia bengalensis, R. etheridgei, Schizoneura gondwanensis, Dizeugotheca phegopteroides, Neomariopteris hughesii, N. khanii, N. lobifolia* (Pl. 1, fig. 1), *Damudopteris bengalensis, Pantopteris gracilis, Pseudoctenis ballii, Surangephyllum elongatum, Handapaphyllum indicum,Senia reticulata* and *Samaropsis raniganjensis.*

Assemblage Zone-III (Sarimunda Hill locality)

Fragments of *Glossopteris* leaves are quite common at this locality. Fragmentary specimens of *Neomariopteris hughesii* and equisetaceous stems with ridges and furrows are also present. Other significant gymnospermous forms present in the assemblage are : *Lepidopteris* sp. (Pl. 1, fig. 6; Text-figure 1E) and *?Dicroidium* sp. (Pl. 1, fig. 5; Text-figure 1F).

Assemblage Zone-IV (Pathargarh locality)

The assemblage is dominated by *Dicroidium*. Other associated elements are : *Lepidopteris* sp. cf. *L. stormbergensis* (Text-figure 1G), *Elatocladus* sp. (Text-figure 1H), *Dicroidium zuberi* (Pl. 1, figs 8, 9; Text-figure 1J), *D. superbum* (Pl. 1, fig. 10; Text-figure 1K), *D. giarensis* (Pl. 1, fig. 7; Text-figure 1I), *Yabiella* sp. (Pl. 1, fig. 11; Text-figure 1L), *Desmiophyllum* sp. (Pl. 1, fig. 12).

DISCUSSION

Four distinct megafloral assemblages have been recognised in the Kamthi Formation of Talcher Coalfield (west-central part).

In Assemblage Zone-I (Lower Member, Madhupur locality) *Glossopteris* is the most frequently occurring form. More or less similar assemblage is known from the Raniganj Formation of Damodar Valley Basin (Lele, 1976) which has been dated as Upper Permian.

Assemblage Zone II from Hinjrida Ghati is dominated by *Glossopteris* and its allies in association with other Upper Permian forms. The Assemblage Zone II, like Assemblage Zone I, is also indistinguishable from the assemblage known from the Raniganj Formation, except for the presence of forms like *Surangephyllum elongatum, Handapaphyllum indicum* and *Senia reticulata* in the Hinjrida Ghati assemblage.

Assemblage Zone III from the Sarimunda Hill contains *Lepidopteris* sp. and *?Dicroidium* sp. in association with equisetaceous stems, *Neomariopteris hughesii* and *Glossopteris* spp. The assemblage Zone III in all probabilities indicates an age younger than that of the Raniganj Formation and comparable with that of the Panchet Formation (Lower Triassic).

Assemblage Zone IV (Pathargarh) represents a *Dicroidium* rich megaflora. This genus is represented by three species, viz., *D. zuberi, D. superbum* and *D. giarensis.* Associated elements are *Lepidopteris* sp. cf. *L. stormbergensis, Elatocladus* sp., *Yabiella* sp. and *Desmiophyllum* sp. *Glossopteris* or other Permian forms are totally absent. On the basis of megafloral evidences Pal *et al.* (1991) and Ghosh (1992) considered that the upper beds of Upper Member (Pathargarh) as equivalent to Tiki Formation of South Rewa Gondwana Basin (Upper Triassic). Assemblage Zone IV also resembles those known from the Middle to Upper Triassic of Nymboida Coal Measures and Hawkesbery Sandstone of Australia,

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PLATE 1 ⟶

1. *Neomariopteris lobifolia* from Hinjrida Ghati locality. X 1.
2. *Glossopteris communis* from Madhupur locality. X 1.
3. *Glossopteris gigas* from Madhupur locality. X 1.
4. *Pseudoctenis ballii* from Madhupur locality. X 1.
5. *? Dicroidium* sp. from Sarimunda Hill locality. X 1.
6. *Lepidopteris* sp. from Sarimunda Hill locality. X 1.
7. *Dicroidium giarensis* from Pathargarh locality. X 1.

8, 9. *Dicroidium zuberi* from Pathargarh locality. X 1.

10. *Dicroidium superbum* from Pathargarh locality. X 1.
11. *Yabiella* sp. from Pathargarh locality. X 2.
12. *Desmiophyllum* sp. from Pathargarh locality. X 1.


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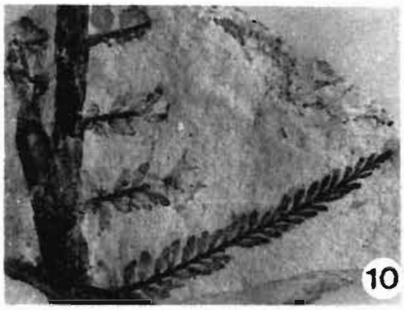
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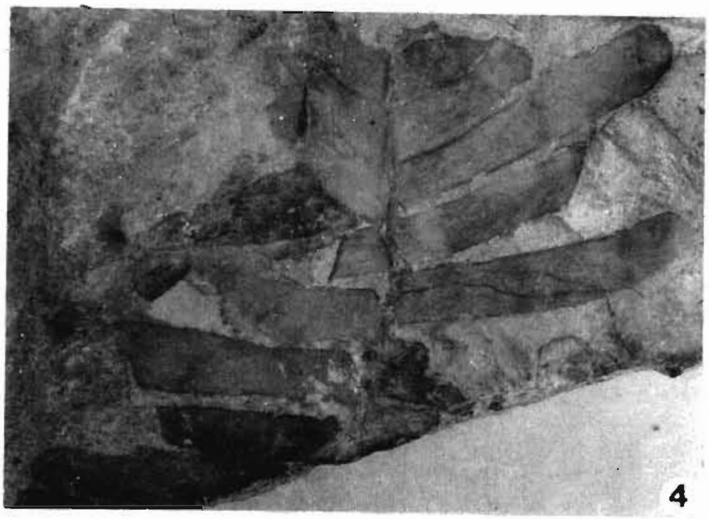
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PLATE 1

Table 1—Overall lithological and megafloral successions in the Kamthi Formation of Talcher Coalfield

		Salient Lithological Features	Megafloral assemblages	Age	
UPPER MEMBER	UPPER BEDS	Predominantly ferruginous, hard and quartzitic sandstones, bands of hard and compact brown to yellow shales and bands and clasts of lavender and creamy white shales.	ASSEMBLAGE ZONE-IV (Pathargarh locality) Dominant: *Dicroidium* Associated elements: *Lepidopteris*, *Elatocladus*, *Yabiella* and *Desmiophyllum*	UPPER	TRIASSIC
	LOWER BEDS	Predominantly medium-grained, buff or white cross-bedded ferruginous sandstones alternating with thick bands of red and grey shales.	ASSEMBLAGE ZONE-III (Sarimunda Hill locality) Dominant: Glossopteris Associated elements: Equisetaceous stem, *Neomariopteris*, *Lepidopteris* and ? *Dicroidium*	LOWER	
			Assemblage Zone -II (Hinjrida Ghati locality) Dominant: *Glossopteris* Associated elements: *Cyclodendron*, *Phyllotheca*, *Stellotheca*, *Trizygia*, *Sphenophyllum*, *Raniganjia*, *Schizoneura*, *Dizeugotheca*, *Neomariopteris*, *Damudopteris*, *Surangephyllum*, *Dictyopteridium*, *Denkania*, *Partha*, *Scutum*, *Cistella*, *Khania*, *Lidgettonia*, *Gondwanolepis*, *Kendostrobus*, *Eretmonia*, *Indocarpus*, *Pseudoctenis*, *Handapaphyllum*, *Senia* and *Samaropsis*	UPPER PERMIAN	
LOWER MEMBER		Predominantly medium to coarse grained, pebbly, cross-bedded ferruginous sandstones, alternating with and containing clasts of greenish-white and greyish-white shales.	ASSEMBLAGE ZONE-1 (Madhupur locality) Dominant: *Glossopteris* Associated elements: *Trizygia*, *Neomariopteris*, *Vertebraria*, *Eretmonia*-type scale leaf and *Pseudoctenis*		

Esk Trough of Queensland, Cacheuta and Ischigulasto Formations of Argentina, Molteno Formation of South Africa (Townrow, 1966; Retallack, Gould & Runnegar, 1977; Flint & Gould, 1975; Jain & Delevoryas, 1967; Archangelsky, 1968; Anderson & Anderson, 1983).

It can thus be concluded that there is a gradual megafloral change from Upper Permian to Lower Triassic forms (Assemblage Zone I to Assemblage Zone III) in the Kamthi Formation of Talcher Coalfield. The Upper Triassic megaflora (Assemblage Zone IV) is clearly distinguishable from the underlying flora. The overall lithological and megafloral successions in the Kamthi Formation of Talcher Coalfield are represented in Table 1.

Probable Permian-Triassic Boundary in the Kamthi Formation

Very few attempts have so far been made to demarcate the Permian-Triassic Boundary in outcrop sections (Maheshwari & Banerji, 1975; Bharadwaj *et al.* (1979); Kumar, 1996; Pal *et al.*, 1996; Srivastava *et al.*, 1997) of different basins in peninsular India. Maheshwari (1997) analysed the data available from different Permian-Triassic sections of peninsular India and concluded that there is no marine control to precisely demarcate the PTB interval in the basins of Indian peninsula. However, according to Maheshwari (1974) in Damodar Valley Basin the PTB interval is located somewhere across the Raniganj-Maitur transition. In Godavari Graben (Srivastava & Jha, 1995) the PTB interval is within the Kamthi Formation.

In peninsular India, the time of deposition of Raniganj Formation (Upper Permian) and its equivalents is the zenith of Glossopteris Flora. Some Upper Permian plants continue in the Lower Triassic (Panchet Formation and its equivalents) accompanied by the introduction of some new elements, viz., *Lepidopteris* and *Dicroidium*; the latter are rare in occurrence. *Dicroidium* is the characteristic element of southern hemisphere Triassic floras. In the Talcher Coalfield *Lepidopteris* and *Dicroidium* first appear in the Assemblage Zone III (Sarimunda Hill). These genera are totally absent in the underlying Hinjrida Ghati beds. Both Hinjrida Ghati and Sarimunda Hill localities expose lower beds of the Upper Member of Kamthi Formation. Though, there is no lithological difference between the two localities, yet, from megafloral evidence it appears that Permian-Triassic Boundary (PTB) in the Talcher Coalfield is located somewhere in the lower beds of the Upper Member of Kamthi Formation.

REFERENCES

Anderson JM & Anderson HM 1983. *Palaeoflora of Southern Africa, Molteno Formation* (Triassic) **1**. Rotterdam.

Archangelsky S 1968. Studies on Triassic fossil plants from Argentina. IV, The leaf genus *Dicroidium* and its possible relation to *Rhexoxylon* stems. *Palaeontology* **11**: 500-512.

Bharadwaj DC, Tiwari RS & Anand-Prakash 1979. Permo-Triassic palynostratigraphy and lithological characteristics in Damodar Basin, India. *Biol. Mem.* **4** (1&2) : 49-82.

Chakraborty SN, Das SN & Banerjee SP 1967. Final report on investigation by drilling in the central part of Talcher Coalfield, Orissa. *Unpublished Report, Geol. Surv. India.*

Chakraborty U 1989. *Unpublished Report, Geol. Surv. India.*

Chandra S & Rigby JF 1981. Lycopsid, sphenopsid and cycadaceous remains from the Lower Gondwana of Handapa, Orissa. *Geophytology* **11**(2) : 214-219.

Flint JCE & Gould RE 1975. A note on the Nymboida and Red Cliff Coal Measures, Southern Clarence-Horeton Basin, N.S.W. *J. Proc. R. Soc. N.S.W.* **108** : 70-74.

Ghosh AK 1992. Contributions to the Triassic palaeobotany and stratigraphy of peninsular India. *Ph. D. Thesis*, Burdwan University, Burdwan.

Jain RK & Delevoryas T 1967. A Middle Triassic flora from the Cacheuta Formation, Minas de Petroleo, Argentina. *Palaeontology* **10**(4) : 564-589.

Khan AN 1969. *Senia reticulata*, a new fossil plant from the Raniganj rocks of the Talcher Coalfield, Orissa, India. *In* : Santapau H *et al.* (Editors)—*J. Sen Memorial Volume* : 335-338. Botanical Society of Bengal, Calcutta, India.

Kumar P 1996. Permo-Triassic palynofossils and depositional environment in Satpura Basin, Madhya Pradesh. *Geophytology* **25** : 47-54.

Lele KM 1976. Late Palaeozoic and Triassic floras of India and their relation to the floras of northern and southern hemispheres. *Palaeobotanist* **23**(2) : 89-115.

Maheshwari HK 1974. Raniganj-Panchet Boundary. *In* : Surange KR *et al.* (Editors)—*Aspects and appraisal of Indian Palaeobotany* : 408-420. Birbal Sahni Institute of Palaeobotany, Lucknow.

Maheshwari HK 1997. Permian-Triassic Boundary : a tyro's view. *Palaeobotanist* **46**(1, 2) : 63-74.

Maheshwari HK & Banerji J 1975. Lower Triassic palynomorphs from the Maitur Formation, West Bengal, India. *Palaeontographica* **B152** : 149-190.

Maithy PK 1977. Three new fern fronds from the Glossopteris Flora of India. *Palaeobotanist* **24**(2) : 96-101.

Pal PK, Chakraborty U, Ghosh AK & Ghosh A 1991. Triassic plant megafossils from the Kamthi Formation of Talcher Coalfield, India a new report. *Indian Jl Geol.* **63**(2) : 119-125.

Pal PK, Some D, Sannigrahi A & Ghosh AK 1996. Raniganj-Panchet transition vis-a-vis Permo-Triassic transition in the Raniganj Coalfield, India (abst.). *In : Golden Jubilee Conference on Physical and biological changes across the major geological boundaries*, Nov. 15-17, 1996 : 26. Birbal Sahni Institute of Palaeobotany, Lucknow.

Raja Rao CS 1982. Coalfields of India, V II. *Geol. Surv. India. Bull.* ser. A. **45**: 41-52.

Rettalack GJ, Gould RE & Runnegar B 1977. Isotopic dating of a Middle Triassic megafossil flora from near Nymboida, north-eastern New South Wales. *Proc. Linn. Soc. N.S.W.* **101** : 77-113.

Singh KJ & Chandra S 1987. Some new species of *Glossopteris* from the Kamthi Formation of Handapa, Orissa. *Geophytology* **17**(1) : 39-55.

Srivastava Suresh C, Anand-Prakash & Kar R 1997. Palynology of Permian-Triassic sequence in Iria Nala, Tatapani-Ramkola Coalfield, M.P., India. *Palaeobotanist* **46**(1, 2) : (000-000).

Srivastava Suresh C & Jha N 1995. Palynostratigraphy and correlation of Permian-Triassic sediments in Budharam area, Godavari Graben, India. *J. geol. Soc. India* **46** : 647-653.

Subramanian KS 1962. Progress report on the geological mapping of the Talcher Coalfield, Orissa. *Unpublished Report, Geol. Surv. India.*

Subramanian KS & Rao CN 1960. *Glossopteris* from the Mahadevas of Hinjrida, Talcher Coalfield, Orissa. *Proc. Indian Sci. Congr. Assoc. 47th session*, Part 3 : 278.

Surange KR & Chandra S 1973a. *Dictyopteridium sporiferum* Feistmantel —female cone from the lower Gondwana of India. *Palaeobotanist* **20** (1): 127-136.

Surange KR & Chandra S 1973b. *Denkania indica* gen. et sp. nov. A glossopteridean fructification from the Lower Gondwana of India. *Palaeobotanist* **20**(2) : 264-268.

Surange KR & Chandra S 1973c. *Partha*, a new type of female fructification from the Lower Gondwana of India. *Palaeobotanist* **20**(3) : 356-360.

Surange KR & Chandra S 1974a. Fructifications of Glossopteridae from India. *Palaeobotanist* **21**(1) : 1-17.

Surange KR & Chandra S 1974b. *Lidgettonia mucronata* sp. nov. : A female fructification from the Lower Gondwana of India. *Palaeobotanist* **21**(1) : 121-126.

Surange KR & Chandra S 1974c. Further observations of *Glossotheca* Surange and Maheshwari; a male fructification of Glossopteridales. *Palaeobotanist* **21**(2) : 248-254.

Surange KR & Chandra S 1974d. Some male fructifications of Glossopteridales. *Palaeobotanist* **21**(2) : 255-266.

Surange KR & Maheshwari HK 1970. Some male and female fructifications of Glossopteridales from India. *Palaeontographica* **B129** : 178-191.

Townrow JA 1966. On *Lepidopteris madagascariensis* Carpentier (Peltaspermaceae). *J. Proc. R. Soc. N.S.W.* **98** : 203-214.

Status of Kamthi Formation : lithological and palaeobotanical evidences

Suresh C. Srivastava & Neerja Jha

Srivastava Suresh C & Jha N 1997. Status of Kamthi Formation : lithological and palaeobotanical evidences. *Palaeobotanist* **46** (1,2) : 88-96.

On the basis of lithological, palynological and megafloral data the status of Kamthi Formation has been reviewed. Hitherto known Kamthi Formation which was said to be a time-transgressive unit (Permian-Triassic) actually represents a Triassic sequence overlying Permian sediments equivalent to Raniganj Formation. Presence of Permian taxa, viz., *Glossopteris*, *Vertebraria* and *Phyllotheca* in red claystone, ferruginous sandstone/shale unit (=Upper Member, Kamthi Formation) represent only the continuations of Permian taxa into the Triassic.

Key-words — Lithology, Megafossils, Palynofossils, Kamthi Formation, Panchet Formation, Triassic, India.

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सारांश

कामथी शैल-समूह की स्थिति : शैलिकीय एवं पुरावनस्पतिक प्रमाण

सुरेशचन्द्र श्रीवास्तव एवं नीरजा झा

शैलिकीय, परागाणविक एवं गुरुवनस्पतिजातीय आँकड़ों के आधार पर कामथी शैल-समूह की स्थिति की समीक्षा की गई है। कामथी शैल-समूह जो अभी तक एक अतिक्रामी इकाई (परमियन-ट्रायॅसिक) कही जाती थी वास्तव में परमियन अवसादों के ऊपर विद्यमान ट्रायॅसिक अनुक्रम का निरूपण करती है। *ग्लॉसॉप्टेरिस, वर्टीब्रेरिया* एवं *फिल्लोथीका* नामक परमियन कालीन वर्गकों की उपस्थिति से ट्रायॅसिक काल में परमियन कालीन वर्गकों की निरन्तरता व्यक्त होती है।

THE name 'Kamthi' was introduced by Blanford (1868) for a group of rocks exposed near military station 'Kamptee' close to Nagpur. The 'Kamthi Group' of rocks as described by Blanford (1877, p. 299) sensu stricto are composed of "grits, sometimes very hard at other times soft and frequently ferruginous. These are often intersected by bands in which the quartz and carbon are cemented together by peroxide of iron. The group also contains sandstone of various kinds, amongst which fine-grained slightly micaceous bed, white in colour with blotches and irregular streaks of red are abundant and the fine homogeneous argillaceous rocks which for want of better name called a compact shale, yellow below the surface, but becoming deep red when exposed". Similar rocks were later identified in Wardha-Godavari Valley in Maharashtra and Andhra Pradesh and in Mahanadi Valley, Orissa. In the latter area it was earlier known as Hingir Formation. Kamthi Formation is generally considered equivalent to Raniganj-Panchet Formation of Damodar Basin, Bijori Formation of Satpura Basin, Pali Formation of South Rewa Basin and Pachhwara Formation of Rajmahal Basin. In coastal tract of Godavari Graben Kamthi Formation was earlier referred as Chintalpudi sandstone.

The name 'Kamthi' has been used in different sense by different authors in different basins. Initially there was no intention to retain the name. It was thought that evidence might be accumulated soon to identify the rocks as the member of group already established in Damodar Basin (Hughes, 1877, p. 67). On the basis of fossil plants the Kamthi beds were correlated with Damudas while the mineral characters of Kamthi were different with that of both Iron Stone Shales and the Raniganj as this was devoid of iron stone shales and coal both. Thus the name 'Kamthi' continued to exist on account of its characteristic lithological attributes and its age was debated on the basis of palaeobotanical contents till recently. Now

Table 1—Status of Kamthi Formation in Godavari Graben

<table>
<tr><th>King
(1881)</th><th>Sengupta
(1970)</th><th colspan="2">Raja Rao
(1982)</th><th colspan="2">Raiverman <i>et al.</i>
(1985)</th><th colspan="2">Kutty <i>et al.</i>
(1988)</th><th colspan="2">Pandey
(1988)</th><th colspan="3">Ramanamurty & Madhusudan Rao
(1987) (1996)</th><th colspan="2">Jha & Srivastava
(1996)</th></tr>
<tr><td rowspan="7">KAMTHI</td><td rowspan="4">KAMTHI</td><td rowspan="6">KAMTHI</td><td rowspan="2">Upper Member</td><td rowspan="6">KAMTHI</td><td rowspan="2">KUDUREPALLI/ CHINTALPUDI</td><td rowspan="3">KAMTHI</td><td>Upper Member</td><td colspan="2" rowspan="3">KAMTHI</td><td rowspan="3">KAM-THI</td><td rowspan="3">KAMTHI</td><td rowspan="2">Upper Member</td><td rowspan="4">KAMTHI</td><td rowspan="2">Upper Member (= Supra-Panchet/ Mahadeva)</td></tr>
<tr><td>Middle Member</td></tr>
<tr><td rowspan="2">Middle Member</td><td>MANER</td><td>Lower Member</td><td>Lower Member</td><td rowspan="2">Lower Member (= Panchet)</td></tr>
<tr><td>KHANPUR</td><td rowspan="4">INFRA KAMTHI</td><td>Litho-zone-4</td><td rowspan="3">Upper Coal Measures</td><td>Litho-facies-2</td><td rowspan="3">RANIGANJ</td><td colspan="2" rowspan="2">Upper</td></tr>
<tr><td>IRON STONE SHALE</td><td rowspan="2">Lower Member</td><td>JAIPURAM</td><td>Litho-zone-3</td><td rowspan="2">Litho-facies-1</td><td colspan="2" rowspan="2">RANIGANJ</td></tr>
<tr><td rowspan="3">BARAKAR</td><td>POTAMADUGU/ BALHARSHAH</td><td>Litho-zone-2</td><td colspan="2">Lower</td></tr>
<tr><td colspan="2">BARREN MEASURES</td><td rowspan="3">SINGARENI</td><td>BELAMPALLI</td><td>Litho-zone-1</td><td colspan="2">Middle Measures</td><td colspan="5">BARREN MEASURES</td></tr>
<tr><td>BARAKAR</td><td colspan="2">BARAKAR</td><td>BARAKAR</td><td colspan="2">BARAKAR</td><td colspan="2">Lower Coal Measures</td><td colspan="5">BARAKAR</td></tr>
<tr><td>TALCHIR</td><td>TALCHIR</td><td colspan="2">TALCHIR</td><td>TALCHIR</td><td colspan="2">TALCHIR</td><td colspan="2">TALCHIR</td><td colspan="5">TALCHIR</td></tr>
</table>

there is growing necessity for the uniformity in stratigraphic classification and terminology because the informal usage in the past has led to much confusions. An attempt has been made to ellucidate the current status of the Kamthi Formation in view of the lithological, palynological and plant fossil data accumulated during recent years. Before going into the details it is essential to understand the Kamthi in type area (*sensu stricto*) and its relationship in different basins.

STATUS OF KAMTHI FORMATION IN DIFFERENT BASINS

The Kamthi Formation as described by Blanford has been given in introduction. The status of Kamthi Formation in different basins is as follows :

<table>
<tr><th>Wardha</th><th>Kamptee</th><th colspan="2">Godavari</th><th>Mahanadi</th></tr>
<tr><td rowspan="3">KAMTHI</td><td rowspan="3">KAMTHI</td><td rowspan="2">KAMTHI</td><td>Supra Panchet =Mahadeva</td><td rowspan="2">KAMTHI</td></tr>
<tr><td>Panchet</td></tr>
<tr><td colspan="2">RANIGANJ</td><td>RANIGANJ</td></tr>
<tr><td>Motur</td><td>Motur</td><td colspan="2">BARREN MEASURES</td><td>? BARREN MEASURES</td></tr>
</table>

Within the Godavari Graben the stratigraphic status of 'Kamthi' Formation has been interpreted in different ways by different authors (Table 1).

Ramanamurty and Rao (1996) classified the Kamthi sediments (*sensu* Raja Rao, 1982) into Raniganj and Kamthi Formations, the latter divisible into two members. Jha and Srivastava (1996) in their classification considered the Lower Member being equivalent to Panchet Formation and Upper Member being equivalent to Supra-Panchet/Mahadeva Formation.

LITHOLOGICAL SET-UP

The lithological set-up of Kamthi Formation in Godavari Graben is given in Table 2.

Kamthi Formation (Raja Rao, 1982) in Wardha and Kamptee coalfields overlies Motur Formation (=Barren Measures) and underlies Lameta Formation with pronounced unconformity at both the ends.

In Mahanadi Valley the sediments unconformably overlying the Barakar Formation are included within the Kamthi Formation. It consists of fine to medium-grained sandstone, carbonaceous shales, coal bands with greenish sandstone, pink clays and pebbly

Table 2—Lithological set-up of Permian-Triassic sediments in three sub-basins of Godavari Graben. (A) indicates *sensu* Raja Rao (1982), and (B) *sensu* Jha and Srivastava (1996) and Ramanamurty and Madhusudan Rao (1996)

A		B		GODAVARI SUB-BASIN	KOTHAGUDEM SUB-BASIN			CHINTALPUDI SUB-BASIN		
FORMATION	MEMBER	FORMATION	MEMBER	UPPER GONDWANA						
KAMTHI	UPPER	KAMTHI	UPPER	Predominantly ferruginous sandstone with subordinate siltstone and clay bands forming hills ranges	**Kamthi :** Coarse to pebble sandstone and clays. (SCCL, 1982, in Lakshminarayana & Murty, 1990).			**Kamthi :** Congolomeratic sandstone, ferruginous sandstone, siltstone and indurated claystone (Lakshminarayana & Murty, 1990)		
	MIDDLE		LOWER	Red/brown sandy calcareous clay and crossbedded sandstone		Bore Core MKD - 25	Chocolate brown siltstone/sandstone		Bore Core GC - 17	Pinkish, violet and yellow sst. and clay
				Greenish grey to green clay, siltstone intercalated with sandstone, micaceous at places			Greenish grey clay			Greenish grey sst. / siltstone
	LOWER	RANIGANJ		Mg-Cg greyish white sandstone with subordinate shale and coal seams	Unconformity		Mg-Cg greyish white sandstone Grey to black shale and coal seams	Unconformity		Fg-Mg. grey sandstone carbshale and coalseams
				BARREN MEASURES			BARREN MEASURES			BARREN MEASURES

sandstone at the top (Raja Rao, 1982). However, recent investigations through Kamthi Formation in Talcher and Ib-River coalfields have shown a close proximity with that of Godavari Graben and all the three litho-units are recognisable and correlatable (Table 3).

Remarks—The entire sedimentary sequence above the Barren Measures and below the Yerrapalli Formation in Godavari Graben assigned to Kamthi Formation by Raja Rao (1982) is actually divisible into three litho-units : (i) the lowermost unit consists of grey shale, carbonaceous shale, coal and sandstone, (ii) the middle unit comprises greenish-grey shale, clay and sandstone overlain by medium to coarse grained sandstone with pinkish red/brown/purple shales/clays, and (iii) the topmost unit consists of ferruginous sandstone with sub-ordinate siltstone, clay bands and pinkish red to purplish brown and yellow limnoic shales. Recent drillings and previous geological data in Kothagudem and Chintalpudi sub-basins have also shown the presence of three litho-units (Table 2).

Initially the Kamthi Formation (*sensu* Blanford, 1872; Hughes, 1877) was distinguished from Raniganj Formation on the basis of absence of coal or carbonaceous deposits or even carbonaceous markings. Now there are sufficient evidences for the presence of coal seams in lowermost litho-unit in Godavari, Wardha and Mahanadi valleys which exhibit gross lithological similarity with Raniganj Formation of Damodar Valley. The distinct lithological change occurs at the base of the middle unit represented by greenish grey clay, shale and sandstone and is equivalent to the Panchet Formation of Damodar Basin (Table 4). This transition is clearly demonstrated in Mailaram, Budharam areas of Godavari Graben, Bazargaon area of Kamptee Coalfield and Chendipada Block of Talcher Coalfield. The Upper Member of the Kamthi Formation forming prominent ridges in Godavari Graben exhibits

Table 3—Lithological set-up of Permian-Triassic sediments in Wardha, Kamptee and Mahanadi Basins. (A) indicates *sensu* Raja Rao (1982), and (B) *sensu* Jha and Srivastava (1996) and Ramanamurty and Madhusudan Rao (1996)

A		B		WARDHA		KAMPTEE		MAHANADI	
FORMATION	MEMBER	FORMATION	MEMBER						
KAMTHI	UPPER	KAMTHI	UPPER		Pinkish / red / brown variegated sandstone, reddish siltstone and shale	Bore Core DGW - 6	Dark brown ferruginous sandstone, conglomerate lenses, red/brick red and yellow lemnoic shales		Conglomerates, ferruginous sandstone and red shales
	MIDDLE		LOWER	Bore Core MWCK - 2	Red / brown sandy clay, coarse bedded sandstone Greenish grey shale and sandstone		Coarse grained sandstone with blotches and streaks of red and purple shale Greenish grey clay, shale and sandstone	Bore Core TCW-6 & TP-8	Pink clays and pebble sandstone Greenish sandstone clay and shale
	LOWER	RANIGANJ			Fg. sst., grey to black shale, micaceous at place		Grey shale, carb shale sandstone and coal		Fg.-Mg. sandstone, carbonaceous, shale and coal seams

gross lithological similarity with that of "Kamthi Group" described by Blanford (1868) and Hughes (1877) and later on by others, both in adjacent Wardha Valley as well as Mahanadi Basin.

This topmost unit shows lithological similarity to the Supra-Panchet/Mahadeva Formations. Now Subramanian, 1962 (in Raja Rao, 1982) and Chakraborty *et al.*, 1967 (in Raja Rao, 1982) appears to be more correct by classifying the post Barakar sequence in Talcher Coalfield into Raniganj, Panchet and Mahadeva Formations. The palynological data in bore core TCW-6 and TP-8 (Tiwari *et al.*, 1991; Tripathi, 1996) from Talcher Coalfield also shows presence of Raniganj and Panchet palynoflora.

Sah and Shingte (1996) have described the lithological succession in Kamptee Basin in which the litho-unit of Kamthi Formation compares the Upper Member of Kamthi Formation in Godavari Graben. However, they consider it to be Late Permian in age. Brown coloured, ferruginous fine to coarse-grained and gritty sandstone and yellow clay sequence represents the Kamthi Formation (*sensu* Ramanamurty & Madhusudan Rao, 1996; *sensu* Jha & Srivastava, 1996) and should be Triassic in age. However, the subsurface data from bore core DGW-6 (Srivastava & Bhattacharyya, 1996) suggest a complete sequence comparable to that of Godavari Graben. The palynological succession in this bore core also shows resemblance with the palynoflora of Raniganj and Kamthi Formations of Godavari Graben.

Consequent upon the identification of strata equivalent to Raniganj Formation, the sediments overlying the Raniganj Formation and underlying the Yerrapalli Formation in Godavari Graben are therefore, referred to as 'Kamthi Formation'. The lithological setup of Kamthi Formation does not exactly matches with that of Panchet Formation of Damodar Valley, hence the name 'Kamthi' has been retained to represent Early Triassic strata in Wardha-Godavari, Kamptee and Mahanadi Basins.

PALYNOSEQUENCE

A number of bore cores drilled across the Kamthi Formation (sensu Raja Rao, 1982) have been studied palynologically in Godavari (Srivastava & Jha, 1988, 1990, 1992a, 1992b, 1995), Kothagudem and Chintalpudi (Srivastava & Jha, 1993, 1994) sub-

Table 4—Lithostratigraphic status of Kamthi Formation in Godavari Graben

Ramanamurty & Madhusudan Rao	1987	1996		Raja Rao (1982)		Jha & Srivastava (1996)		Lithology
Ferruginous sandstone with subordinate siltstone, claybands forming hill ranges	KAMTHI	KAMTHI	UPPER MEMBER	KAMTHI	UPPER MEMBER (400 m)	KAMTHI	UPPER MEMBER = SUPRA PANCHET/ MAHADEVA (400 m)	Ferruginous sandstone with subordinate siltstone and clay bands
Alternating sequence of red/ brown sandy calcareous clay and coarse bedded sandstone	PANCHET		LOWER MEMBER		MIDDLE MEMBER (1000 m)		LOWER MEMBER = PANCHET FORMATION (500 m)	Red-brown sandy calcareous clays and cross bedded sandstone
Greyish white to greenish grey sandstone, grey shale/clay with carbonaceous matter	RANIGANJ	UPPER						Greenish grey, shale and sandstone
Coarse sandstone with subordinate shales and coal seams		LOWER			LOWER MEMBER (200 m)		= RANIGANJ FORMATION (700 m)	Coarse sandstone, grey shale, clays and coal seam

basins, Wardha Valley, Kamptee Coalfield (Srivastava & Bhattacharyya, 1996) and Mahanadi Valley (Tiwari, Tripathi & Jana, 1991; Tripathi, 1997). The palynoassemblages in different basins have been summarised in Table 5.

Ten distinct palynoassemblages have been recognised in the succession above the Barren Measures and below the Upper Member of Kamthi Formation (*sensu* Jha & Srivastava, 1996). These palynoassemblages can be categorised under two groups; the older group dominated by striate disaccates (assemblages 1-6 from bottom) belongs to Late Permian and is recorded in Raniganj Formation having grey shales, sandstone, carbonaceous shale and coal seams. The younger group having taeniate, non-striate disaccate pollen and cingulate cavate spores (assemblage 7-10) belongs to Early Triassic and is identified in greenish grey shale and sandstone sequence of the Lower Member of Kamthi Formation. Red ferruginous sandstone/siltstone of Upper Member do not yield palynofossils.

No published palynological record from Kamthi Formation of Kothagudem sub-basin exists till date. However, recently dominance of striate disaccates chiefly *Faunipollenites* and *Striatopodocarpites* and low percentage of some stratigraphically significant taxa, viz., *Lunatisporites, Guttulapollenites, Corisaccites, Chordasporites, Weylandites* and *Falcisporites,* indicating Late Permian (Raniganj) affinity, has been recorded in carb shale-coal sequence of bore core MKD-25 from Kothagudem area.

An Early Triassic palynoassemblage containing *Falcisporites* and *Playfordiaspora* alongwith *Goubinispora, Klausipollenites, Lunatisporites, Rajmahalispora, Callialasporites, Densoisporites, Chordasporites, Weylandites, Hamiapollenites, Crescentipollenites* and *Lundbladispora* has been recorded from Krishnavaram area of Chintalpudi sub-basin (Srivastava *et al.*, MS). Similarly in Mahanadi Basin Permian palynoassemblages *(Striatopodocarpites-Faunipollenites* assemblage and *Striatopodocarpites-Densipollenites* assemblage) have been recorded in compact grey shale-coal sequence in bore-core TP-8, Talcher Coalfield (Tripathi, 1996). In this bore core also the Early Triassic palynoassemblage marked by *Striatopodocarpites* + *Lundbladispora* associated with *Playfordiaspora, Lunatisporites, Alisporites, Goubinispora, Densoisporites,*

Table 5—**Permian-Triassic palynoassemblages in Godavari, Wardha, Kamptee and Mahanadi basins. (A) indicates *sensu* Raja Rao (1982), and (B) *sensu* Jha and Srivastava (1996) and Ramanamurty and Madhusudan Rao (1996). Fauni. = *Faunipollenites*; Striatopodo. = *Striatopodocarpites*; Cori. = *Corisaccites*; Guttula. = *Guttulapollenites*; Falci. = *Falcisporites; Striates*= Striate disaccates**

AGE	A	B	ASSEMBLAGE	GODAVARI GRABEN			WARDHA	KAMPTEE	MAHANADI		LITHOLOGY
				GODAVARI	KOTHAGUDEM	CHINTALPUDI			Ib River	Talcher	
E. TRIASSIC	MIDDLE MEMBER	KAMTHI (LOWER)	10. *Lundbladispora* + *Densoisporites*	* * *						*Striatopodocarpites* *Lundbladispora*	Greenish grey clay/shale intercalated in sandstone
			9. *Lunatisporites* + *Verrucosisporites*	* * *						*Striatopodocarpites* *Lunatisporites*	
			8. Striates + *Callumispora*				* * *				
			7. Striates + *Falcisporites* + *Playflordiaspora*			* * *		* * *			
PERMIAN		RANIGANJ	6. *Striatopodocarpites* *Corisaccites* + *Guttulapollenites*	* * *							Grey shale, sandstone, carb. shale and coal seam sequence
			5. *Striatopodocarpites* + *Crescentipollenites*	* * *			* * *	* * *		* * *	
			4. *Striatopodocarpites* *Densipollenites*	* * *	* * *	* * *		* * *		* * *	
	LOWER		3. *Striatopodocarpites* *Parasaccites*	* * *							
			2. *Faunipollenites* *Striasulcites*	* * *	* * *	* * *				Striates + *Gondisporites*	
			1. *Faunipollenites* *Striatopodocarpites*	* * *	* * *	* * *			* * *		

Cyathidites, Concavissimisporites, Foveotriletes, Guttatisporites, Polycingulatisporites has been recorded in greenish sandstone overlying grey shale-coal sequence.

Remarks—The dominance of striate disaccate pollen has been observed in Late Permian palynosequence in other basins in India as well other Gondwana continents. Taeniate, non-striate disaccates and cingulate cavate spores mark the onset of Triassic. This palynofloral transition is clearly observed in Mailaram, Budharam and Krishnavaram areas of Godavari Graben, Bazargaon area of Kamptee Coalfield and in Talcher Coalfield of Mahanadi Basin.

Table 6

Plant Fossils	Area	Horizon/ Lithology	Reference
1. *Vertebraria, Glossopteris* & *Phyllotheca*	Chintalpudi sub-basin	Upper Member of Kamthi Formation siltstone & pinkish or red claystone unit associated with grey and buff sandstone	King (1881), Lakshminarayana & Murty (1990)
2. Fragmentary plant fossils resembling *Ptilophyllum*	Jaipuram	Upper Member pinkish shale/clay	Nageshwar Rao in Raja Rao, (1982)
3. *Alethopteris* spp. and *Pterophyllum* spp.	Godavari	—	Maheshwari (1992)

MEGAFLORAL EVIDENCES

Godavari Graben

Megaflora records from Kamthi Formation of Godavari Graben are very rare and have been summarised in Table 6.

Wardha and Kamptee Coalfields

Bunbury (1861) recorded megafossils from the Kamthi beds from Nagpur area which included *Phyllotheca, Cladophlebis, Pecopteris, Glossopteris, Taeniopteris, Noeggerathia* and *Vertebraria.* Besides, a large number of Permian taxa were reported from similar beds near Chanda (Feistmantel, 1881; Agashe *et al.*, 1984), Nagpur (Hughes, 1877) and Kamptee area (Feistmantel, 1881). Chandra and Prasad (1981) have also recorded plant fossils from hard, compact ferruginous sandstone, buff purple and grey coloured coarse sandstone unit in Kanhargaon in Wardha Valley coalfields and Bazargaon area near Nagpur.

Mahanadi Basin

Ball (1877) first described plant fossils of the Kamthi beds from Mahanadi Basin. Subramanian and Rao (1960), Surange and Maheshwari (1970), Surange and Chandra (1975), and Chandra and Singh (1992) described plant fossils rich in *Glossopteris* from Handapa beds. Khan (1969) described *Senia reticulata* from Hinjrida Ghati section north of Handapa in Talcher Coalfield and treated these beds as equivalent to Raniganj Formation.

Pal *et al.* (1991) have recorded *Lepidopteris* and *Dicroidium* in addition to *Glossopteris* and *Neomariopteris* from Sarimunda Hill and a *Dicroidium* rich flora along with *Lepidopteris, Yabiella, Desmiophyllum* from locality near Pathargarh in Talcher Coalfield. They considered these beds equivalent to the Upper Member of Kamthi Formation and assigned Late Triassic age. *Dicroidium* is also reported from Talcher Coalfield (Coal Wing News 9(1) : 24) and Ib-River Coalfield (Mukhopadhyay & Paul, 1989; Chowdhury *et al.*, 1991) in pale brown shale band and red claystone and shale bed at the top of Kamthi successions. *Podozamites* associated with *Schizoneura gondwanensis* and *Phyllotheca* is recorded in red claystone bed of Kamthi Formation around Punjipathra area in Raigarh Coalfield (Chakraborty & Sengupta, 1995).

Remarks—It is usually considered that Glossopteris flora is an important age (Permian) indicator for the essentially nonmarine Lower Gondwana sequence. In view of the presence of *Glossopteris, Phyllotheca* and *Vertebraria*, etc., the Kamthi Formation was assigned to Late Permian in age. However, *Glossopteris* species continue to occur in Triassic also. The presence of *Glossopteris* along with *Lepidopteris* and *Dicroidium* has been recorded from equivalent beds near Sarimunda Hills close to Handapa (Pal *et al.*, 1991), and dated as Triassic. *Glossopteris angustifolia, G. browniana, G. communis, G. gopadensis, G. nidpurensis, G. retifera*, are known from Triassic sediments also. So the presence of Glossopteris in Kamthi Formation (Early Triassic) shows only the continuation of Permian flora into the Triassic. *Glossopteris* has also been recorded from Mahadevas of Auranga Coalfield (Ball, 1880), from Upper Member of Kamthi Formation in Godavari Graben (King 1881; Lakshminarayana & Murty, 1990), in Kamthi area (Feistmantel, 1881); and in Wardha Valley (Chandra & Prasad, 1981). In Mangli beds of Wardha Valley *Glossopteris* occurs along with *Estheria* (Tasch *et al.*, 1975). *Handapa* beds which are lithologically similar to Upper Member of Kamthi Formation contain a rich Glossopteris flora. About 50 per cent of the *Glossopteris* species known from Triassic of India are recorded in Handapa beds.

Dicroidium odontopteroides, D. dubium, D. dubium var. *hingiriensis* recorded from pale brown shale band (Chowdhury *et al.*, 1991), *Dicroidium* sp. (Pal *et al.*, 1991) in Talchir Coalfield and *Dicroidium* sp. from red claystone, shale bed of Upper Member of Kamthi Formation in Ib-River (Mukhopadhyay & Pal, 1989) suggest Early Triassic age for these beds.

The Kamthi sediments from clay quarries near Bazargaon (Chandra & Prasad, 1981; Kulkarni & Parmane, 1991) having plant fossils in all probability belong to the Upper Member of the Kamthi Formation. The authors have assigned Late Permian age to Kamthi sediments on the basis of plant fossil assemblage but in view of the order of superposition the Kamthi Formation is considered to represent Early Triassic.

DISCUSSION

The status of the Kamthi Formation has been debated ever since on the basis of the fossil contents and its age was considered to be Permian/ Triassic or Permian-Triassic.

Recent studies mainly from the sub-surface have allowed to classify the Kamthi Group of King, into Barren Measures (450 ± 50 m), Raniganj Formation (650 ± 50 m) and Kamthi Formation (Lower Member 500-600 m and Upper Member 450 ± 50 m), in order of superposition (Ramanamurthy & Madhusudan Rao, 1996). This classification is largely based on lithological characteristics and mineral contents. It has been further modified through palynological studies and minor readjustment in the thickness of Lower Member has been suggested (Srivastava & Jha 1996). In sub-surface studies these sequences have been identified in bore hole GAM-7 from Mailaram area, bore-hole GBR-7 from Budharam area in Godavari Graben, bore-hole DGW-6 from Bazargaon near Nagpur, bore-hole MWCK-2 in Wardha Basin and bore-hole TCW-6 in Talchir Coalfield.

The Lower Member of Kamthi sediments (*sensu* Jha & Srivastava, 1996) in the above mentioned bore cores have revealed the presence of Panchet equivalent palynoflora. This sequence represents the Early Triassic (=Scythian) in Wardha-Godavari (Jha & Srivastava, 1996); Kamptee (Srivastava & Bhattacharyya, 1996) and Mahanadi basins (Tripathi, 1996).

The Upper Member of the Kamthi Formation in Godavari Graben compares closely with the rocks exposed in the type area near Kamthi. This member often gives rise to prominent topographic features in Wardha-Godavari and Mahanadi basins and shows overlapping nature with the underlying beds. This unit lithologically fits with the "Kamthi" strata often described by earlier workers like Blanford, Hughes and King.

The plant fossils described so far from Wardha Valley (Bunbury, 1861), Bazargaon area (Chandra & Prasad, 1981), Mahanadi (Chandra & Singh, 1992; Pal *et al.*, 1991) belong to this Upper Member of the Kamthi Formation.

It is very much desirable that similar such bore-holes are required to be drilled at shallower depths on the margin of Kamthi ridge in east of Jaipuram and west of Bhimaram Village in Godavari Graben and also east of Handapa or Madhupur in Talcher Coalfield in order to solve the stratigraphic status of the Kamthi Formation.

REFERENCES

Agashe SN, Gowda, PRN, Suresh FC & Geetha KR 1984. Recent advances in the palaeobotanical studies on Lower Gondwana strata of Chandrapur District, Maharashtra. *In*: Sharma AK *et. al* (Editors)—*Proc. Symp. Evolutionary botany and biostratigraphy, Calcutta 1979, A.K. Ghosh Commen. Vol., Curr. Trends Life Sci.* : 369-382.

Ball V 1877. On the geology of Mahanadi Basin and its vicinity. *Rec. geol. Surv. India* **10**(4) : 167-185.

Ball V 1880. On the Auranga and Hutar Coalfields and the iron ores of Palamow and Toree. *Mem. geol. Surv. India* **15**(1) : 1-127.

Blanford WT 1868. Coal near Nagpur. *Rec. geol. Surv. India* **22**(2) : 23-54.

Blanford WT 1872. On the description of geology of Nagpur and its neighbourhood. *Mem. geol. Surv. India* **9**(2) : 295-358.

Bunbury CJF 1861. Notes on a collection of fossil plants from Nagpur, central India. *Q. Jl geol. Soc. London* **17** : 325-346.

Chakraborty B & Sengupta S 1995. New fossil find. *Coal Wing News* **14**(2) & **15**(1) : 24.

Chakraborty SN, Das SN & Banerjee SP 1967. Final report on investigation by drilling in the central part of Talcher Coalfield, Orissa. *Unpublished Report. Geological Survey of India. In*: Raja Rao 1982.

Chandra S & Prasad MNV 1981. Fossil plants from the Kamthi Formation of Maharashtra and their biostratigraphic significance. *Palaeobotanist* **28-29** : 99-121.

Chandra S & Singh KJ 1992. The genus *Glossopteris* from the Late Permian beds of Handapa, Orissa, India. *Rev. Palaeobot. Palynol.* **75** : 183-218.

Chowdhury PN, Bose S & Pal AK 1991. A Middle Triassic age for the Kamthi Formation of Lower Gondwana, Ib River Basin, Orissa : New Palaeobotanical evidence. *Coal Wing News* **11**(1) : 12.

Feistmantel O 1881. The fossil flora of the Gondwana System. The flora of the Damuda and Panchet divisions. *Mem. geol. Surv. India Palaeont. indica*, ser. **12**(3): 1-149.

Hughes TWH 1877. The Wardha Valley coalfields. *Mem. geol. Surv. India* **13**(1) : 1-154.

Jha N & Srivastava SC 1996. Kamthi Formation - Palynofloral diversity. In : Guha PK *et al.* (Editors)—*Gondwana Nine* **1** : 355-368. Hindustan Publ. Co., New Delhi.

Khan AM 1969. *Senia reticulata*, a new plant fossil from the Raniganj rocks of the Talcher Coalfield, Orissa, India. *In* : Santapau H *et al.* (Editors)—*J. Sen Mem. Vol.* : 335-337. Bot. Soc. Bengal, Calcutta.

King W 1881. The geology of Pranhita-Godavari Valley. *Mem. geol Surv. India* **18**(3) : 150-311.

Kulkarni KM & Parmane PV 1991. Two pteridophytic fronds from Kamthi Formation, Bazargaon, district Nagpur, Maharashtra, India. *Birbal Sahni Birth Centenary Palaeobotanical Conference, Lucknow* : 72 (Abstract).

Kutty TS, Jain SL & Roy Chowdhury T 1988. Gondwana sequence of the northern Pranhita Godavari Valley: its stratigraphy and vertebrate faunas. *In* : Venkatachala BS & Maheshwari HK (Editors)—*Concepts, limits and extension of Indian Gondwana. Palaeobotanist* **36** : 214-229

Lakshminarayana G & Murty KS 1990. Stratigraphy of the Gondwana formations in the Chintalpudi sub-basin, Godavari Valley, Andhra Pradesh. *J. geol. Soc. India* **36**(1) : 13-25.

Maheshwari HK 1992. Provincialism in Gondwana floras. *Palaeobotanist* **40**: 101-127.

Mukhopadhyay SK & Pal AK 1989. Records of *Dicroidium* sp. from Ib-River and ichnofossils from South Karanpura, Auranga and Raniganj basins. *Coal Wing News* **9**(2) : 8.

Pal PK, Chakraborty U, Ghosh AK & Ghosh A 1991. Triassic plant megafossils from the Kamthi Formation of Talchir Coalfield, India—a new report. *Indian J. Geol.* **63**(2) : 119-125.

Pandey BC 1988. Kamthi—a new concept. *In* : Venkatachala BS & Maheshwari HK (Editors)—*Concepts, limits and extension of Indian Gondwana. Palaeobotanist* **36** : 51-57.

Raja Rao CS 1982. Coalfields of India-2. Coal resources of Tamil Nadu, Andhra Pradesh, Orissa and Maharashtra. *Geol. Surv. India. Bull.* ser. A **45** : 9-40.

Ramanamurty BV & Madhusudan Rao C 1987. A new classification of Lower Gondwana (Permian) lithostratigraphy of Ramagundam area, Godavari Valley Coalfield, Andhra Pradesh. *In* : Singh RM (Editor)—*Proc. Nat. Sem. Coal Resources India 1986* : 112-120. Banaras Hindu University, Varanasi.

Ramanamurty BV & Madhusudan Rao C 1996. A new lithostratigraphic classification of Permian (Lower Gondwana) succession of Pranhita - Godavari Basin with special reference to Ramagundam coalbelt, Andhra Pradesh, India.*In* : Guha PK *et al.* (Editors)—*Gondwana Nine.* **1** : 67-78. Hindustan Publ. Co., New Delhi.

Sah R & Shingte SK 1996. Depositional history of Kamptee Basin, northern part of Pranhita-Godavari Valley Graben, Maharashtra, India. *In* : Guha PK et al. (Editors)-*Gondwana Nine.***1** : 723-735. Hindustan Publ. Co., New Delhi.

Sengupta S 1970. Gondwana sedimentation around Bheemaram (Bhimaram), Pranhita-Godavari Valley, India. *J. Sed. Petrol.* **40** : 140-170.

Srivastava SC & Bhattacharyya AP 1996. Permian-Triassic palynofloral succession in sub-surface from Bazargaon, Nagpur District, Maharashtra. *Palaeobotanist* **43**(2) : 10-15.

Srivastava SC, De B, Jha N & Ganguli B (MS). "A Triassic palynoflora from Krishnavaram Area, Chintalpudi sub-basin". *In* : *National Seminar on recent advances in geology of coal and lignite basins of India,* at G.S.I. Calcutta, November, 1997.

Srivastava SC & Jha N 1988. Palynology of Kamthi Formation in Godavari Graben. *In* : Venkatachala BS & Maheshwari HK (Editors)—*Concepts, limits and extension of Indian Gondwana. Palaeobotanist* **36** : 123-132.

Srivastava SC & Jha N 1990. Permian-Triassic palynofloral transition in Godavari Graben, Andhra Pradesh. *In* : Jain KP & Tiwari RS (Editors)—*Vistas in Indian palaeobotany. Palaeobotanist* **38** : 92-97.

Srivastava SC & Jha N 1992a. Permian palynostratigraphy in Ramakrishna puram area, Godavari Graben, Andhra Pradesh, India. *Geophytology* **20**(2) : 83-95.

Srivastava SC & Jha N 1992b. Palynostratigraphy of Permian sediments in Manuguru area, Godavari Graben, Andhra Pradesh. *Geophytology* **22** : 103-110.

Srivastava SC & Jha N 1993. Palynostratigraphy of Lower Gondwana sediments in Chintalpudi sub-basin, Godavari Graben, Andhra Pradesh, India. *Geophytology* **23**(1) : 93-98.

Srivastava SC & Jha N 1994. Palynological dating of Lower Gondwana sediments in Sattupalli area, Chintalpudi sub-basin, Andhra Pradesh, India, *Palaeobotanist* **42**(2) : 169-173

Srivastava SC & Jha N 1995. Palynostratigraphy and correlation of Permian-Triassic sediment in Budharam area, Godavari Graben, India. *J. geol. Soc. India* **46** : 647-653.

Subramanian KS 1962. Progress Report on the geological mapping of the Talchir Coalfield, Orissa. *Unpublished report,* Geological Survey of India. *In* : Raja Rao (1982).

Subramanian KS & Rao CN 1960. *Glossopteris* from Mahadevas of Hingrida, Talcher Coalfield, Orissa. *Proc. 47th Indian Sci. Congr. Bombay* part 3 (Abstract) : 278.

Surange KR & Chandra S 1975. Morphology of the gymnospermous fructifications of the Glossopteris flora and their relationship. *Palaeontographica* **B149** : 153-180.

Surange KR & Maheshwari HK 1970. Some male and female fructifications of Glossopteridales from India. *Palaeontographica* **B129** : 178-192.

Tasch P, Sastry MVA, Ghosh SC, Rao BRJ, Rao CN & Shah SC 1975. Indian Gondwana Estheriids and significance of continental fit. *In* : Campbell KSW (Editor)—*Gondwana, Geology 3rd Int. Symp. Gondw. Stratigr.* : 443-452. Canberra, Australia.

Tiwari RS, Tripathi A & Jana BN 1991. Palynological evidence for Upper Permian Raniganj coals in western part of Talcher Coalfield, Orissa, India. *Curr. Sci.* **61**(6) : 407-420.

Tripathi A 1996. Early and Late Triassic palynoassemblage from subsurface Supra-Barakar sequence in Talcher Coalfield, Orissa, India. *Geophytology* **26**(1) : 109-118.

Floral change across the Permian-Triassic Boundary in Damodar and Auranga Valleys

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Banerji Jayasri 1997. Floral change across the Permian-Triassic Boundary in Damodar and Auranga Valleys. *Palaeobotanist* **46**: (1,2) : 97-100.

Megafloral change across the Permian-Triassic boundary is distinct but not very abrupt. The general composition of the flora is more or less similar in the Upper Permian-Lower Triassic time slice except for the appearance of a few significant taxa in the Lower Triassic, such as, *Lepidopteris* and *Dicroidium*. The size of *Glossopteris* leaves becomes smaller in the Panchet beds. *Dicroidium* appeared a little later than *Lepidopteris* in the uppermost part of Lower Triassic. Palynological studies of Panchet beds (Maitur Formation) indicate that striate disaccate rich mioflora gradually declines accompanied by the emergence of some new elements like—*Decisporis*, *Verrucosisporites*, *Playfordiaspora* and *Arcuatipollenites (Lunatisporites)*. The megaspores — *Banksisporites*, *Maiturisporites* and *Pantiella* are confined to Panchet Formation only.

Key-words—Megaflora, Palynology, Permian-Triassic transition, India.

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सारॉंश

दामोदर एवं औरंगा घाटियों में परमियन-ट्रायॅसिक सीमा पर वनस्पतिजातीय परिवर्तन

जयश्री बैनर्जी

परमियन-ट्रायॅसिक सीमा पर गुरुवनस्पतिजातीय परिवर्तन स्पष्ट है परन्तु आकस्मिक नहीं है। अधरि ट्रायॅसिक काल में कुछ विशेष वर्गकों जैसे *लेपिडॉप्टेरिस* एवं *डाइक्रोयडियम्* के प्रादुर्भाव को छोड़कर उपरि परमियन-अधरि ट्रायॅसिक काल में वनस्पतिजात की संरचना लगभग एक जैसी ही है। पंचेत संस्तरों में *ग्लॉसॉप्टेरिस* की पत्तियाँ आकार में छोटी पाई गई हैं। अधरि ट्रायॅसिक काल के ऊपरी भाग में *लेपिडॉप्टेरिस* की अपेक्षा *डाइक्रोयडियम* कुछ बाद में विकसित हुआ। पंचेत संस्तरों के परागाणविक अध्ययन से प्रदर्शित होता है कि रेखीय द्विकोष्ठीय सूक्ष्मवनस्पतिजात धीरे-धीरे कम हो गया तथा कुछ नये अवयवों *डेसिस्पोरिस*, *वेरुकॉसिस्पोराइटिस*, *प्लेफोर्डियास्पोरा* एवं *आर्कुएटीपोलिनाइटिस* का प्रादुर्भाव हुआ है। पंचेत शैल-समूह में केवल *बैंकसिस्पोराइटिस*, *मैटुरिस्पोराइटिस* एवं *पन्तियॅल्ला* नामक गुरुबीजाणु मिलते हैं।

FLORISTIC CHANGE ACROSS P/T BOUNDARY

Damodar Valley (Raniganj Basin)

THE Raniganj Basin is one of the significant Gondwana basins of India, which contains plant mega- and micro-remains of Early Permian to Late Triassic age. The generalised stratigraphic sequence in the Raniganj Basin is as folllows :

	Formation
	Supra Panchet
Triassic	----------------Unconformity--------------------
	Panchet
	----------------Unconformity---------------------
	Raniganj
Permian	Kulti
	Barakar
	Talchir
	---------------Unconformity----------------
Precambrian	

In the Raniganj Basin, the Permian-Triassic boundary is usually recognised on the basis of lithological changes between Raniganj and Panchet Formations which are best exposed in Nonia Nala section in the vicinity of Asansol and southwards across the Damodar River, and at Junut, north of Damodar River. The Raniganj Formation is usually characterised by alternating sequence of sandstones, shales and coal seams which is overlain conformably by the Panchet Formation. The contact between the two formations is marked at places by a minor angular unconformity. The Panchet Formation is characterised by a thick sequence of yellow or buff to khaki-green medium to coarse-grained sandstone with cross-stratification, greenish shales and sandstones. There is a distinct change between the lower Panchet (Maitur Formation) and the upper Panchet (Hirapur Formation). The upper Panchet is characterised by the appearance of red clay bands while the lower beds (Maitur Formation) comprise thick khaki-green silty shale and greenish-brown mudstone (Gee, 1930). The Raniganj-Panchet boundary in the Raniganj Coalfield is represented by a minor unconformity above the fossil wood sandstone of Kumarpur. The only criterion to fix the boundary between Raniganj and Panchet is the presence or absence of calcareous material in them; the Panchet is completely devoid of carbonaceous matter. Fresh water *Estheria mangaliensis* is common in the Panchet Formation and hence faunistically, the Raniganj-Panchet boundary may be fixed below the first occurrence of *Estheria*.

Plant megafossils of the Panchet Formation are known from a locality near Maitur Village (Feistmantel, 1880). The assemblage includes *Schizoneura gondwanensis, Vertebraria indica, Pecopteris concinna, Cyclopteris pachyrachis, Glossopteris angustifolia, G. communis, G. conspicua, G. indica, G. intermedia, G. browniana, G. linearis* and *G. retifera*. Banerji and Bose (1977) described some plant remains from north-western branch of Nonia Nala, east of Kumarpur and northern branch of Nonia Nala near 'Indigo' factory road bridge near Asansol. This assemblage includes *Schizoneura gondwanensis, Glossopteris browniana, G. angustifolia, G.* sp. cf. *G. intermedia, Macrotaeniopteris* sp., ? *Dicroidium/Lepidopteris* sp., *Podozamites* sp. cf. *P. lanceolatus, Cordaicarpus* sp. and ? *Lepidopteris*.

The Panchet megaflora has more or less same forms as found in the Raniganj megaflora, except for the presence of *Pecopteris concinna, Cyclopteris pachyrachis, Podozamites* sp. and ?*Dicroidium/Lepidopteris* sp. Thus there is no clear cut distinction between the Raniganj and Panchet assemblages at the level where the lithostratigraphical boundary lies. The Panchet flora is comparatively scarce and the new forms appear slightly late in the Maitur Formation.

Extensive palynological studies have been carried out on Panchet Group of Raniganj Coalfield. Srivastava and Pawde (1962) studied bore-hole R.O. 1 (B) in Ondal area of West Bengal. In their range table it is observed that there is a sudden and significant change in the mioflora at 3.49 metre depth. It indicates an appreciable gap in sedimentation and this confirms the view of Gee (1932) that in this area the rocks of Upper Raniganj directly underlie the strata of Upper Panchet and Maitur Formation is missing here. Kar (1970) described a miofloral assemblage from greenish-grey shales of the Panchet Group in bore-hole No. RE9. The assemblage includes 80 per cent trilete spores with dominance of *Decisporis* and *Divaripunctites*; disaccates are comparatively less. Sarbadhikari (1972) investigated a mioflora from Panchet Formation in the Laudoha bore-hole RE-1. The assemblage is dominated by trilete spores which is in contrast to the striate-disaccate rich Raniganj mioflora. Satsangi, Chandra and Singh (1972) studied the miofloral assemblage from khaki-green shales overlying the Raniganj Formation showing dominance of bisaccate pollen. Maheshwari and Banerji (1975) investigated the palynomorphs from the Maitur Formation exposed in Nonia Nala, east of Kumarpur. According to them the bed above the Raniganj-Panchet contact has abundance of striate bisaccate pollen as in the underlying Raniganj beds. In the beds further above the contact, the number of trilete forms gradually increases and striate bisaccate pollen decrease in frequency. The significant taxa of Maitur Formation are—*Verrucosisporites, Decisporis, Playfordiaspora* and *Arcuatipollenites (Lunatisporites)*. The characteristic forms of Raniganj Formation, viz., *Indospora, Gondisporites, Microbaculispora, Microfoveolatispora* and *Vittatina*, etc. are absent.

The miofloral assemblage from Maitur Formation exposed on the northern bank of the Damodar River near the village Junut (Banerji & Maheshwari, 1977) is very much similar to Lower Triassic assemblage of Nonia Nala. Here, the boundary between the Raniganj and Maitur Formations is marked by a small unconformity which occurs immediately above the fossil wood horizon. Plant remains are rare and unidentifiable.

Tiwari and Rana (1981) studied the *sporae dispersae* of some Lower and Middle Triassic sediments from Damodar Basin and observed that there was a gradual but definite change in the miofloral pattern from Permian through Triassic sediments in India. Miofloral study carried out by Singh and Tiwari (1982) from bore-hole RAD-2, East Raniganj Coalfield shows a quick and sharp change in spore-pollen spectrum at the Permian-Triassic boundary which indicates a probable gap in the deposition in this region.

There is a definite but insignificant miofloral change above the Raniganj-Panchet boundary in Raniganj Coalfield, but whether this change took place in the Late Palaeozoic or at the Permian-Triassic boundary is still not clearly known. Singh and Shah (1971) and Maheshwari (1974) suggested that if the Permian-Triassic boundary in India is taken as fixed on lithological evidence, then the flora of the Upper Permian and Lower Triassic is very similar except some minor differences. On the other hand, if the boundary is considered on the floral contents alone, it should be extended into the Maitur Formation. Thus, it may be concluded that there is a definite, though insignificant miofloral change at the Raniganj-Maitur boundary, but whether this change took place in the Late Palaeozoic or at the Permian-Triassic boundary is still a question to solve.

Tiwari and Singh (1986) suggested that Permian-Triassic boundary should be in between the *Striatopodocarpites-Crescentipollenites* zone and *Striatopodocarpites-Klausipollenites* cf. *Lunatisporites* zone. The palynological boundary is thus the shale-sandstone unit while the lithological boundary is at the top of the sandstone bed. Further, Vijaya and Tiwari (1987) have tried to demarcate the Permian-Triassic boundary in Raniganj Coalfield on the basis of selected palynofossils at specific level.

Megaspore assemblage described by Maheshwari and Banerji (1975) from Maitur Formation exposed at Nonia Nala includes several species belonging to eight genera. The characteristic genera, viz., of Maitur Formation are *Banksisporites, Pantiella* and *Maiturisporites*. Four genera, viz., *Biharisporites, Jhariatriletes, Srivastavaesporites* and *Talchirella* are also found in the older formations but the species of these genera, viz., in the Maitur Formation are new. Two genera, viz., *Maiturisporites* and *Pantiella* are also new, whereas, the other two genera—*Banksisporites* and *Nathorstisporites* are known from the Mesozoic rocks.

Auranga Valley

The Auranga Coalfield is the largest and complicated coalfield of Palamau District of Bihar. The sedimentary sequence in the coalfield is as follows (Rizvi, 1972):

Mahadeva Series
Triassic -------------Erosional break-------------
Panchet Series
-------------Erosional break-------------
Raniganj Series
------------- Erosional break--------------
Permian Barakar Series
-------------- Erosional break-------------
Talchir Series
-------------unconformity-------------
Archaean

The Raniganj and Panchet rocks are mostly conformable and the transition from Raniganj to Panchet is not well marked and the boundary consequently is arbitrary (Ball, 1878, p. 83) The Panchet Formation comprises alternating bands of coarse grained highly feldspathic sandstone and white to yellowish green sandy shales with rare calcareous and ferruginous lenses. Some of the thin micaceous shaly sandstones resemble the *Estheria* beds of the Raniganj Coalfield. Ball (1878) reported some plant fossils from rocks occurring on the northern face of the Latehar Hill. Feistmantel (1886) believed that it represents his 'Transitional beds' probably homotaxial with the 'Parsora Stage' of the South Rewa Basin. He recorded several taxa, viz., *Schizoneura gondwanensis, Vertebraria indica, Glossopteris communis, G. damudica, G. indica, Gangamopteris* sp., scales and winged seeds from these rocks. Bhattacharyya (1963) recorded a megafloral assemblage from the Panchet sediments exposed near Deobar. The forms include *Gangamopteris cyclopteroides, Rhipidopsis densinervis, Trizygia speciosa* and *Dicroidium sahnii.* Bose (1974) remarked that probably this assemblage is a mixed assemblage and needs restudy. Later, Bose and Banerji (1976) described megafossils, viz., *Trizygia speciosa, Schizoneura gondwanensis, Glossopteris angustifolia, G. communis, G. indica, Vertebraria indica,* ? *Noeggerathiopsis* sp. and *Dicroidium* sp. from Deobar. In addition to these, a few detached pinnules with cuticle like *Lepidopteris* have been described from Sukri River near Tubed. Nandi (1992) has confirmed the occurrence of *Lepidopteris* in Panchet Formation of Auranga Coalfield, Bihar.

The palynological assemblage from the Panchet rocks exposed in the Sukri River near Kaima on the whole is dominated by striate bisaccate pollen, non-striate bisaccate pollen and the pteridophytic spores share nearly equal percentage (Banerji & Maheshwari, 1975). The characteristic forms are *Punctatisporites, Decisporis, Verrucosisporites, Playfordiaspora, Gondwanipollenites, Protohaploxypinus, Arcuatipollenites (Lunatisporites), Striatites, Rhizomaspora, Alisporites, Klausipollenites* and *Falcisporites* which are similar to Maitur Formation palynomorphs of Lower Triassic age.

CONCLUSION

On the basis of above studies it has been suggested that lithologically the basal limit of the Maitur Formation (Lower Panchet) is demarcated by the occurrence of undecomposed feldspar and absence of carbonaceous streaks. Faunistically the Raniganj-Panchet boundary vs. Permo-Triassic boundary, atleast in the Raniganj Coalfield is marked below the *Estheria* horizon. Megafloristically, *Glossopteris* starts declining in frequency, new elements, viz., *Lepidopteris* and *Dicroidium* start appearing a little late so the boundary may extend into the Panchet and the flora changes gradually in the upper part of Early Triassic across the lithological P/T boundary. Miofloristically the dominance of striate bisaccate assemblage shows gradual decline and later it is replaced by trilete *(Lundbladispora, Decisporis)*, monosaccate (*Playfordiaspora*), non-striate disaccate (*Alisporites, Falcisporites, Arcuatipollenites* and taeniate forms *(Lunatisporites)*.

REFERENCES

Ball V 1878. On the Auranga and Hutar coalfields and the Iron ores of Palamau and Toree. *Mem. geol. Surv. India* **15**(1) : 55-90.

Banerji Jayasri & Bose MN 1977. Some Lower Triassic plant remains from Asansol region, India. *Palaeobotanist* **24** : 202-210.

Banerji Jayasri & Maheshwari HK 1974. Palynology of the Panchet Group exposed in the Nonia Nala, near Asansol, West Bengal. *Palaeobotanist* **21** : 368-372.

Banerji Jayasri & Maheshwari HK 1975. Palynomorphs from the Panchet Group exposed in Sukri River, Auranga Coalfield, Bihar. *Palaeobotanist* **22** : 158-170.

Banerji Jayasri & Maheshwari HK 1977. A mioflorule from Maitur Formation near Junut, West Bengal. *Palaeobotanist* **24** : 146-148.

Bhattacharyya AK 1963. The assemblage of mega plant fossil from the Lower Gondwana rocks of the western part of the Auranga Valley Coalfield, Palamau District, Bihar. *Q. Jl geol. Min. metall. Soc. India* **35**(2) : 123-128.

Bose MN 1974. Triassic flora. *In* : Surange KR, Lakhanpal RN & Bharadwaj DC (Editors)—*Aspect and appraisal of Indian Palaeobotany* : 285-293. Birbal Sahni Institute of Palaeobotany, Lucknow.

Bose MN & Banerji Jayasri 1976. Some fragmentary plant remains from the Lower Triassic of Auranga Valley, district Palamau. *Palaeobotanist* **23** : 139-144.

Feistmantel O 1880. The fossil flora of the Gondwana System- II. The flora of the Damuda and Panchet divisions. *Mem. geol. Surv. India Palaeont. indica* ser.12 **3**(2) : 1-77.

Feistmantel O 1886. The fossil flora of the Gondwana System-2. The fossil flora of some of the coalfields in western Bengal. *Mem. geol. Surv. India Palaeont. indica* ser. 12 **4**(2) : 1-71.

Gee ER 1930. New fossil localities within the Panchet series of the Raniganj Coalfield. *Rec. geol. Surv. India* **63** : 205-207.

Gee ER 1932. The geology and coal resources of the Raniganj Coalfield. *Mem. geol. Surv. India* **61** : 1-343.

Kar RK 1970a. Sporae dispersae from Panchet (Lower Triassic) in the bore-core No. RE9 Raniganj Coalfield, West Bengal. *Palaeobotanist* **18** : 50-62.

Maheshwari HK 1974. Raniganj-Panchet Boundary. *In* : Surange KR, Lakhanpal RN & Bharadwaj DC (Editors)—*Aspects and appraisal of Indian Palaeobotany*: 408-420. Birbal Sahni Institute of Palaeobotany, Lucknow.

Maheshwari HK & Banerji Jayasri 1975. Lower Triassic palynomorphs from the Maitur Formation, West Bengal, India. *Palaeontographica* **B152** : 149-190.

Nandi A 1992. New find of *Lepidopteris* in Panchet Formation of Gondwana sequence from Auranga Coalfield, Bihar. *Indian Min.* **2** : 165-166.

Rizvi SRA 1972. Geology and sedimentation trends in Palamau Coalfield, Bihar, India. *Mem. geol. Surv. India* **104** : 1-108.

Sarbadhikari TR 1972. Gondwana miospores from a bore-hole in the Raniganj Coalfield, India. *Bull. geol. Min. metall. Soc. India* **45** : 1-26.

Satsangi PP, Chandra A & Singh G 1972. Sporological analysis of Panchet Series, Raniganj Coalfield and its bearing on Permo-Triassic transition. *Rec. geol. Surv. India* **99**(2) : 101-108.

Singh G & Shah SC 1971. Lower Gondwana palynology and related stratigraphic problems. *Abst. Seminar Palaeopalynol. Indian Stratigr. Calcutta 1971* : 17.

Singh V & Tiwari RS 1982. Pattern of miofloras through Permo-Triassic transition in bore-hole RAD-2, East Raniganj Coalfield, W. Bengal. *Geophytology* **12** : 181-186.

Srivastava RN & Pawde MB 1962. Palynological study of bore hole R.O. 1(B), Ondal, West Bengal. *Rec. geol. Surv. India* **91**(2) : 269-384.

Tiwari RS & Rana V 1981. Sporae dispersae of some Lower and Middle Triassic sediments from Damodar Basin, India. *Palaeobotanist* **27** : 190-220.

Tiwari RS & Singh V 1986. Palynological evidence for Permo-Triassic boundary in Raniganj Coalfield, Damodar Basin, India. *Bull. geol. Min. metall. Soc. India* **54** : 256-264.

Vijaya & Tiwari RS 1987. Role of spore pollen species in demarcating the Permo-Triassic boundary in Raniganj Coalfield, West Bengal. *Palaeobotanist* **35** : 242-248.

Palynological evidence for the Permian-Triassic Boundary in Sohagpur Coalfield, India

Ram-Awatar

Ram-Awatar 1997. Palynological evidence for the Permian-Triassic Boundary in Sohagpur Coalfield, India. *Palaeobotanist* **46** (1,2) : 101-106.

Palynological analysis of the Upper Pali sediments exposed along the Chundi River Section has been discussed. The palynotaxa recovered from the above sediments reveal the presence of non-striate disaccate pollen in dominance along with the striate disaccate pollen. Besides, the other significant taxa recorded in the assemblage are—*Goubinispora, Playfordiaspora, Densoisporites, Lundbladispora, Nidipollenites, Satsangisaccites, Brachysaccus, Foveosporites, Staurosaccites, Todisporites, Converrucosisporites* and *Kamthisaccites*. The overall palynoassemblages (I, II) decipher that the sediments of Chundi River Section have been deposited during Late Permian to Early-Middle Triassic period. Correlation of the palynofloral assemblages suggests that the sediments of the Chundi River Section lie between Nidpur bed and Tiki Formation of the South Rewa Basin.

Key-words—Palynology, Permian-Triassic Boundary, Sohagpur Coalfield, Gondwana, India.

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सारांश

सोहागपुर कोयला-क्षेत्र में परमियन-ट्रायेसिक सीमा के परागाणविक प्रमाण

राम अवतार

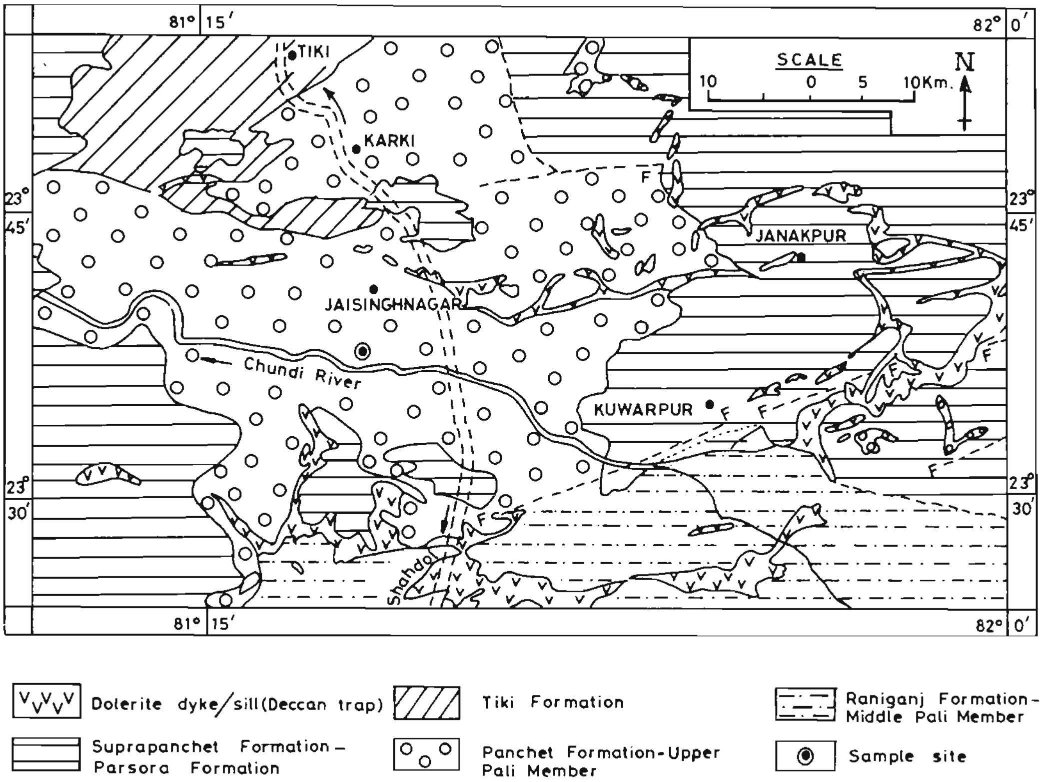
चंडी नदी खंड के संग-संग अनावरित उपरि पाली अवसादों के परागाणविक विश्लेषण से प्राप्त समुच्चय में अरेखीय द्विकोष्ठीय एवं रेखीय द्विकोष्ठीय परागकण उपलब्ध हुए हैं जिनमें अरेखीय द्विकोष्ठीयों की बाहुल्यता है। इसके अतिरिक्त *गाउबिनिस्पोरा, प्लेफोर्डियास्पोरा, डेन्सोस्पोराइटिस, लुन्ब्लाडिस्पोरा, निदिपोलिनाइटिस, सत्संगीसेक्काइटिस, ब्रेकिसेक्कस, फोवियोस्पोराइटिस, स्टोरोसेक्काइटिस, टोडिस्पोराइटिस* आदि विशिष्ट वर्गक भी समुच्चय में मिलते हैं। ऐसा प्रस्तावित किया गया है कि चंडी नदी खंड के अवसाद अनंतिम परमियन से प्रारम्भिक मध्य ट्रायेसिक कल्प में निक्षेपित हुए हैं तथा इनकी स्थिति दक्षिण रीवा द्रोणी के निदपुर संस्तर एवं टिकी शैल-समूह के मध्य है।

DURING the last four decades extensive palynological investigations have been carried out on Gondwana sediments in South Rewa Basin. However, meagre palynological work has been done on the Sohagpur Coalfield (Ram-Awatar, 1993, 1996b). The present paper deals with palynology across the Permian-Triassic boundary in the Chundi River Section, 4.5 km south of Jaisinghnagar, Madhya Pradesh. The boundary has been delineated in the lower part of the Upper Pali Member.

The geological succession of the post-Barakar sequence in the western part of the Sohagpur Coalfield is given below (Tarafdar *et al.*, 1993).

AGE		FORMATION/MEMBER
Eocene to Cretaceous		Deccan Trap
Lower-Middle Jurassic		Parsora Formation
		.... hiatus.............
Rhaetic-Carnic		Tiki Formation
Middle-Lower Triassic	P	Upper Member
Upper Permian	A	Middle Member
Middle Permian	L	Lower Member
Lower Permian	I	Barakar

The Upper Member of Pali Formation shows a conformable relationship with the Middle Pali Member in Chundi River Section. It comprises coarse to medium-grained sandstone, yellow colour



Map 1—Generalised geological map of part of South Rewa Basin showing the location of Chundi River Section (after Kundu *et al.*, 1993).

sandstones, olive green micaceous sandstone, gritty sandstone, grey to greyish white siltstone, carbonaceous shale and red-green mottled clays.

MATERIAL

Fifteen outcrop samples have been collected from the Chundi River Section (Map 1). Of them, nine samples were found to be productive. Details of the samples are given below.

Sample No.	Lithology	Thickness in m	Reference
•CRS-1A	Micaceous sandstone	0.25-1	Top
•CRS-1	Fine grained sandstone (grey colour)	0.75-1	
•CRS-2	Micaceous sandstone	1- 2	
•CRS-3	Fine-grained sandstone	1- 2	
•CRS-4	Fine-grained sandstone	1- 2	
•CRS-5	Fine-grained sandstone	1- 2	
•CRS-6	Fine-grained sandstone	0.70-1	
•CRS-7	Carbonaceous shale	0.75-1	
•CRS-8	Carbonaceous shale	0.50-1	
CRS-9	Claystone (yellow colour)	0.25-.50	
CRS-10	Claystone (red colour)	0.20-.50	
CRS-11	Claystone (yellow colour)	0.30-.50	
CRS-12	Carbonaceous shale	0.50-1	
CRS-13	Claystone (grey colour)	0.40-1	
CRS-14	Micaceous siltstone	0.50-1	Bottom

•Productive samples

PALYNOLOGICAL ASSEMBLAGES, DATING AND CORRELATION

The recovery of the palynofossils was poor in most of the samples except for sample nos. CRS-1A, 1, 3. Based on the taxonomic composition and quantitative estimation two palynoassemblages have been identified (Text-figure 1).

Assemblage I—In this assemblage (Sample nos. CRS 4, 5, 6, 7, 8), *Horriditriletes, Densipollenites, Striatopodocarpites, Faunipollenites, Alisporites* and *Satsangisaccites* each represents 2-5 per cent. The other taxa encountered less than one per cent are *Brevitriletes, Microfoveolatispora, Playfordiaspora, Ibisporites, Scheuringipollenites, Verticipollenites, Cuneatisporites, Krempipollenites (=Klausipollenites), Falcisporites, Nidipollenites, Arcuatipollenites (= Lunatisporites)* and *Striatites*. The stratigraphically significant palynotaxa in Assemblage - I are *Striatopodocarpites venustus, Faunipollenites gopadensis, Crescentipollenites fuscus* and *Densipollenites invisus* associated with the rare occurrence of *Playfordiaspora cancellosa, Alisporites tenuicorpus, Satsangisaccites* sp. and *Goubinispora morondavensis*. This assemblage compares with the

Palynotaxa	ASSEMBLAGE I					ASSEMBLAGE II			
Sample Nos.	CRS.8	7	6	5	4	3	2	1	1A
HORRIDITRILETES	+		+	+	+				
BREVITRILETES	+		+	+			+		
MICROFOVEOLATISPORA	+	+	+	+			+		
IBISPORITES	+	+							
STRIATOPODOCARPITES	+	+	+	+		+	+	+	
FAUNIPOLLENITES	+	+	+	+		+	+	+	
CRESCENTIPOLLENITES		+		+		+			
VERTICIPOLLENITES		+		+					
DENSIPOLLENITES			+	+				+	
SCHEURINGIPOLLENITES			+						
STRIATITES			+	+		+		+	
CUNEATISPORITES				+					
ALISPORITES				+	+	+	+	+	+
FALCISPORITES				+		+	+	+	+
KREMPIPOLLENITES				+		+		+	+
NIDIPOLLENITES				+	+	+		+	+
SATASANGISACCITES				+				+	+
PLAYFORDIASPORA				+				+	
GOUBINISPORA				+		+	+	+	+
ARCUATIPOLLENITES					+	+	+	+	
CONVERRUCOSISPORITES									+
CHORDASPORITES						+		+	+
LUNDBLADISPORA						+		+	+
DENSOISPORITES						+		+	+
BRACHYSACCUS									+
KAMTHISACCITES									+
FOVEOSPORITES									+
STAUROSACCITES									+
TODISPORITES									+
Age	Late Permian					Early-Middle Triassic			

Text-figure 1—Distribution of qualitatively significant palynotaxa recorded from Chundi River Section.

youngest palynozone of the Raniganj Formation (*Densipollenites magnicorpus* Zone, Tiwari & Tripathi, 1992).

The other known palynoassemblages equivalent to Palynoassemblage-I have recently been recorded from Umaria Coalfield(Ram-Awatar, 1996a); Satpura Basin (Kumar, 1996) and Bazargaon, Kamptee Coalfield (Srivastava & Bhattacharyya, 1996). Tiwari and Vijaya (1994) have opined that occurrence of high percentage of striate-disaccates with rare occurrence of *Playfordiaspora*, *Goubinispora* and *Lundbladispora* (FAD-U) at the top of the last coal seam in the Damodar Basin marks a major floral change. Similar sequence has also been observed in the Chundi River Section; though percentage of the striated-disaccates pollen is relatively poor.

Assemblage II—The dominant palynotaxa in the assemblage (Sample nos. CRS - 3, 2, 1 & 1A) are *Falcisporites* (25%), *Alisporites* (28%) and *Krempipollenites* (10%). Other important palynotaxa in the assemblage are *Densipollenites* (2%), *Striatopodocarpites* (5%), *Faunipollenites* (2%), *Striatites* (5%), *Crescentipollenites* (3%), *Arcuatipollenites* (5%), *Nidipollenites* (2%), *Satsangisaccites* (3%), *Goubinispora* (5%), *Densoisporites* (2%), *Chordasporites* (3%), *Lundbladispora* (2%) and *Brachysaccus* (1%). Certain taxa such as *Todisporites, Playfordiaspora, Kamthisaccites* and *Converrucosisporites* though rare (1%) in occurrence, yet suggest a Panchet (= Early Triassic) equivalent affinity of Assemblage-II. The presence of *Brachysaccus ovalis, Foveosporites triassicus* and *Staurosaccites marginalis* indicates their early appearance in the Chundi River sediments.

Palynoassemblage-II is closely comparable with Nidpur palynoassemblage (Tiwari & Ram-Awatar, 1990) in view of the presence of non-striate disaccates pollen, i.e., *Falcisporites, Alisporites* and *Krempipollenties,* in association with cavate and cingulate spores. The occurrence of *Brachysaccus, Staurosaccites, Densoisporites, Kamthisaccites* and *Foveosporites* makes this assemblage younger to the Nidpur palynoflora. The Nonia Nala palynoassemblage from the Raniganj Coalfield described by Banerji and Maheshwari (1974), fairly resembles the Chundi River palynoassemblage in having non-striate disaccates in dominance but the latter *Playfordiaspora* is recorded in low percentage and *Decisporites* is completely absent. It is also somewhat comparable with the Denwa palynoassemblage (Nandi, 1996) from Satpura Basin. However, in the present assemblage *Samaropollenites, Camerosporites, Tethysispora, Dictyophyllidites, Polycingulatisporites, Ringosporites* and *Guttatisporites* are absent, hence it seems to be older than the Denwa assemblage. The stratigraphically significant taxa of the Tiki Formation, i.e., *Aulisporites, Convolutispora, Decisporites, Rimaesporites* and *Samaropollenites* (Kumaran & Maheshwari, 1980) also do not encounter in the Chundi River Section. However, presence of *Staurosaccites, Brachysaccus, Todisporites, Converrucosisporites, Foveosporites* and *Kamthisaccites* suggests that the Assemblage-II lies somewhere between the Nidpur bed and Tiki Formation.

DISCUSSION AND CONCLUSION

The Permian/Triassic boundary in the Indian Gondwana has been drawn mainly on the basis of palaeobotanical/palynological and lithological characteristics. Ghosh *et al.* (1996) have drawn the Permian/Triassic boundary on the basis of estheriids, small vertebrates and burrows in the Raniganj Coalfield which corroborate with lithofacies. In South Rewa Basin, there is no homogeneity regarding the lithological characteristics as compared to Damodar Basin due to the paucity of khaki-green shales in the Upper Pali sediments.

The Palynoassemblage-I of Chundi River Section (Upper Pali Member) contains high percentage of striate-disaccates *Faunipollenites* and *Striatopodocarpites,* in association with *Crescentipollenites, Densipollenites, Verticipollenites* and *Cuneatisporites.* Similar palynological assemblages have been identified in Johilla, Korar, Singrauli and Umaria coalfields (Tiwari & Ram-Awatar, 1987a, 1987b, 1990; Ram-Awatar, 1996a). This assemblage suggests the presence of Late Permian (Middle Pali) palynoflora in the Chundi River Section. The Assemblage-II, comprises high percentage of non-striate disaccates, i.e., *Alisporites, Falcisporites* and *Krempipollenites* associated with *Densoisporites, Goubinispora, Arcuatipollenites, Kamthisaccites, Playfordiaspora, Lundbladispora* and *Satsangisaccites.* This composition suggests an Early Triassic age of the sediments. *Brachysaccus, Foveosporites, Staurosaccites* and *Todisporites* are some of the stratigraphically significant taxa which show the presence of Middle Triassic sediments in the Chundi River Section.

The present finding is significant because for the first time P/T boundary has been demarcated on the basis of spores and pollen in the lower part of the Upper Member of Pali Formation. Chakraborti (1982) has also expressed similar view on the basis of lithological characteristics in the north-western part of Sohagpur Coalfield.

REFERENCES

Banerji J & Maheshwari HK 1974. Palynology of the Panchet Group exposed in the Nonia Nala near Asansol, West Bengal. *Palaeobotanist* **21** : 368-372.

Chakraborti U 1982. Geology and coal resources of the western part of Sohagpur Coalfield, Shahdol District, M.P. *Progr. report Geol. Surv. India* (Unpublished).

Ghosh SC, Nandi A, Ahmed G & Roy DK 1996. Study of Permo-Triassic Boundary in Gondwana sequence of Raniganj Basin, India. *In* : Guha PKS *et al.* (Editors)—*Gondwana Nine* **1** : 179-193. Oxford & IBH Publ. Co. Pvt. Ltd., New Delhi.

Kumar P 1996. Permo-Triassic palynofossils and depositional environment in Satpura Basin, Madhya Pradesh. *Geophytology* **25** : 47-54.

Kumaran KPN & Maheshwari HK 1980. Upper Triassic *Sporae dispersae* from the Tiki Formation-2: Miospores from the Janar Nala Section, South Rewa Gondwana Basin, India. *Palaeontographica* **173B** : 26-84.

Kundu A, Pillai KR & Thanavelu C 1993. Elucidation of the stratigraphic interrelationship of Pali, Tiki and Parsora formations of South Rewa Gondwana basins. *Gondwana geol. Mag. Spec. Vol.* : 49-55.

Nandi A 1996. Palynodating of carbonaceous shales from Denwa Formation, Satpura Basin, M.P., India. *In* : Guha PKS (Editor)—*Gondwana Nine* **I** : 79-87. Oxford & IBH Publ. Co. Pvt. Ltd., New Delhi.

PLATE 1

→

(All photomicrographs are enlarged, ca x 600 ; coordinates on Leitz Labourlux D, Microscope no. 512794/066300).

1. *Staurosaccites marginalis,* Slide. no. BSIP 11715; coordinates 40 x 95.
2. *Kamthisaccites* sp., Slide no. BSIP 11721; coordinates 15 x 101.
3. *Playfordiaspora cancellosa,* Slide no. BSIP 11720; coordinates 18 x 120.
4. *Arcuatipollenites noviaulensis,* Slide no. BSIP 11715; coordinates 18 x 97.
5. *Chordasporites* sp., Slide no. BSIP 11713; coordinates 25 x 101.
6. *Lundbladispora brevicula,* Slide no. BSIP 11711; coordinates 34 x 108.
7. *Brachysaccus ovalis,* Slide no. BSIP 11711; coordinates 35 x 107.
8. *Nidipollenites monoletus,* Slide no. BSIP 11714; coordinates 12 x 95.
9. *Densoisporites complicatus,* Slide no. BSIP 11713; coordinates 41 x 105.
10. cf. *Todisporites* sp., Slide no. BSIP 11715; coordinates 40 x 105.
11. *Foveosporites* sp., Slide no. BSIP 11712; coordinates 17 x 105.
12. *Cuneatisporites* sp., Slide no. BSIP 11720; coordinates 15 x 107.
13. *Goubinispora morondavensis,* Slide no. BSIP 11724; coordinates 16 x 110.
14. *Satsangisaccites* sp., Slide no. BSIP 11724; coordinates 28 x 98.
15. *Osmundacidites senectus,* Slide no. BSIP 11718; coordinates 44 x 99.
16. *Densipollenites indicus* sp., Slide no. BSIP 11711; coordinates 46 x 102.
17. *Falcisporites nidpurensis,* Slide no. BSIP 11711; coordinates 45 x 102.
18. *Converrucosisporites* sp., Slide no. BSIP 11716; coordinates 20 x 109.
19. *Krempipollenites indicus,* Slide no. BSIP 11711; 48 x 104.

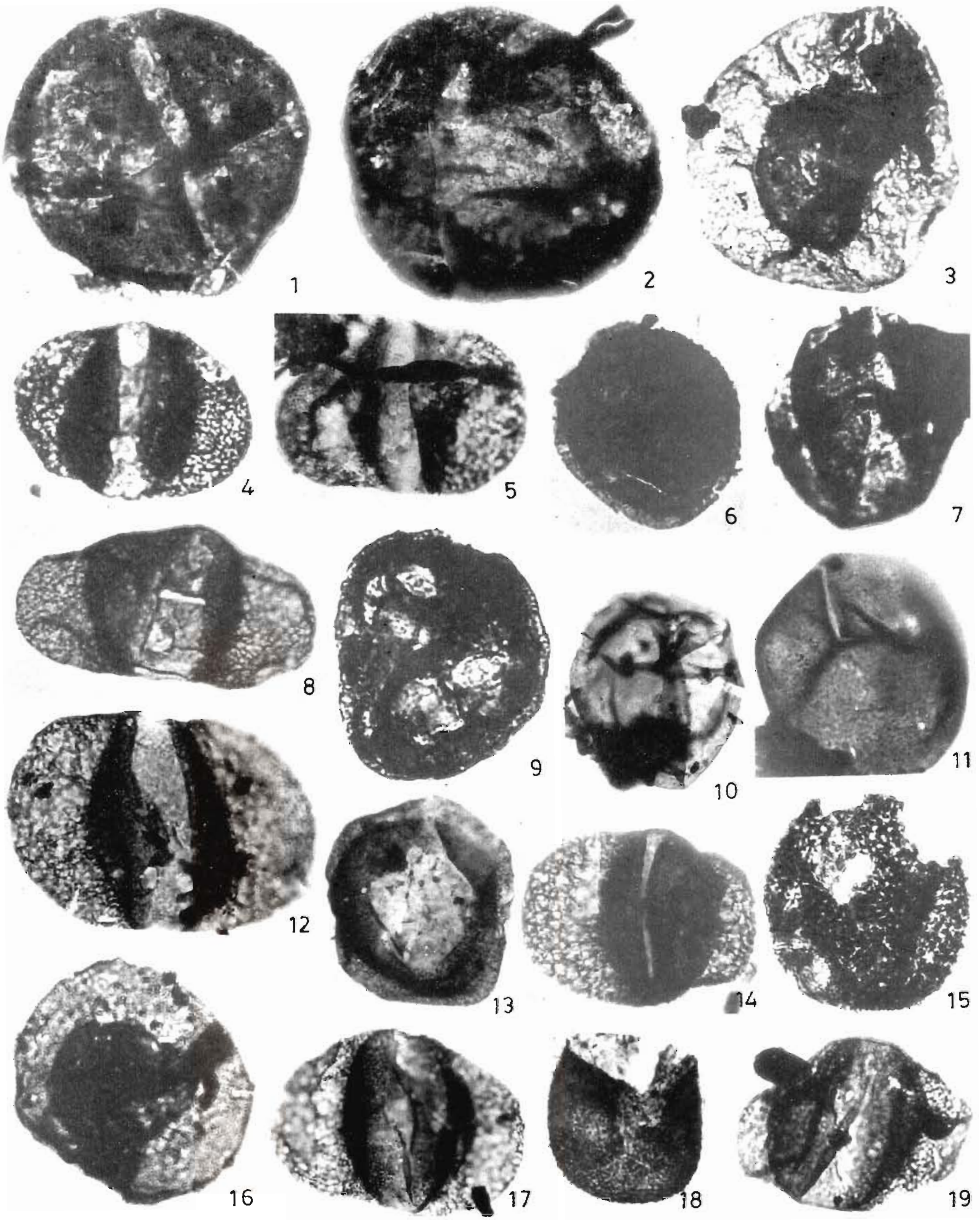


PLATE 1

Ram-Awatar 1993. Palynological dating of subsurface sequence of Middle Pali Member in Sohagpur Coalfield (M.P.), India. *Geophytology* **23** : 107-114.

Ram-Awatar 1996a. Palynostratigraphy of Supra-Barakar sediments (Pali, Tiki and Parsora formations) and their stratigraphic positions in South Rewa Basin, M.P., India. *In* : Guha PKS *et al.* (Editors)—*Gondwana Nine* **I** : 439-454. Oxford & IBH Publ. Co. Pvt. Ltd., New Delhi.

Ram-Awatar 1996b. Palynozonation of the Middle Pali Member in Sohagpur Coalfield, M.P. *Palaeobotanist* **43** : 96-101.

Srivastava SC & Bhattacharyya AP 1996. Permian-Triassic palynofloral succession in subsurface from Bazargaon, Nagpur District, Maharashtra. *Palaeobotanist* **43** : 10-15.

Tarafdar P, Sinha PK, Das DP, Kundu A, Datta DR, Rajaiya V, Pauri PK, Patel MC, Thanavelu C, Ashok Kumar MR, Pillai KR, Agasty A & Dutta NK 1993. Recent advances in post-Barakar stratigraphy in part of Rewa Gondwana Basin. *Gondwana geol. Mag. Spec. Vol.* : 60-68.

Tiwari RS & Ram-Awatar 1987a. A palynological assemblage from Parsora Formation, Johilla Coalfield, South Rewa Gondwana Basin, Madhya Pradesh. *Geophytology* **17** : 104-109.

Tiwari RS & Ram-Awatar 1987b. Palynostratigraphic studies of subsurface Supra-Barakar sediments from Korar Coalfield, Son Valley, Madhya Pradesh. *Geophytology* **17** : 256-264.

Tiwari RS & Ram-Awatar 1990. Palyno-dating of Nidpur beds, Son Graben, Madhya Pradesh. *Palaeobotanist* **38** : 105-121.

Tiwari RS & Tripathi A 1992. Marker Assemblage-zones of spores and pollen species through Gondwana Palaeozoic and Mesozoic sequence in India. *Palaeobotanist* **40** : 194-236.

Tiwari RS & Vijaya 1994. Synchroneity of palynological events and pattern of extinction at Permo-Triassic boundary in terrestrial sequence of India. *In* : Guex J & Baud A (Editors)—*Recent development on Triassic stratigraphy*, *Mem. Geol.* **22** : 139-154.

Almod Bed : a Permian-Triassic transition zone

Pramod Kumar

Kumar P 1997. Almod Bed : a Permian-Triassic transition zone. *Palaeobotanist* 46 (1, 2) : 107-111.

The Almod Bed located between the Bijori (Late Permian) and Pachmarhi Formations (Early Triassic) in Satpura Basin, has been palynologically analysed. The palynoassemblage is dominated by *Striatopodocarpites* + *Faunipollenites* complex. Other characteristic palynofossils are *Arcuatipollenites (=Lunatisporites), Chordasporites, Falcisporites, Goubinispora, Krempipollenites, Lundbladispora, Playfordiaspora, Podocarpidites, Satsangisaccites*, etc. In its totality the palynological assemblage has a Late Permian aspect though the presence of the genera *Goubinispora, Playfordiaspora* and *Lundbladispora* in significant frequency indicates an Early Triassic influence.

Key-words — Almod Bed, Transition zone, Permian-Triassic, India.

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साराँश

अल्मोद संस्तर : एक परमियन-ट्रायॅसिक परिवर्तन मंडल

प्रमोद कुमार

सतपुड़ा द्रोणी में बिजौरी (अनंतिम परमियन) एवं पचमढ़ी (प्रारम्भिक ट्रायॅसिक) शैल-समूहों में स्थित अल्मोद संस्तर का परागाणविक विश्लेषण किया गया है। उपलब्ध समुच्चय *स्ट्रिएटोपोडोकार्पाइटिस* + *फॉनिपोलिनाइटिस* सम्मिश्र से प्रभावी है। इसमें *आर्कुएटीपोलिनाइटिस, कोर्डास्पोराइटिस, फाल्सीस्पोराइटिस, गाउबिनिस्पोरा, क्रेम्पीपोलिनाइटिस, लुन्ब्लाडिस्पोरा, प्लेफोर्डियास्पोरा, पोडोकार्पिडाइटिस, सत्संगीसेक्काइटिस* आदि अन्य लाक्षणिक वर्गक भी विद्यमान हैं। हालाँकि *गाउबिनिस्पोरा, प्लेफोर्डियास्पोरा* एवं *लुन्ब्लाडिस्पोरा* नामक प्रजातियों की अच्छी प्रतिशत बारम्बारता प्रारम्भिक ट्रायॅसिक प्रभाव व्यक्त करती हैं तथापि कुल मिलाकर यह समुच्चय अनंतिम परमियन आयु की है।

THE Almod Beds exposed near Almod Village on the southwestern flank of Pachmarhi plateau in Satpura Basin are characterised by a sequence of sandstones alternating with carbonaceous shales (Medlicott, 1873). The latter contain plant fossils, mainly *Glossopteris*. Fox (1931) and Crookshank (1936) did not favour maintaining "Almod Beds" as a separate unit since they were lithologically similar to the Upper Bijoris, except being slightly more arenaceous in nature.

Ghosh *et al.* (1988) on the basis of the occurrence of certain conchostracans assigned an Early Triassic age to these beds. In view of the limited palaeobotanical records from these beds, the palynoflora has been studied from an exposure in Tultula Nala, 500 m north of Almod Village, in order to assess the stratigraphic status of the Almod Beds.

GEOLOGY OF THE AREA

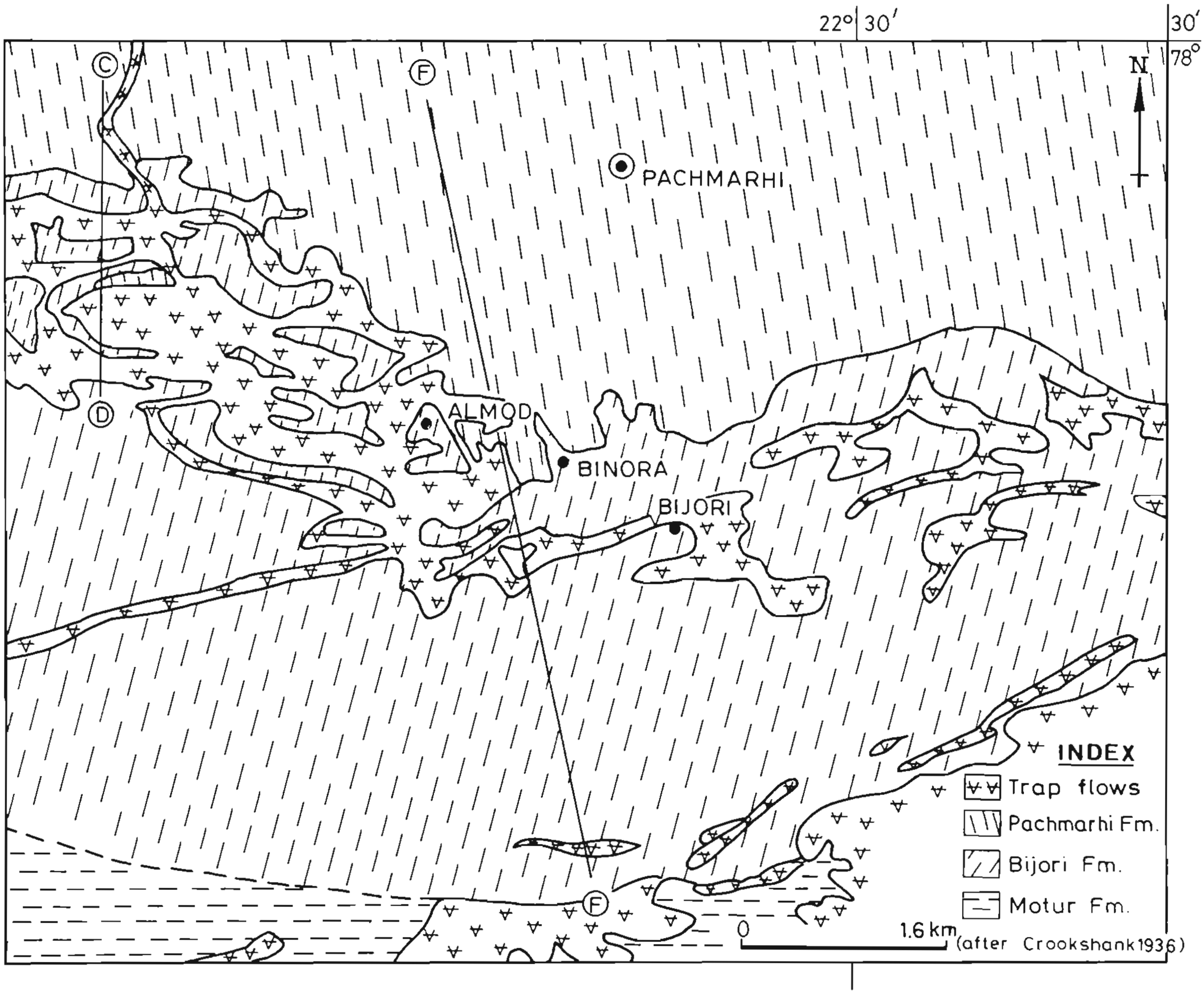
The geological succession exposed near Almod village (22° 23'N lat. : 78° 22' E long.; Text-figure 1) is given in Table 1.

Table 1

AGE	FORMATION/BED	LITHOLOGY (THICKNESS IN METERS)
Lower Triassic	Pachmarhi	White coarse-grained, massive thick, cross - bedded sandstones with lenses of subangular quartz pebbles.
	Almod	Maroon clays, carbonaceous shales mixed with micaceous shales and sandstones.
Upper Permian	Bijori	Micaceous flaggy sandstones and shales, at places micaceous.

Details of the samples collected from the Almod Bed are given in Table 2.

The contact of Almod Bed with the underlying Bijori Formation and overlying Pachmarhi Formation is gradational. The sandstones of Almod Bed are medium to coarse-grained, and the carbonaceous shales are more micaceous as compared to those of the Bijori Formation. Towards the top of the succession maroon clays are predominant.



Text-figure 1 — Geological map of the Almod area.

Table 2

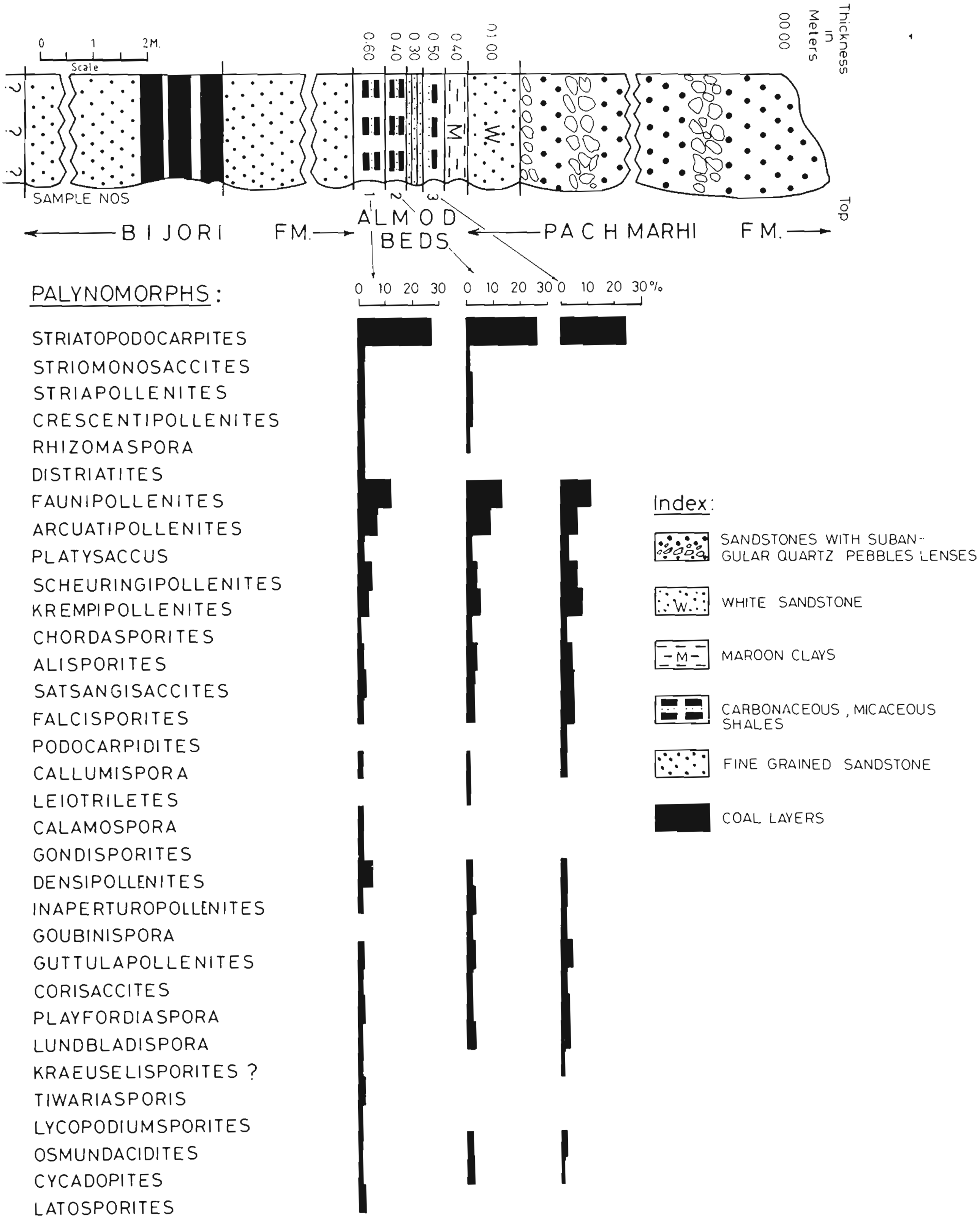
SAMPLES NOS.	LITHOLOGY	THICKNESS IN METER	PALYNOMORPHS PRESENT (+) ABSENT (-)
4464/3	Carbonaceous micaceous shales	00.50	+
	Sandstone	00.30	-
4464/2	Carbonaceous micaceous shales	00.40	+
4464/1	Carbonaceous micaceous shales	00.60	+
Bijori Formation	Sandstone fine-grained	??	-

The carbonaceous shales of the unit contain fragments of *Glossopteris* leaves and have yielded a rich assemblage of palynofossils. The spore-pollen slides studied are preserved in the repository of Museum of Birbal Sahni Institute of Palaeobotany, Lucknow.

PALYNOLOGICAL COMPOSITION

Following is the list of taxa recorded from the assemblage. A frequency count at generic level is plotted in Text-figure 2.

Callumispora gretensis (Balme & Hennelly) Bharadwaj & Srivastava 1969, *Leiotriletes* sp., *Calamospora exila* Bharadwaj & Salujha 1964, *Osmundacidites pilatus* Tiwari & Rana 1981, ?*Lycopodiumsporites* sp., *Gondisporites raniganjensis* Bharadwaj 1962, *Densoisporites novicus* (Weyland & Krieger) Bharadwaj & Kumar 1972, *D. complicatus* (Balme) Maheshwari & Banerji 1975, *Lundbladispora microconata* Bharadwaj & Tiwari 1977, *L. brevicula* (Balme) Venkatachala & Rawat 1978, *L. willmotti* (Balme) Venkatachala & Rawat 1978, *Indotriradites mamillatus* Bharadwaj & Tiwari 1977, *Latosporites*



Text-figure 2 — Percentage frequency of palynomorphs from Almod Beds exposed at Almod Village, Hoshangabad District, Madhya Pradesh

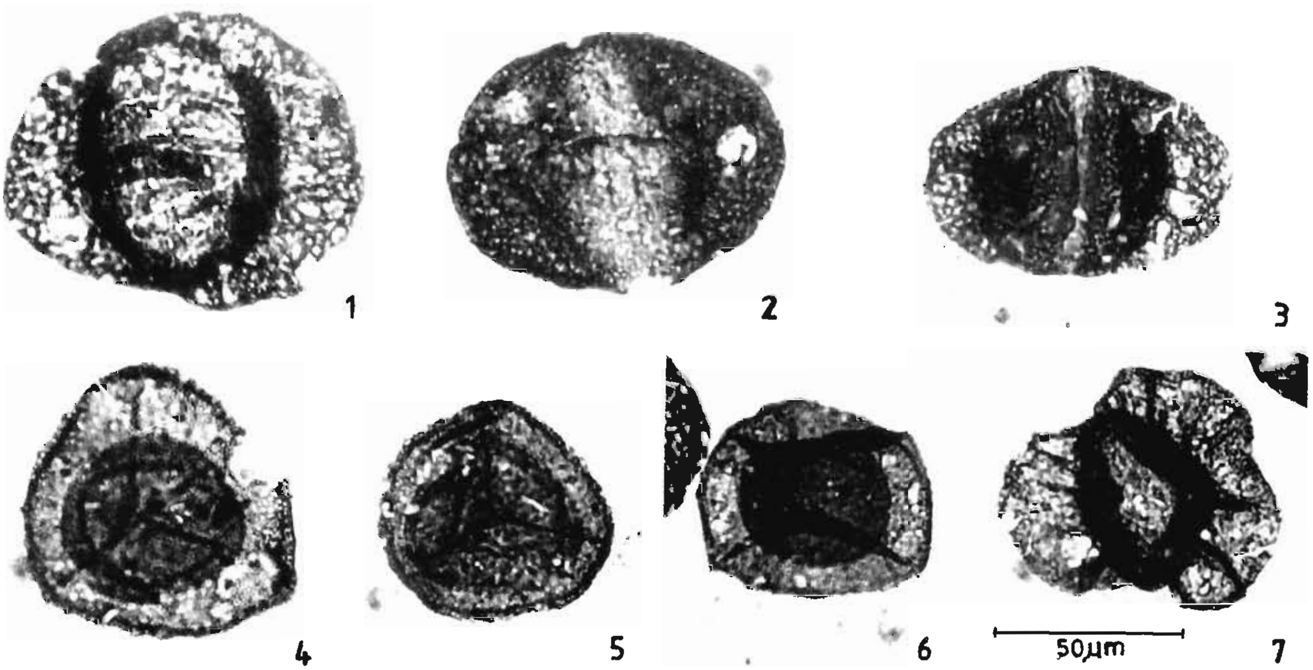


PLATE 1

(All figures ca x 500; Microscope Labourlax-D, Carl Zeiss coordinates within parenthesis)

1. *Striatopodocarpites nidpurensis*, Slide no. BSIP 11706 (19 x 94.5).
2. *Krempipollenites indicus*, Slide no. BSIP 11708 (43 x 111).
3. *Falcisporites stabilis*, Slide no. BSIP 11709 (22 x 107).
4. *Lundbladispora brevicula*, Slide no. BSIP 11706 (40 x 107).
5. *Lundbladispora microconata*, Slide no. BSIP 11710 (40.5 x 96.5).
6. *Lundbladispora willmotti*, Slide no. BSIP 11709 (38 x 99.5).
7. *Goubinispora* cf. *morandavensis*, Slide no. BSIP 11710 (41.5 x 106.5).

colliensis (Balme & Hennelly) Bharadwaj 1962, *Playfordiaspora cancellosa* (Playford & Dettmann) Maheshwari & Banerji 1975, *Goubinispora* cf. *morandavensis* (Goubin) Tiwari & Rana 1980, *Striomonosaccites ovatus* Bharadwaj 1962, *Plicatipollenites indicus* Lele 1964, *Densipollenites invisus* Bharadwaj & Salujha 1964, *D. densus* Bharadwaj & Srivastava 1969, *Alisporites indicus* Bharadwaj & Srivastava 1969, *A. ovalis* Kumar 1973, *Platysaccus queenslandii* de Jersey 1962, *Podocarpidites* sp., *Falcisporites minutosaccus* Kumaran & Maheshwari 1980, *F. stabilis* (Balme) Banerji & Maheshwari 1975, *F. nuthalensis* (Clarke) Balme 1970, *Satsangisaccites royii* Bharadwaj & Srivastava 1969, *Krempipollenites indicus* Tiwari & Vijaya 1975, *Scheuringipollenites tentulus* Tiwari 1973, *Faunipollenites varius* Bharadwaj 1962, *F. perexigus* (Tiwari) Tiwari *et al.* 1989, *Striatopodocarpites ovalis* Sinha 1972, *S. dubrajpurensis* Tripathi *et al.* 1990, *S. nidpurensis* Bharadwaj & Srivastava 1969, *Crescentipollenites fuscus* (Bharadwaj) Bharadwaj *et al.* 1974, *Rhizomaspora divaricata* Wilson 1962, *R. triassica* Tiwari & Rana 1981, *Striatites levistriatus* Bharadwaj & Tiwari 1977, *S. sidhiensis* Bharadwaj & Srivastava 1969, *Lunatisporites gopadensis* Bharadwaj & Srivastava 1969, *Verticipollenites finitimus* Bharadwaj & Salujha 1964, *Circumstriatites ovatus* (Lele & Makada) Maheshwari & Banerji 1975, *Striapollenites obliquus* Bharadwaj & Salujha 1964, *Distriatites insculptus* (Playford & Dettmann) Kumaran & Maheshwari 1980, *Arcuatipollenites pellucidus* (Goubin) Tiwari & Vijaya 1995, *Chordasporites australiensis* de Jersey 1962, *Guttulapollenites hannonicus* (Goubin) Venkatachala *et al.* 1967, *Corisaccites alutas* Venkatachala & Kar 1968, *Tiwariasporis* sp., *Cycadopites* sp., *Inaperturopollenites nebulosus* Balme 1970.

COMPARISON

Palynological assemblage from the Bijori Formation has dominance of striated disaccates pollen, viz., *Striatopodocarpites* followed by *Faunipollenites*, in association with *Crescentipollenites* and *Densipollenites* (Bharadwaj *et al.*, 1978; Sarate & Patil, 1994). The significant aspect of the assemblage is the appearance of nonstriated disaccates, such as, *Alisporites, Krempipollenites*, as well as, *Corisaccites, Guttulapollenites* and the trilete cavate *Lundbladispora*. The palynoassemblage from the Almod Beds shows a similar dominance of *Striatopodocarpites* and *Faunipollenites* in association with *Crescentipollenites*. But these forms are present here in comparatively low frequencies. Some forms which appeared in the Bijori exhibit an increasing trend in percentage frequency, such as, *Alisporites, Krempipollenites* and *Lundbladispora*. The Almod palynoassemblage contains some significant forms, e.g., *Podocarpidites, Chordasporites, Satsangisaccites, Falcisporites, Goubinispora*, etc., which are absent in the Bijori Formation. These forms have been reported from the younger sequences, i.e., Panchet Formation (Tiwari & Singh, 1983) and Pachmarhi Formation (Kumar, 1995, 1996). But elsewhere these forms have been reported from older horizons also. The Pachmarhi palynoassemblage has the dominance of nonstriated disaccates *Falcisporites, Satsangisaccites* and *Alisporites*.

Thus the Almod palynoassemblage though shows a close relationship with the Late Permian Bijori palynoassemblage in having dominance of striated disaccates with a few taeniate pollen and trilete cavate forms. Yet it apparently has a younger aspect in having comparatively more nonstriated disaccate pollen and in the appearance of *Goubinispora, Chordasporites, Lundbladispora*, etc. generally found in the Early Triassic.

CONCLUSION

The palynoassemblage from the Almod Beds is characterised by the dominance of *Striatopodocarpites* followed by *Faunipollenites* and *Crescentipollenites*. Apart from these striated disaccate pollen, it also contains some significant forms, viz., *Goubinispora, Chordasporites, Podocarpidites, Krempipollenites, Satsangisaccites, Lundbladispora, Playfordiaspora, Cycadopites*, etc. The Almod Beds are thus definitely younger than the Bijori Beds of Sukh-Tawa area and in Denwa River, Harshdwar Nala and Tamia scarp (Bharadwaj *et al.*, 1978; Sarate & Patil, 1994; Kumar, 1996). The Almod Beds exhibit onset of *Striatopodocarpites-Krempipollenites-Falcisporites* assemblage zone. The occurrence of *Goubinispora* in sample nos. 2 and 3 indicates the influence of Early Triassic.

It would thus seem that the Almod palynological assemblage, though having strong Late Permian affinities, yet has certain elements which clearly indicate an Early Triassic influence. It may fall in the Permian-Triassic transition zone but much more data are required for exactly fixing the age of the Almod Beds.

ACKNOWLEDGEMENT

The author is thankful to Dr Suresh C. Srivastava for critically going through the manuscript and helpful discussions.

REFERENCES

Bharadwaj DC, Tiwari RS & Anand-Prakash 1978. Palynology of Bijori Formation (Upper Permian) in Satpura Gondwana Basin, India. *Palaeobotanist* **25** : 70-78.

Crookshank H 1936. Geology of the northern slopes of the Satpuras between the Morand and Sher rivers. *Mem. geol. Surv. India.* **66**(2): 242-272.

Fox CS 1931. The Gondwana System and related formations. *Mem. geol. Surv. India* **58** : 1-241.

Ghosh SC, Datta A, Nandi A & Mukhopadhyay S 1988. Estheriid zonation in the Gondwana. *In* : Venkatachala BS & Maheshwari HK (Editors)—*Concepts, limits and extension of the Indian Gondwana. Palaeobotanist* **36** : 143-153.

Kumar P 1995. Palynofossils from Pachmarhi Formation, Satpura Basin, Madhya Pradesh. *Geophytology* **24**(2) : 237-240.

Kumar P 1996. Permo-Triassic palynofossils and depositional environment in Satpura Basin, Madhya Pradesh. *Geophytology* **25** : 47-54.

Medlicott HB 1873. Notes on the Satpura Coal Basin. *Mem. geol. Surv. India* **10** : 159.

Sarate OS & Patil GV 1994. Palynostratigraphy of the Bijori sediments, Satpura Basin, India. *Geophytology* **23**(2) : 197-201.

Tiwari RS & Singh V 1983. Miofloral transition at Raniganj Panchet boundary in East Raniganj Coalfield and its implication on Permo-Triassic time boundary. *Geophytology* **13**(2) : 227-234.

Representation of acritarchs across the Permian-Triassic Boundary in India

Archana Tripathi

Tripathi A 1997. Representation of acritarchs across the Permian-Triassic Boundary in India. *Palaeobotanist* **46** (1,2) : 112-117.

The paper deals with the review of published as well as new data on acritarchs from the Late Permian and Early Triassic sediments of peninsular India. Acritarch representation in terms of form diversity and quantitative acme phase is assessed. From the present state of knowledge the Acritarcha Group shows high form diversity during latest Permian with high quantity in South Rewa and Rajmahal basins and Godavari Graben. During Early Triassic low to medium form diversity is observed in Damodar and South Rewa Gondwana basins. During late Early Triassic high form diversity and high quantity is represented in Talcher Coalfield. The record of *Micrhystridium*, *Cymatiosphaera* and *Veryhachium* in the Late Permian and *Muraticavea* in Early Triassic sediments significantly points towards transgression of sea during Late Permian and Late Early Triassic in India although no physical data is available.

Key-words—Acritarch, Palaeoenvironment, Permian-Triassic Boundary, India.

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सारॉंश

भारत में परमियन-ट्रायॅसिक सीमा पर ऍक्रीटार्कों की उपस्थिति

अर्चना त्रिपाठी

इस शोध-पत्र में प्रायद्वीपीय भारत के अनंतिम परमियन एवं प्रारम्भिक ट्रायॅसिक अवसादों से प्राप्त एक्रीटार्को पर प्रकाशित साहित्य एवं नये ऑंकड़ों की विवेचना की गई है । आकारिकीय विभिन्नता एवं परिमाणात्मक विश्लेषण के आधार पर इनका मूल्यॉंकन किया गया है। गोदावरी द्रोणिका तथा दक्षिण रीवा एवं राजमहल द्रोणीयों में अनंतिम परमियन काल से प्राप्त एक्रीटार्क अत्यधिक विविधता प्रदर्शित करते है । प्रारम्भिक ट्रायॅसिक काल में दामोदर एवं दक्षिण रीवा गोंडवाना द्रोणीयों में निम्न से मध्यम प्रकार की विविधता प्रेक्षित की गई है। लेकिन तलचीर कोयला-क्षेत्र में अनंतिम-प्रारम्भिक ट्रायॅसिक काल में इनमें अधिक विविधता एवं इनकी अधिक मात्रा मिलती है । अनंतिम परमियन काल में *माइक्रोहिस्ट्रिडियम्*, *साइमेटोस्फेयरा* और *वेरीहाचियम* तथा प्रारम्भिक ट्रायॅसिक अवसादों में *मूरटिकेविआ* की उपस्थिति से इस काल में भारत में समुद्री अतिक्रमण इंगित होता है हालॉंकि इसकी पुष्टी हेतु कोई भौतिक ऑंकड़े उपलब्ध नहीं है ।

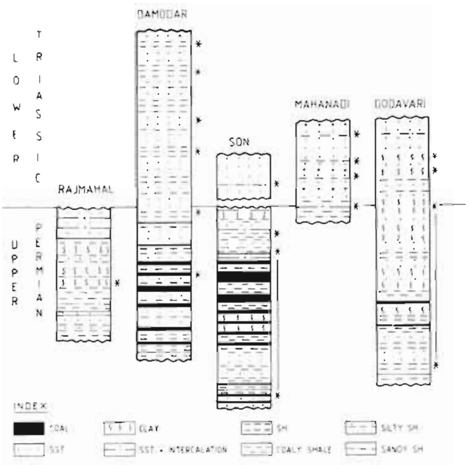
THE organic-walled planktonic fossils are referred to as the informal group Acritarcha. This group has received much attention due to its significance in palaeoenvironmental interpretation (Tappan, 1980; Traverse, 1988; Venkatachala & Tiwari, 1988). The acritarchs have been reported from the Indian Gondwana sediments, particularly in the coal deposits (Sinha, 1969; Bharadwaj & Sinha, 1969; Srivastava & Anand-Prakash, 1973; Rawat, 1984; Banerjee & D'Rojario, 1990). The data on acritarch from Permian and Triassic sequences has been synthesized (Tiwari *et al.*, 1995; Prasad *et al.*, 1995) and recently new data on acritarch has accrued from palynological studies of latest Permian and Triassic sequences of Talcher Coalfield (Tripathi, 1996). In the present communication the representation of group Acritarcha across the Permian-Triassic boundary has been discussed.

MATERIAL

The synthesis is based on the following published palynological reports :

Raniganj Coalfield, Damodar Basin—Bharadwaj & Tiwari, 1977; Bharadwaj *et al.* 1979; Tiwari & Rana, 1981, 1984; Tiwari & Singh, 1983; Singh & Tiwari, 1982.

Singrauli, Korar & Pali coalfields, Son Basin–Sinha, 1969; Bharadwaj & Sinha, 1969; Tiwari & Srivastava, 1984; Tiwari & Ram-Awatar, 1986, 1987.



Text-figure 1—Showing the representative lithocolumns from Rajmahal, Damodar, Son, Mahanadi basins and Godavari Graben considered for the present study.

Talcher Coalfield, Mahanadi Basin–Tripathi, 1996.

Rajmahal Basin–Present work.

Khamam, Chelpur, Chintalpudi, Yellendu, Manuguru, Budharam, Godavari Graben–Srivastava & Jha, 1987, 1992a, 1992b, 1993, 1995.

The lithosequences extracted from these reports are plotted in Text-figure 1 for Damodar, Son, Rajmahal and Mahanadi basins and Godavari Graben. It is observed that the acritarchs are recorded from all sorts of lithofacies—coal, shale and clay. This indicates that the presence of acritarchs is independent of lithofacies.

Analysis of data

The acritarchs are represented by the following genera.

Sphaeromorphitae

Leiosphaeridia
Pilasporites
Lophospheridium
Singraulipollenites
Hindisporis
Schismatosphaeridium

Netromorphitae

Navifusa
Eupoikilofusa

Herkomorphitae

Dictyotidium
Maculatasporites
Greinervillites
Muraticavea
Cymatiosphaera

Schizomorphitae

Hemisphaerium
Peltacystia
Circulisporites
Brazilea
Balmeella

Polygonomorphitae

Veryhachium

Tasmanititae

Tasmanites

Porata

Tetraporina
Schizosporis

Acanthomorphitae

Micrhystridium

Many of these acritarchs have been shown to have affinities with extant algae on the basis of morphological similarities of the cyst and phycoma (Tappan, 1980; Brenner & Foster, 1994; Colbath & Grenfell, 1995; Grenfell, 1995). The acritarchs recorded from the Permian and Triassic sequences of peninsular India represent following living algal groups.

Prasinophyceae

Fossil	Living
Tasmanites	*Phachysphaera*
Leiosphaeridia	*Holosphaera*
Cymatiosphaera	*Pterosperma*
Dictyotidium	*Pterosperma*
Muraticavea	*Pterosperma*

Chlorophyceae

Fossil	Living
Quadrisporites horridus	*Tetrastrum punctatum*

Zygnematophyceae

Fossil	Living
Tetraporina	*Mougeotia*
Peltacystia	*Debarya*
Circulisporites	*Debarya*
Schizosporis	*Debarya*

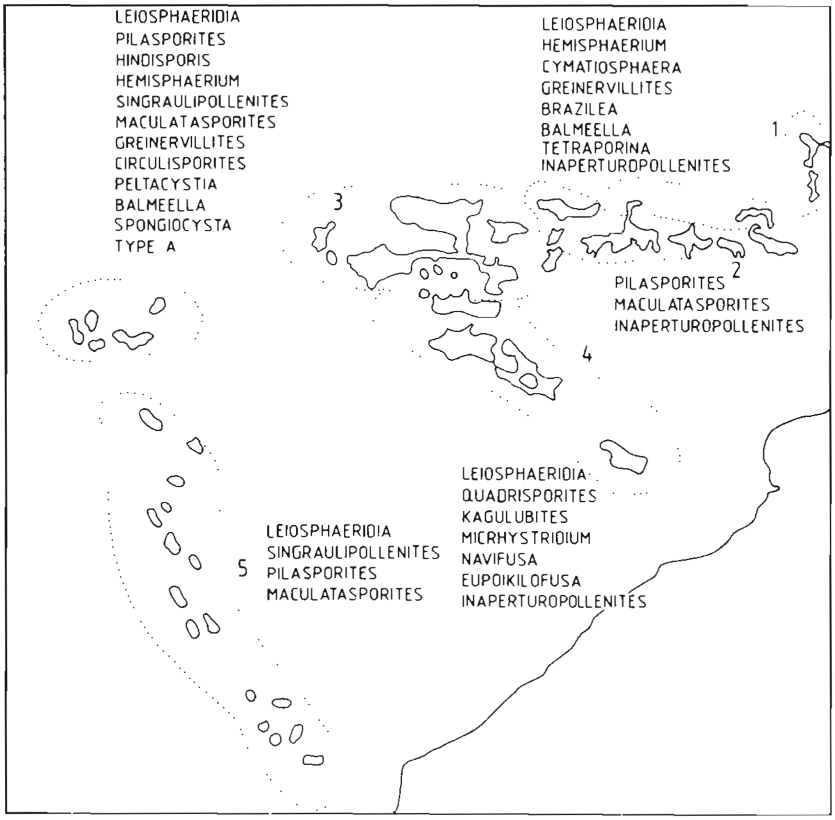
Brazilea	*Spirogyra*
Kagulubites	*Spirogyra*
Singraulipollenites	*Zygnema*
Maculatasporites	*Zygnema*

Recently the taxa *Muraticavea, Cymatiosphaera, Eupoikilofusa, Schismatosphaeridium, Navifusa* and *Tympanicysta* are recorded in addition to already known forms from the subsurface Permian-Triassic sediments of Talcher Coalfield and Rajmahal area. The presence of *Micrhystridium* in Talcher Coalfield (Tripathi, 1996) and *Veryhachium* in Godavari Graben (Surésh C. Srivastava, personnel communication) in Late Permian sediments is noteworthy.

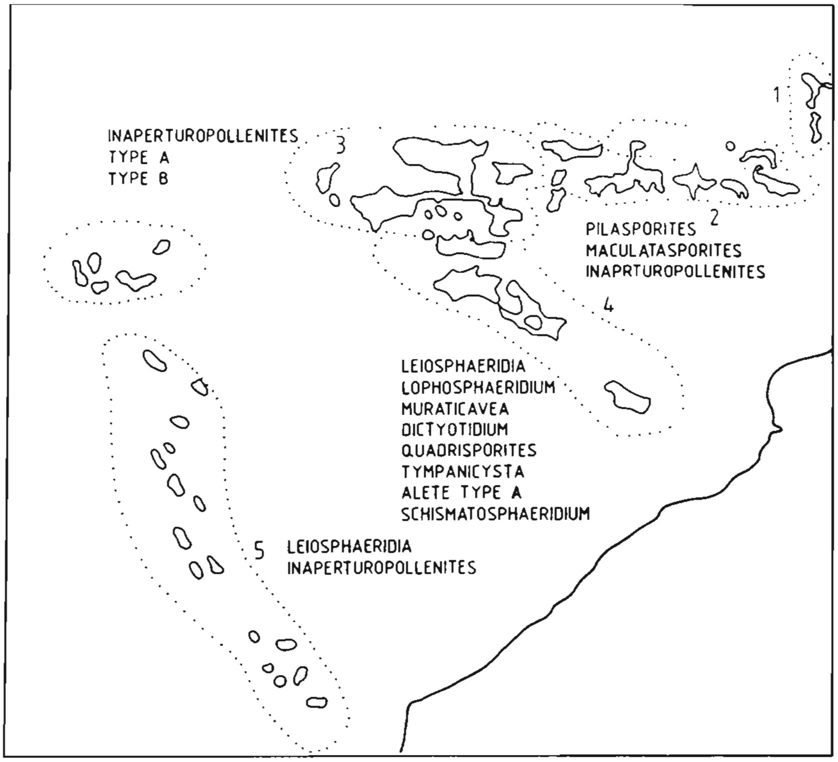
DISCUSSION

Bringing together all the available reports of Late Permian and Triassic acritarch genera, Text-figures 2 and 3 are drawn, respectively showing occurrences of various taxa in different basins. Summarising the data at hand, the qualitative and quantitative representation of acritarchs at a glance is depicted in Text-figure 4. During Permian a High Form Diversity (HFD) is observed in Rajmahal, Son and eastern part of Mahanadi basins and Medium Form Diversity (MFD) in Godavari Graben. It is noted that the HFD is reported from coalfacies in Talcher and Singrauli coalfields, while MFD in Godavari Graben. The clay lithofacies in Rajmahal Basin shows HFD while in Godavari the condition is reverse, the clays have a level of Low Form Diversity (LFD). In Raniganj Coalfield which provides complete and continuous palynosequence from Late Permian to Early Triassic, LFD is on record throughout. Analysing the quantitative distribution of acritarchs during Late Permian it is clear that High Quantity (HQ) is recorded in Rajmahal, Son and Godavari and Low Quantity (LQ) in Talcher and Damodar.

The representation of acritarchs in the Early Triassic sequence (Text-figure 4) indicates a LFD in Raniganj and Korar, HFD in Talcher Coalfield, and LFD in Godavari Graben. Regarding the quantitative occurrence LQ in Damodar and Son basins, MQ in Godavari Graben and HQ in Mahanadi Basin is recorded.



Text-figure 2—Occurrence of acritarchs during Late Permian in peninsular India. Numbers 1-5 represent Rajmahal, Damodar, Son and Mahanadi basins and Godavari Graben, respectively.



Text-figure 3—Occurrence of acritarchs during Early Triassic in peninsular India. The numbers 1-5 represent Rajmahal, Damodar, Son and Mahanadi Basins and Godavari Graben, respectively.

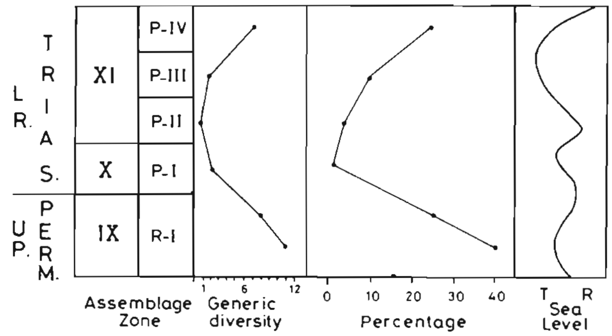
Summing up the data in nut shell the diversity (at generic level) and frequency curves are drawn (Text-figure 5). The curves reveal fluctuations in diversity and frequency both. During Late Permian the diversity and frequency both were high which gradually go down in the earliest Triassic. During late Early Triassic a prominent increase is evidenced in diversity as well as richness.

SYSTEM	PALYNOZONE		RAJMAHAL	DAMODAR	SON	MAHANADI	GODAVARI
	(1)	(2)					
LOWER TRIASSIC	*Playfordiaspora cancellosa*	P-IV		LFD, LQ		HFD, HQ	
		P-III		LFD, LQ			LFD, HQ
		P-II		LFD, LQ			
	Kremp-pollenites indicus	P-I		LFD, LQ	LFD, LQ		
UPPER PERMIAN	*Densipollenites magnicorpus*	R-I	HFD, HQ	LFD, LQ LFD, LQ	MFD, HQ HFD, HQ	HFD, LQ	MFD, HQ LFD, HQ

FD - FORM DIVERSITY: Q - QUANTITY, L - LOW M - MEDIUM, H - HIGH
LFD - < 2; MFD - 2-4, HFD - > 5; LQ - 1-5%, MQ - 5-10%, HQ - > 10%

Text-figure 4—Summary of qualitative and quantitative representation of acritarchs across the Permian-Triassic Boundary in peninsular India.

There are two aspects of acritarch usage-stratigraphical and palaeoecological. The stratigraphical aspect is proved promising for the Early Palaeozoic sequences as most of the forms appear by Devonian and towards the end of Devonian "phytoplankton blackout" is recognised (Riegel, 1996). For deducing palaeoecology and palaeoenvironment the presence of *Micrhystridium* and *Veryhachium* in Late Permian palynoassemblage, although rare, is significant, as these represent definite marine environment; these may represent increased salinity due to backflow of sea water during transgression. Similarly *Cymatiosphaera* and *Muraticavea*, known from the Early Palaeozoic marine sediments, are present in the Late Permian of Rajmahal Basin and late Early Triassic of Talcher Coalfield, respectively. *Cymatiosphaera* and *Muraticavea* of Herkomorphitae Group show affinity with Prasinophyceae. According to Colbath and Grenfell (1995), the prasinophytes, having established fossilisation potential, are restricted to marine microplankton. Hence, the two taxa provide information regarding the increased salinity during Late Permian and late Early Triassic. Strikingly the abundance of *Muraticavea* to the extent of dominant



Text-figure 5—Diversity and frequency curves of acritarchs and the sea level changes in Late Permian and Early Triassic period (sea level changes adapted after Vail *et al.*, 1977).

category in the late Early Triassic sediments of Talcher Coalfield corroborates with the regressive phase of Early Triassic transgression (Text-figure 4). This provides a clue for the Early Triassic transgression in India although no physical evidences are known so far.

CONCLUSIONS

From the preceding account following conclusions are drawn:

1. High Form Diversity is evidenced during latest Permian.
2. During latest Permian High Quantity is present in Rajmahal and South Rewa Gondwana basins and Godavari Graben.
3. Low to Medium Form Diversity is observed during Early Triassic in Damodar and South Rewa Gondwana basins.
4. High Form Diversity and High Quantity occur during late Early Triassic in Talcher Coalfield.
5. The presence of taxa *Micrhystridium, Veryhachium* and *Cymatiosphaera* in the Late Permian sediments and the abundance of taxa *Muraticavea* in late Early Triassic sediments provide clues for the Late Permian and Early Triassic transgression in India.

REFERENCES

Banerjee 'M & D'Rozario A 1990. Palynostratigraphic correlation of Lower Gondwana sediments in the Chuperbhita and Hura basins, Rajmahal Hills, eastern India. *Rev. Palaeobot. Palynol.* **65** : 239-256.

Bharadwaj DC & Sinha V 1969. Sporological succession and age of Jhingurdah seam, Singrauli Coalfield, M.P., India. *Palaeobotanist* **17** : 275-287.

Bharadwaj DC & Tiwari RS 1977. Permian-Triassic miofloras from the Raniganj Coalfield, India. *Palaeobotanist* **24** : 26-69.

Bharadwaj DC, Tiwari RS & Anand-Prakash 1979. Permo-Triassic palynostratigraphy and lithological characteristics in Damodar Basin, India. *Biol. Mem.* **4**(1 & 2) : 49-82.

Brenner W & Foster CB 1994. Chlorophyceae algae from the Triassic of Australia. *Rev. Palaeobot. Palynol.* **80** : 209-234.

Colbath GK & Grenfell HR 1995. Review of biological affinities of Palaeozoic acid resistant, organic-walled eukaryotic algal microfossils including acritarchs. *Rev. Palaeobot. Palynol.* **86** : 287-314.

Grenfell HR 1995. Probable fossil zygnematacean algal spore genera. *Rev. Palaeobot. Palynol.* **84** : 201-220.

Prasad B, Jain AK & Mathur YK 1995. Standard palynozonation scheme for the Cretaceous and pre-Cretaceous subsurface sediment of Krishna-Godavari Basin, India. *Geoscience* **16**(2) : 155-232.

Rawat MS 1984. Palynological studies of Jatraj seam, Korba Coalfield, M.P., India. *Geophytology* **14** : 228-234.

Riegel W 1996. The geologic significance of the Late Palaeozoic phytoplankton blackout. *Abstract : Ninth International Palynological Congress, Texas, 1996* : 133.

Singh V & Tiwari RS 1982. Pattern of miofloras through Permo-Triassic transition in bore-hole RAD-2, East Raniganj Coalfield, W. Bengal. *Geophytology* **12**(2) : 181-186.

Sinha V 1969. Some "Acritarchs" and other microfossils from Barakar Stage of Lower Gondwana, India. *Palaeobotanist* **17** : 326-331.

Srivastava SC & Jha N 1987. Palynology of Kamthi Formation from Chelpur area, Godavari Graben, Andhra Pradesh, India. *Palaeobotanist* **35**(3) : 342-346.

Srivastava SC & Jha N 1992a. Palynological dating of coal seams in Amavaram area, Khamam District, A.P., India. *Geophytology* **20**: 161.

Srivastava SC & Jha N 1992b. Palynostratigraphy of Permian sediments in Manuguru area, Godavari Graben, Andhra Pradesh. *Geophytology* **22**: 103-110.

Srivastava SC & Jha N 1993. Palynostratigraphy of Lower Gondwana sediments in Chintalpudi sub-basin, Godavari Graben, Andhra Pradesh. *Geophytology* **23**(1) : 93-98.

Srivastava SC & Jha N 1995. Palynostratigraphy and correlation of Permian-Triassic sediments in Budharam area, Godavari Graben, India. *J. geol. Soc. India* **46** : 647-653.

Tappan H 1980. *The palaeobiology of plant Protists.* Freeman, Oxford.

Tiwari RS & Ram-Awatar 1986. Late Permian palynofossils from the Pali Formation, South Rewa Basin, Madhya Pradesh. *Bull. geol. Min. metall. Soc. India* **54** : 250-255.

Tiwari RS & Ram-Awatar 1987. Palynostratigraphic studies of subsurface Supra-Barakar sediments from Korar Coalfield, Son Valley, Madhya Pradesh. *Geophytology* **17**(2) : 256-264.

Tiwari RS & Rana V 1981. Sporae dispersae of some Lower and Middle Triassic sediments from Damodar Basin, India. *Palaeobotanist* **27** : 190-220.

Tiwari RS & Rana V 1984. Palyno-dating of Permian and Triassic sediments in two bore-holes from the eastern limits of Raniganj Coalfield, West Bengal. *In*: Sharma AK *et al.* (Editors)—*Symposium on Evolutionary botany & biostratigraphy, Calcutta 1979*: 425-449. Today & Tomorrow's Printers & Publishers, New Delhi.

Tiwari RS & Singh V 1983. Miofloral transition at Raniganj-Panchet boundary in East Raniganj Coalfield and its implication on Permo-Triassic time boundary. *Geophytology* **13**(2) : 227-234.

Tiwari RS & Srivastava SC 1984. Palynological dating of Jhingurdah Seam, Singrauli Coalfield : a reappraisal. *Palaeobotanist* **31**(3) : 263-269.

Tiwari RS, Tripathi A & Vijaya 1995. Organic-walled microfossils of doubtful origin in Permian and Triassic sequences on peninsular India. *Palaeobotanist* **43**(1) : 1-38.

Traverse A 1988. *Palaeopalynology.* Unwin Hyman Ltd., London.

Tripathi A 1996. Early and Late Triassic palynoassemblages from subsurface Supra-Barakar sequence in Talcher Coalfield, Orissa, India. *Geophytology* **26** : 109-118.

Vail PR, Mitchum RM, Todd RG, Widmier JM, Thompson S, Sangree JB, Bubb JN & Hatlelid WG 1977. Seismic stratigraphy and global changes of sea level. *Am. Assoc. Pet. Geol. Mem.* **26** : 49-212.

Venkatachala BS & Tiwari RS 1988. Lower Gondwana marine incursion periods and pathways. *In* : Venkatachala BS & Maheshwari HK (Editors)—*Concept, limits and extension of the Indian Gondwana. Palaeobotanist* **36** : 24-29.

Post-Cretaceous record of larger foraminifera from the Shillong Plateau, India : an evidence of environmental recovery during Early Cenozoic

A.K. Jauhri

Jauhri AK 1997. Post-Cretaceous record of larger foraminifera from the Shillong Plateau, India : an evidence of environmental recovery during Early Cenozoic. *Palaeobotanist* **46** (1,2) : 118-126.

The Late and post-Cretaceous succession of larger benthic foraminifera and planktic microfossils from the Shillong Plateau indicates events of extinction and recovery of the biotic forms. These events are interpreted using a conceptual framework involving biological responses to environmental changes caused by eustatic and climatic variations. Stratigraphic distribution shows that the Late Maastrichtian larger benthic foraminiferal assemblage disappears earlier than the planktic microfossils at the boundary interval. After their last occurrence in the Upper Maastrichtian, the larger foraminifera reappear in the carbonates of the Lakadong Formation dated by *Glomalveolina primaeva* as the Thanetian (P4).

The event of first appearance of larger foraminifera in the Shillong Plateau correlates with the zone P4. When compared with other Tethyan sections (e.g., Mediterranean) where they start occurring in the strata equivalent to zone P3b, the event of their reappearance appears to be slightly delayed in the studied section. The P3b zone is the interval marked by onsetting of habitable conditions on shelves (oligotrophic environments) and is followed by an interval (equivalent of the P4 zone) of extensive carbonate generation, during which highly diversified larger foraminiferal assemblages evolve and become widely distributed. The Shillong assemblage, therefore, marks the phase of "expanded oligotrophy" in which recovery of carbonate platform environments occurred on a large scale on shallow neritic shelves.

Key-words— Larger foraminifera, Shillong Plateau, Cretaceous, Thanetian, India.

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सारांश

भारत में शिलौंग पठार से बृहत फोरामिनीफरो का पश्च-क्रीटेश्यस अभिलेख : प्रारम्भिक सीनोजोइक कल्प में पर्यावरण में सुधार का एक प्रमाण

अनिक कुमार जौहरी

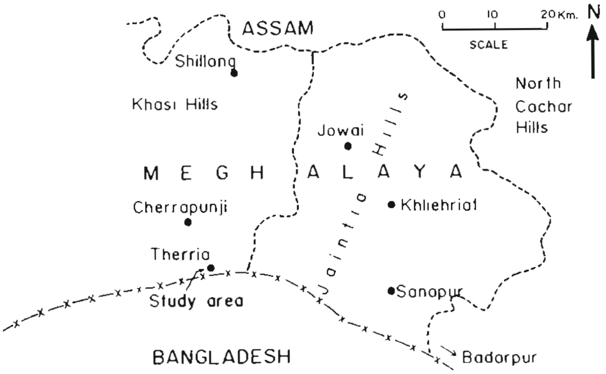
शिलौंग पठार से बृहत् फोरामिनीफरों एवं प्लवकीय सूक्ष्मजीवाश्मों के अनंतिम एवं पश्च-क्रीटेश्यस अनुक्रम से जीविता के विलोप एवं पुनरुज्जीवन की घटनायें प्रदर्शित होती हैं। सुस्थितिक और जलवायवी उतार-चढ़ावों के कारण पर्यावरण के प्रति जैविक प्रतिक्रिया नामक अवधारणा के आधार पर इन घटनाओं की व्याख्या की गई है। स्तरिकीय वितरण से प्रदर्शित होता है कि अनंतिम मास्ट्रिक्शियन बृहत् नितलस्थ फोरामिनीफर समुच्चय का सीमा अन्तराल पर प्लवकीय सूक्ष्मजीवाश्मों से पहले ही विलोप हो गया था। उपरि मास्ट्रिक्शियन में इनकी अन्तिम उपस्थिति के बाद बृहत् फोरामिनीफर थनेटियन कालीन लाकाडौंग शैल-समूह के कार्बोनेटों में पुनः मिलने लगते हैं।

शिलौंग पठार में बृहत् फोरामिनीफरों की प्रथम उपस्थिति की घटना पी-4 मंडल से तुलनीय है। जब अन्य टेथीय खंडों (मास्ट्रिक्शियन), जहाँ ये पी. 3 बी मंडल के समतुल्य स्तरों में मिलने प्रारम्भ हो जाते हैं, से इनकी तुलना की जाती है तो इनकी पुनः उपस्थिति अध्ययन किये गये खंड में थोड़ी सी बाद में प्रतीत होती है। पी. 3 बी. मंडल वह अन्तराल है जो अल्पपोषी पर्यावरण का प्रादुर्भाव व्यक्त करता है। इसके बाद अत्याधिक कार्बोनेट की उत्पत्ति वाला ऐसा अन्तराल (पी. 4 मंडल के समतुल्य) आया जिसमें विविधतायुक्त बृहत् फोरामिनीफरों का विकास हुआ तथा दूर-दूर तक इनका प्रसार हो गया। अतएव शिलौंग समुच्चय ''विस्तृत अल्पपोषी'' अवस्था का निरूपण करती है।

THE Cretaceous/Tertiary (K/T) boundary witnessed the major turnover in the taxonomic composition of marine biotic groups. The change is well seen in the fossils record of both the benthic and planktic organisms. During this time, the well established biotic communities of the Mesozoic oceans of the world became extinct, and new biotic forms evolved in the aftermath of the terminal Cretaceous extinction. The evolution of Early Cenozoic larger foraminifera has been considered a consequence of environmental regeneration after the terminal Cretaceous event of major extinction. The geologic record of larger benthic foraminifera from the Late Maastrichtian and Early Palaeogene from different parts of the world presents a picture which, in conjunction with the fossil record of other benthic invertebrates and planktic microfossils, suggests a pattern of extinction and diversification which seems to be related to the sensitivity of organisms and their adaptation of reproductive strategy to changes in shallow, neritic environments (nutrient-related factors). It has been shown that the sensitivity depends on whether organisms are facies dependent (benthic) or facies independent (pelagic), and that their reproductive strategy varies with climate and eustatic cycles (Pianka, 1970; Fischer & Arthur, 1977; Caron & Homewood, 1983).

Some studies, in recent years, in the Mediterranean and adjoining regions have documented the pattern of extinction and origination among the shallow-water invertebrates. In the opinion of the author, however, these studies have not quite considered such pattern in the light of earth-bound processes influencing environments and responses of organisms to such influences often preserved in the rock record of the K/T boundary interval.

The present paper presents a study of the larger foraminiferal record from a K/T boundary succession in the South Shillong region (Text-figure 1), examines the biostratigraphic significance of the events of disappearance and reappearance of larger benthic taxa against the background of the data of planktic microfossils (Pandey, 1990; Garg & Jain, 1995), and attempts to relate them to factors which seem to be significant in the phenomenon of extinction and recovery of such taxa.

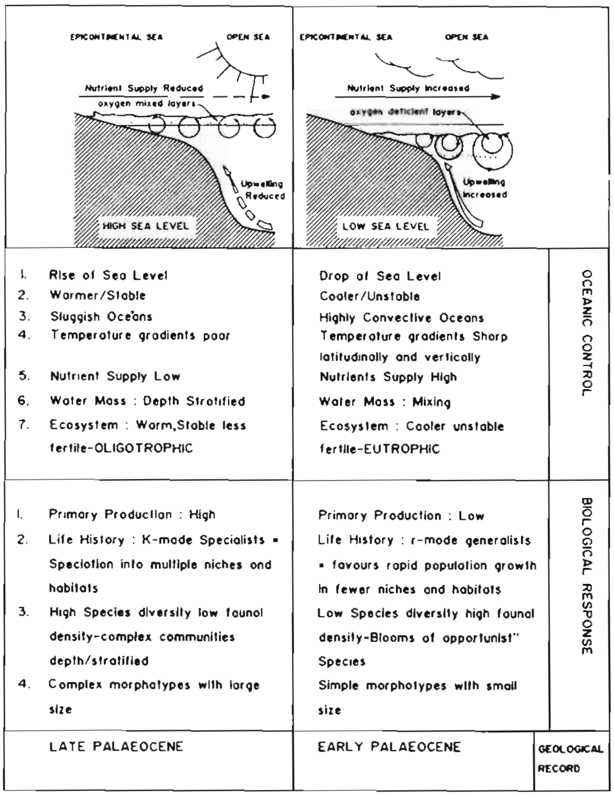


Text-figure 1—Index map of the area of study.

CONCEPTUAL BACKGROUND

The framework used in the present study for interpreting the Shillong succession of the fossil biota is borrowed from the models relating to biological responses to environmental changes brought about by eustatic and climatic variations (Pianka, 1970; Fischer & Arthur, 1977; Hallock *et al.*, 1991; Brasier, 1995). Its salient features (illustrated in Text-figure 2) are summarised below.

The ecosystem of the sea is under profound influence of oceanic control which operates through interaction mainly of factors of climate, sea level, influx of nutrients (terrigenous input), oceanic mixing, etc. As these factors change through time, the ecosystem of sea also undergoes changes. Two broad environmental states generated by aforesaid changes have alternately developed from time to time. They are termed the Oligotrophic and Eutrophic states of ecosystem. Biological response to each state of ecosystem is different and results in the accommodation of biotic forms which will be excluded in the other state; the oligotrophic state



1. Rise of Sea Level	Drop of Sea Level	OCEANIC CONTROL
2. Warmer/Stable	Cooler/Unstable	
3. Sluggish Oceans	Highly Convective Oceans	
4. Temperature gradients poor	Temperature gradients Sharp latitudinally and vertically	
5. Nutrient Supply Low	Nutrients Supply High	
6. Water Mass : Depth Stratified	Water Mass : Mixing	
7. Ecosystem : Warm,Stable less fertile-OLIGOTROPHIC	Ecosystem : Cooler unstable fertile-EUTROPHIC	
1. Primary Production : High	Primary Production : Low	BIOLOGICAL RESPONSE
2. Life History : K-mode Specialists = Speciation into multiple niches and habitats	Life History : r-mode generalists = favours rapid population growth in fewer niches and habitats	
3. High Species diversity low faunal density-complex communities depth/stratified	Low Species diversity high faunal density-Blooms of opportunist" Species	
4. Complex morphotypes with large size	Simple morphotypes with small size	
LATE PALAEOCENE	EARLY PALAEOCENE	GEOLOGICAL RECORD

Text-figure 2—Biological strategies in response to changes in marine ecosystem due to fluctuations in major oceanic controls (e.g., sea level, nutrient supply, temperature, rate of upwelling, etc.) (modified after Caron & Homewood, 1983).

promotes a high biotic diversity with low faunal density, whereas the eutrophic state yields a low biotic diversity with rich faunal density.

The state of oligotrophy is generated during high stand of sea level when climate is warmer and sea waters are sluggish, with highly partitioned habitats and low nutrient supply. This situation is stress free and suits species having complex morphologies and larger size. It allows them to adapt to variety of niches which are enhanced during oligotrophy. Such forms are known as k-mode specialists which take long to mature and show low reproductive potential and high degree of specialisation in adaptation to increased number of niches and habitats. Because of decreased terrigenous input and increased production of carbonate-precipitating organisms, oligotrophy enhances carbonate generation on shallow shelves (Hottinger, 1987; Hallock *et al.*, 1991).

Eutrophic conditions, on the other hand, develop during low stand of sea level when climate is cooler and sea waters are highly convecting, with considerable mixing of water mass and the enriched state of nutrient supply. This situation gives rise to unstable (stressful) environments which favour "opportunist" species with simpler morphologies and smaller size, called r-mode generalists. They are able to increase their population densities in fewer niches and habitats by high reproductive potential and early maturation. Because of increased terrigenous input and considerable reduction of carbonate-precipitating organisms, carbonate platform environments are destroyed on shallow shelves (Hottinger, 1987; Hallock *et al.*, 1991).

Larger foraminifera are k-mode specialists adapted to stable oligotrophic environments characterized by a wide range of ecological niches and habitats, as available in carbonate platforms on shallow shelves. They are characterised by relatively longer life cycle, low reproductive potential, large size, complex morphologies and usual dependence on symbiotic algae —the characters which make them adaptive to stable environments deficient in nutrients. On the other hand, smaller benthic foraminifera, in general, have characteristics such as high reproductive potential, smaller life cycle, simple morphology, small size and non-dependence on symbiotic algae, which allow them to flourish in nutrient-rich eutrophic environments (Hottinger, 1982, 1983).

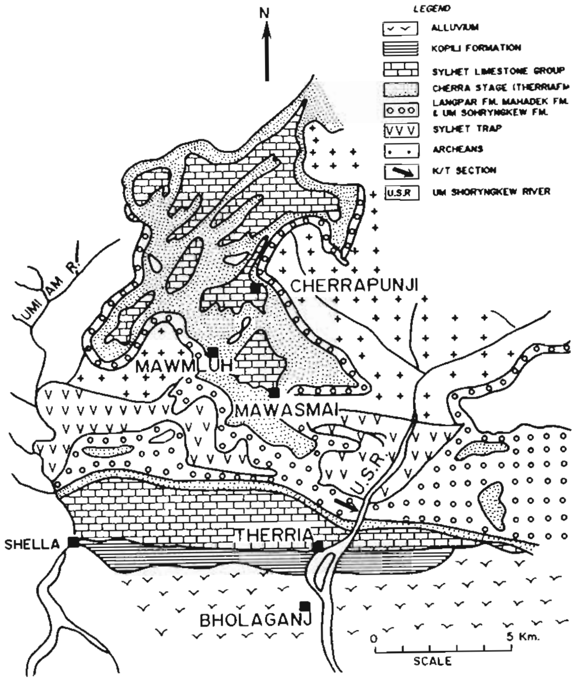
GEOLOGICAL SETTING

The area of study is a part of the Assam shelf which is the northeastern extension of the Indian Peninsular Shield (Murty, 1983). It includes the Shillong Plateau, Garo, Khasi, Jaintia and Mikir Hills and the Upper Assam Valley. Structurally, this part of the shield is dissected by a number of faults. The Shillong Plateau is an uplifted part of the basement bounded by nearly east-west aligned faults towards the northern and southern boundaries of the plateau.

The studied section is located at the southern fringe of the plateau on the western bank of Um Sohryngkew River northeastward of the village Therria in the foot-hills of the East Khasi Hills (Text-figure 3). The Late Maastrichtian to the earliest Palaeocene interval is represented by the upper part of the Mahadeo Formation, and the Early Palaeocene by the Langpar Formation. The Therria Formation and the lower part of the Lakadong Formation represent the Late Palaeocene (Pandey & Ravindran, 1988; Pandey, 1990).

Upper Maastrichtian is represented by the calcareous to silty shales which are followed by a reddish-brown 1.5 cm clay layer which forms the contact between the Cretaceous shales and the overlying 1.5 m greyish to yellowish brown shales which represent the lowest Palaeocene. The succeeding 34 m shales of the Langpar Formation represent the Lower Palaeocene. The topmost part of this formation and the overlying Therria Formation, poor in diagnostic species, are considered to represent the lower part of Upper Palaeocene on the basis of position in sequence. The lower part of the Lakadong Limestone distinguished by larger benthic foraminifera represents the Uppermost Palaeocene (Pandey & Ravindran, 1988; Garg & Jain, 1995; Jauhri, 1996).

Platform conditions were established during the Late Cretaceous and Early Palaeocene and the sediments were mainly deposited in shallow marine environment. During the Late Palaeocene, when the supply of terrigenous clastics was least, carbonate deposition took place. The latter, though interrupted occasionally due to increased supply of clastics and shallowing, continued until the close of the limestone deposition in the topmost part of the Sylhet Limestone Group (Prang Formation) (Murty, 1983; Ghose, 1976).



Text-figure 3—Geological map of the area (after Garg & Jain, 1995).

BIOSTRATIGRAPHY

Upper Maastrichtian and K/T Boundary

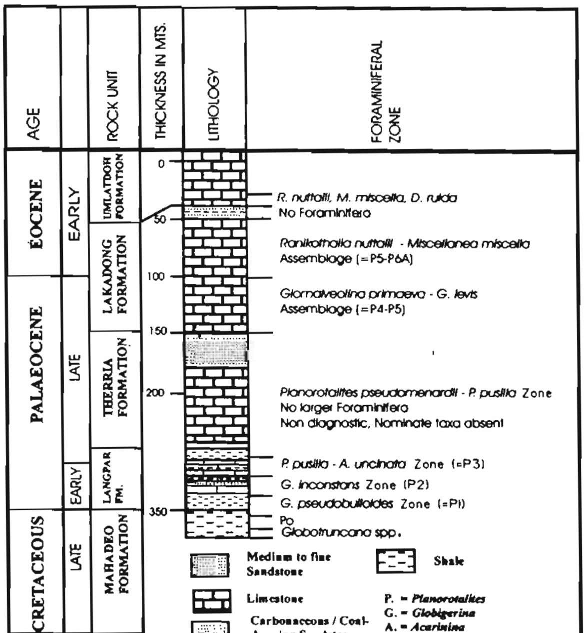
Nagappa (1959) was first to indicate the K/T boundary interval in the South Shillong Plateau (Therria section). He recorded the larger benthic assemblage of *Siderolites calcitrapoides* and *Orbitoides* sp. from the calcareous bands near the top of the Mahadeo Formation. It is characteristic of the Upper Maastrichtian and is comparable with the similar assemblage of foraminifera from the Upper Maastrichtian of the Haymana-Polatli area of Central Turkey (Sirel *et al.*, 1986).

The age control for this section of the Shillong area has been provided by the planktic microfossils, e.g., planktic foraminifera (Pandey, 1981, 1990; Pandey & Ravindaran, 1988) and nannoplankton and dinoflagellates (Garg & Jain, 1993, 1995). The observations on these microfossils have helped establish the K/T boundary interval and the associated terminal event in this section precisely.

The silty shales immediately below the 1.5 cm reddish reddish-brown clay layer have yielded *Globotruncana stuarti*, *Rugoglobigerina scotti* and *R. rotundata* which broadly correlate with the *Abathomphalus mayaroensis* Zone. However, the clear evidence of the terminal Maastrichtian has been provided by Garg and Jain (1995) who established the presence of *Micula prinsii* Zone in this section. The overlying 1.5 m greyish to yellow-brown shales are referable to *Guembelitria cretacea* Zone (Po) (Pandey & Ravindran, 1988; Pandey, 1990), in which Garg and Jain (1993) record FAD of *Danea californica*, etc. *G. cretacea* Zone marks the earliest Palaeocene. It is overlain by 22.5 m thick *''Globigerina" eugubina* Zone (P_1) (Pandey & Ravindran, 1988; Pandey, 1990). The K/T boundary is geochemically marked by 1.5 cm reddish-brown clay layer containing positive anomalies of iridium (Bhandari *et al.*, 1994).

Post-Cretaceous Fauna

Danian sediments that overlie the Upper Maastrichtian do not show development of larger benthic foraminifera. On the other hand, the Langpar shales overlying the *''G." eugubina* Zone (P_1) have yielded planktic foraminiferal species which establish zonal equivalence with planktic zones *''Globigerina' inconstans* Zone (=P_2) and *Planorotalites pusilla - Acarinina uncinata* Zone (=P_3). The topmost part of the Langpar Formation and the Therria Formation



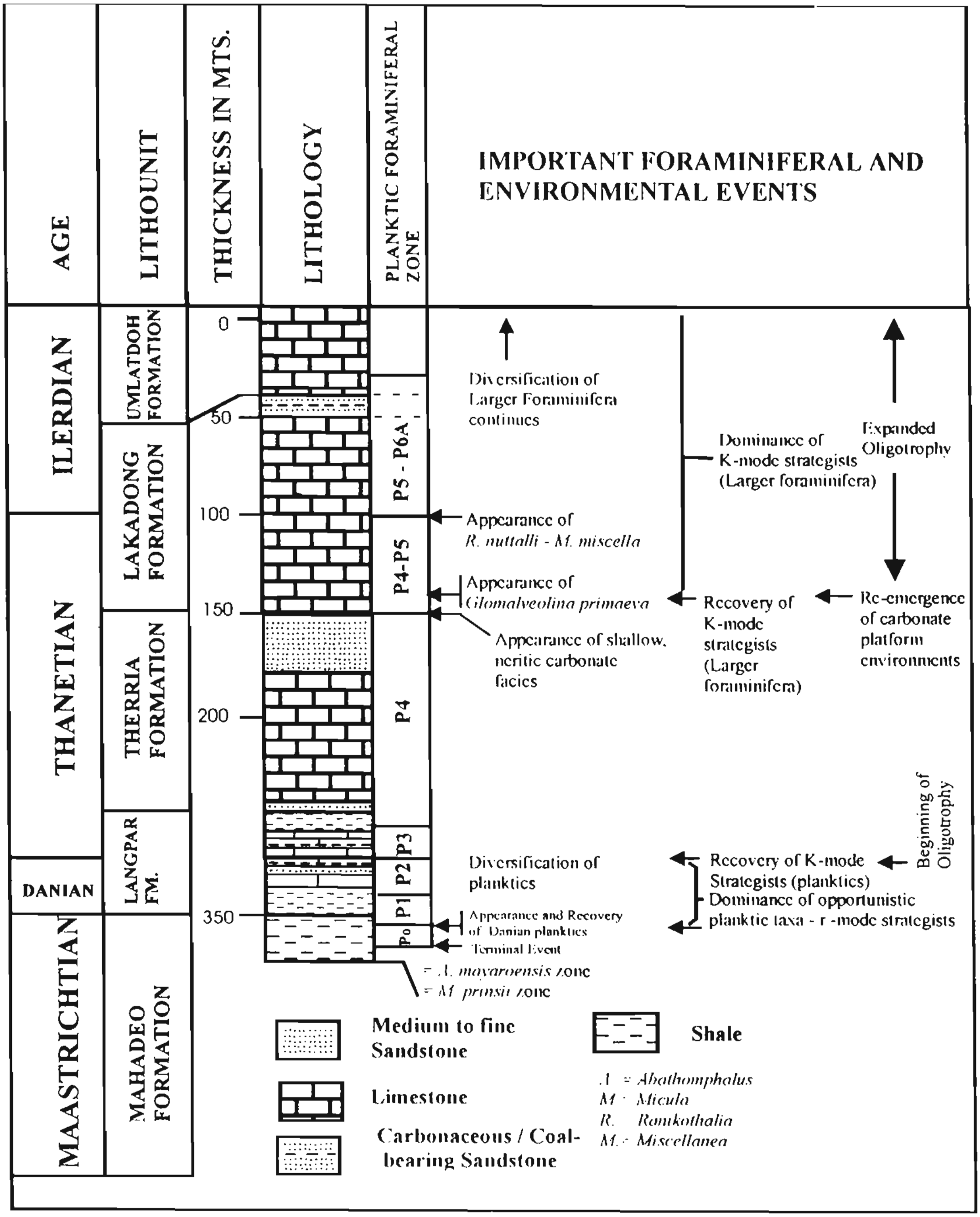
Text-figure 4—Biostratigraphy of the post-Cretaceous succession of the Um Sohryngkew River section (Therria) (modified after Pandey & Ravindran, 1988).

referred to *Planorotalites pseudomenardii - P. pusilla* Zone (=P_4) on the basis of their position in sequence (Pandey & Ravindran, 1988); see Text-figure 4.

In the post-Cretaceous succession, the larger foraminifera are first seen in the basal part of the Lakadong Formation of the Sylhet Limestone Group. The rich foraminiferal assemblage includes some markers which indicate precise correlation with the Palaeocene-Eocene stages of the type sections in the Mediterranean (Hottinger, 1994) and provide a good age control for the succession of the Shillong region in which planktic microfossils are absent.

Stratigraphically, the sequence is divisible into two major assemblages :

(i) Lower *Glomalveolina primaeva - G. levis* assemblage correlative with P_4-P_5 Zones (Thanetian).



Text-figure 5—Main foraminiferal and environmental events inferred from the post-Cretaceous succession of the larger foraminifera in the studied section of Shillong Plateau.

(ii) Upper *Ranikothalia nuttalli-Miscellanea miscella* assemblage correlative with P_5 Zone (Ilerdian).

FAUNAL EXTINCTION AND RECOVERY

Stratigraphic distribution shows that the Upper Maastrichtian larger benthic foraminiferal assemblage disappears earlier than the planktic microfossils (e.g., foraminifera, nannoplankton, etc.) at the boundary interval (Pandey, 1990; Garg & Jain, 1995).

After their last occurrence in the Upper Maastrichtian, the larger foraminifera reappear in the carbonates of the Lakadong Formation dated by *Glomalveolina primaeva* as the Thanetian (P_4) (Jauhri, 1994).

The different levels of disappearance of planktic microfossils and larger foraminifera in the studied section suggests that the phenomenon of extinction was a prolonged episode and may have occurred due to changing environmental conditions set in before the major extinction event at the K/T boundary.

The extinction of Upper Maastrichtian larger benthics has been related to loss of carbonate environments (indicated by extensive development of clastic facies in the studied area) on the shelves in response to environmental changes (progressive cooling, higher influx of clastic material, etc.). These changes resulted in a decrease of primary production and loss of ecological niches in carbonate platforms on shallow shelves. This imbalance in the environment in the beginning affected the larger benthic foraminifera and host of other carbonate-producing groups of mega-invertebrates such as rudistid bivalves, and finally, when it became devastating in proportion, wiped out a wide spectrum of animal groups, especially planktic ones, at the K/T boundary transition.

The delayed first appearance of the larger benthics during Palaeocene in the Shillong region shows that they were under a prolonged period of stress which lasted through P_0, P_1, P_2 and P_3 planktic foraminiferal zones. During this period, they could not recolonise the shallow, neritic regimes of the Shillong shelf. Their appearance in the carbonates of the Lakadong Formation dated as Thanetian (*Glomalveolina primaeva* Zone = P_4 Zone) indicates that the stress-free conditions became available only when carbonate environments were regenerated in the area during the zone P_4. When compared with that of the planktic microfossils, the event of first appearance of the larger benthics during Palaeocene seems to be a delayed one and may have occurred approximately after 7 Ma of the K/T boundary event.

In the comparable sections of the Mediterranean (e.g., the Pyrenean and Central Turkish ones), the larger benthics, represented by *Operculina, Miscellanea,* etc., appear early in the Thanetian, coinciding with the first appearance of morozovellids and acarininids (k-strategists among planktic foraminifera) indicative of P_{3b} Zone (Hottinger, 1994). The zone P_{3b} is, in fact, the interval that marks the onset of large scale generation of carbonate environments in response to oligotrophic conditions in euphotic zones of sea. This event is considered to mark the beginning of the recovery of larger benthic foraminifera and the k-strategists among planktic foraminifera in the Cenozoic after the terminal Cretaceous extinction event. It is followed by an interval of extensive development of carbonate platforms on the shallow shelves of tropical seas in the world, the phenomenon being referred to as "expanded oligotrophy" (Hallock *et al.,* 1991). Larger benthic foraminifera which are k-strategists, attain maximum diversity and complexity and became widely distributed during this phase. Usually, they are well preserved in the carbonate deposits of the Old World and are referable to the planktic foraminiferal zone P_4 (Hottinger, 1987, 1994; Hallock *et al.,* 1991).

The carbonate deposits of the Shillong area record the event of "expanded oligotrophy" which is indicated by the rich assemblage of larger foraminifera dominated by *Glomalveolina primaeva* (Reichel) in the lower part of the Lakadong Limestone; other common species are *Miscellanea juliettae villattae* Leppig, *Miscellanea* spp., *Broeckinella arabica* Henson, *Aberisphaera gambanica* Wan, *Orbitolites* sp., etc. (Jauhri, in review). Some of these forms are illustrated in Plate 1. This assemblage is characteristic of P_4 Zone. The older assemblage of larger foraminifera correlated with the P_{3b} Zone in the Mediterranean sections is, however, missing in the Shillong successions as the habitable carbonate environments could not be generated due to delayed development of state of oligotrophy in the Shillong area.

DISCUSSION AND CONCLUSION

The larger benthic foraminiferal horizon of the uppermost Maastrichtian was deposited in a shallow, neritic carbonate environment which showed a change to terrigenous clastic environment in the succeeding horizons. This change which decimated the Upper Maastrichtian larger foraminifera, seems to have been introduced due to loss of carbonate environments on the shelves. This has been attributed to a decrease in primary production caused by progressive cooling, increased bottom water circulation and higher influx of nutrients-all contributing to reduction of ecological niches on tropical shelves (Hallock, 1987; Hallock *et al.*, 1991). The effect of this change which began well before the K/T boundary transition, became considerably pronounced at the end of the latest Cretaceous *Micula prinsii* Zone (Garg & Jain, 1995) resulting in the decimation of a wide spectrum of organisms, including plankton. It appears that the environmental deterioration responsible for this change of the Late Cretaceous life was not abrupt but progressed gradually during the later part of the Maastrichtian in response to the above noted factors.

The disappearance pattern of the larger benthic foraminifera and planktic microfossils in the studied area indicates progressive deterioration of habitable environments which may have selectively removed organisms from the scene. Environment-sensitive ones (like the facies-dependent benthic groups) were first to disappear, while the plankton groups which are not facies dependent (in the sense in which benthic groups are) were last to depart when the crisis became intolerably severe.

The pattern of reappearance of the planktic species and the larger benthic foraminifera in the area of study also points to their selective and gradual recovery during Early Cenozoic. In the post-Cretaceous scenario of events, the evolution of marine organisms took several million years to restore their normal diversity (Keller, 1988). Like the environmental deterioration of the Late Maastrichtian, the environmental amelioration (regeneration of habitable environments) during Early Palaeogene was also a slow process in which less sensitive (facies independent), morphologically simple plankton groups and smaller benthic foraminifera (r-strategists) appeared and diversified first in the stressful environments of the Danian seas. The specialised animal groups with complex morphologies (k-strategists to which the larger benthic foraminifera belong) recovered and diversified later when stable, stress-free, oligotrophic environments were restored in the Thanetian seas.

The state of oligotrophy, once destroyed in the terminal Cretaceous event, could not recover soon. It was re-established only when primary production was revitalised to the levels capable of sustaining a large number of ecological niches for carbonate-precipitating organisms on shallow shelves. The oligotrophy is a complex and slow process because it is related to warming, high sea level, low influx of terrigenous (nutrient) supply, reduced upwelling, etc. It may have taken several million years to accelerate the recovery of shallow, neritic carbonate depositional regimes.

The beginning of oligotrophy, characterised in many Early Palaeogene Tethyan sections by the first appearance of larger benthic foraminifera comprising operculines, miscellaneids, etc., has been correlated with the zone P_{3b}. It is followed by an interval of extensive carbonate deposition (referred to as the period of "expanded oligotrophy", Hallock *et al.*, 1991) when the larger foraminifera began to become highly diversified and widely distributed geographically. This interval is considered equivalent of the zone P_4, in which *Glomalveolina primaeva* first appears, and is characterised by full diversity of larger foraminifera (Hottinger, 1994). In the Shillong

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PLATE 1

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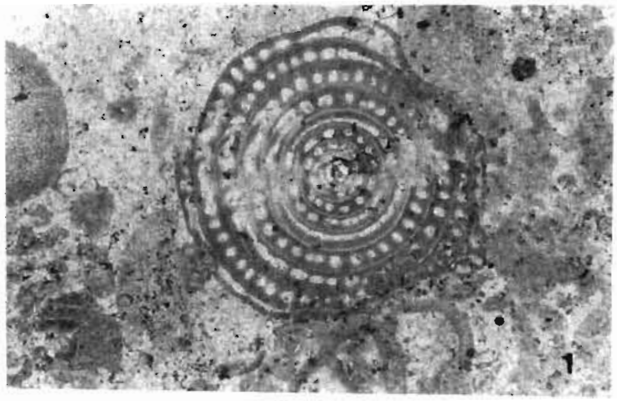
1. *Glomalveolina primaeva* (Reichel) (axial section), lumps of algae and skeletal debris (sample No. 86/Lkd/DR1), x 25.
2. *Miscellanea juliettae villattae* Leppig (equatorial section), algal lumps and fragments of foraminifera (sample No. 86/Lkd/DR5), x 30.
3. *Miscellanea juliettae villattae* Leppig (axial section) (sample No. 86/Lkd/DR2), x 30.
4. *Glomalveolina primaeva* (Reichel) (axial sections) and algal lumps (sample No. 86/Lkd/DR4), x 25.
5. Microfacies showing Orbitolites sp., fragments of other foraminifera, *Distichoplax biserialis* and algal lumps (sample No. 86/Lkd/DR4), x 20.
6. *Operculina* sp. (equatorial section), algal lumps, fragments of foraminifera (sample No. 86/Lkd/DR1), x 30.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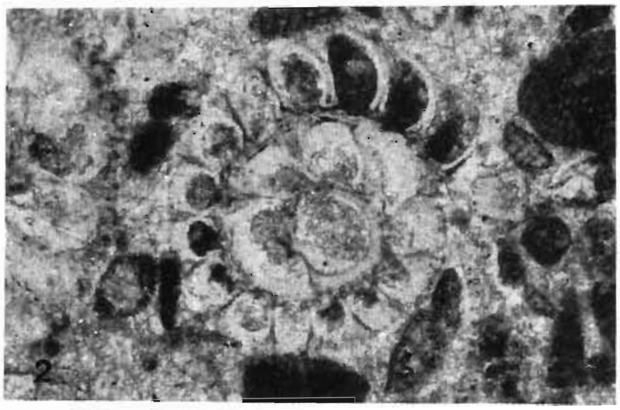
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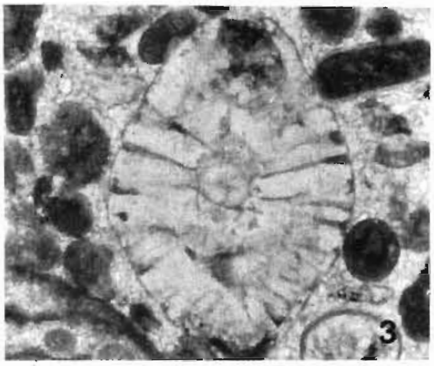
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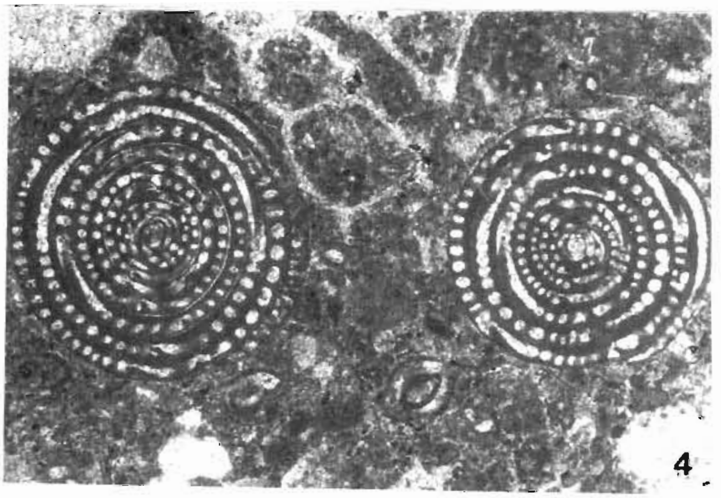
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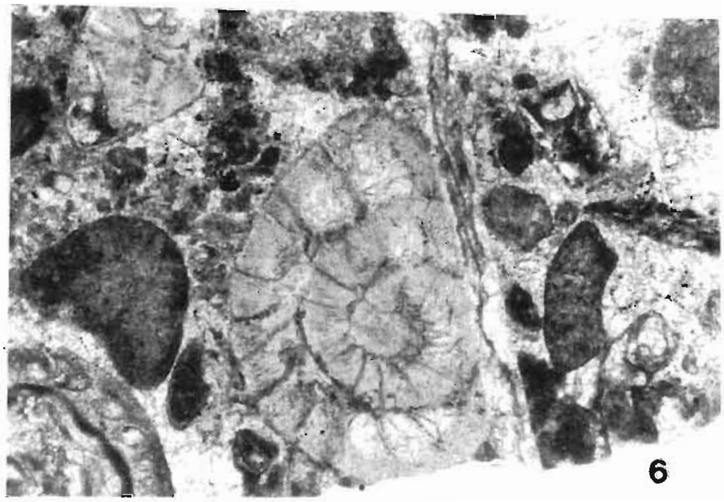
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PLATE 1

area, the assemblage equivalent of the P_{3b} Zone is not developed and there is thus no indication of the early phase of oligotrophy. The Shillong assemblage of larger benthic foraminifera has been dated as the Thanetian (=P_4 Zone) by the presence of *G. primaeva* and is considered here to mark 'expanded oligotrophy' which seems to have created a large number of ecological niches for rapid evolution of larger foraminifera in the Shillong area.

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REFERENCES

Bhandari N, Gupta M, Pandey J & Shukla PN 1994. Chemical profiles in K/T boundary section of Meghalaya, India; Cometary, asteroidal or volcanic. *Chem. Geol.* **113** : 45-60.

Brasier MD 1995. Fossil indicators of nutrient levels. 2: Evolution and extinction in relation to oligotrophy. *In* : Bosence DWJ & Allison PA (Editors)— *Marine palaeoenvironmental analysis from fossils, Geol. Soc. Spec. Publ.*, **83** : 133-150.

Caron M & Homewood P 1983. Evolution of Early planktic foraminifers. *Marine Micropaleont.* **7** : 453-462.

Fischer RG & Arthur MA 1977. *Secular variations in the pelagic realm. SEPM Spec. Publ.* **25** : 19-50.

Garg R & Jain KP 1993. Dinoflagellate cysts and calcareous nannoplankton across K/T Boundary Event at Um Sohryngkew River, Meghalaya, India. Abstract *Fifth Int. Conf. Modern and fossil dinoflagellates, Zeist* : **43**. The Netherlands.

Garg R & Jain KP 1995. Significance of the terminal Cretaceous calcareous nannofossil marker *Micula prinsii* at the Cretaceous-Tertiary boundary in the Um Sohryngkew section, Meghalaya, India. *Curr. Sci.* **66**)(12) : 1012-1017.

Ghose BK 1976. Palaeogene reef rock-complex of Meghalaya and its oil potentialities. *Sci. Cult.* **42** : 248-253.

Ghosh AMN 1940. The stratigraphical position of the Cherra Sandstone, Assam. *Rec. geol. Surv. India* **75** : 1-19.

Hallock P 1987. Fluctuations in the trophic resource continuum : a factor in global diversity cycles? *Palaeoceanography* **2** : 457-471.

Hallock P, Premoli Silva I & Boersma A 1991. Similarities between planktonic and larger foraminiferal evolutionary trends through Paleogene paleoceanographic changes. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **83** : 49-64.

Hottinger L 1982. Larger foraminifera, giant cells with a historical background. *Naturwissenschaften* **69** : 361-371.

Hottinger L 1983. Processes determining the distribution of larger foraminifera in space and time. *Utrecht Micropaleont. Bull.* **30** : 239-253.

Hottinger L 1987. Conditions for generating carbonate platforms. *Mem. Soc. Geol. italiana* **40** : 267-271.

Hottinger L 1994. Early Palaeogene Benthos-286. Aspect Field Meeting Report. *UNESCO and IUGS supplementary Contribution* (unpublished) : 1-9.

Jauhri AK 1994. Carbonate buildup in the South Shillong Plateau, N.E. India : a micropalaeontological perspective. *In* : Matteucci R, Carboni MG & Pignatti JS (Editors)—*Studies on ecology and palaeoecology of benthic communities, Boll. Soc. Palaeont. Italliana*, Spec. Vol. **2** : 157-169. Mucchi, Modena.

Jauhri AK 1996. *Ranikothalia nuttalli* (Davies), a distinctive early Ilerdian marker, in the Shillong Plateau. *In* : Pandey J, Azmi RJ, Bhandari A & Dave A (Editors)—*Contributions to XV Indian Colloquium on Micropalaeontology and Stratigraphy, Dehradun* : 209-217.

Jauhri AK (in review). The Thanetian-Ilerdian transition in the South Shillong Plateau, N.E. India : some interpretations in the light of sequence-stratigraphic observations.

Keller G 1988. Biotic turnover in benthic foraminifera across the Cretaceous/Tertiary boundary at EL KEF, Tunisia. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **66** : 153-171.

Murty KN 1983. Geology and hydrocarbon prospects of Assam shelf - recent advances and present status. *In* : Bhandari LL *et al.* (Editors)-*Petroliferous basins of India, Petroleum Asia Jl* **1** : 1-14.

Nagappa Y 1959. Foraminiferal biostratigraphy of Cretaceous-Eocene succession in the India-Pakistan-Burma region. *Micropaleontology* **5**(2) : 141-181.

Pandey J 1981. Cretaceous foraminifera of Um Sohryngkew River section, Meghalaya. *J. palaeont. Soc. India* **25** : 53-74.

Pandey J 1990. Cretaceous/Tertiary boundary, iridium anomaly and foraminiferal breaks in the Um Sohryngkew River section, Meghalaya. *Curr. Sci.* **59** : 570-575.

Pandey J & Ravindran CN 1988. Foraminiferal control in the Indian Palaeocene. *In* : Maheshwari HK (Editor)—*Palaeocene of India*, I.A.P. Publ. **4** : 124-184.

Pianka ER 1970. On r- and k-selection. *Am. Naturalist* **104** : 592-597.

Sirel E, Dager Z & Sozeri B 1986. Some biostratigraphic and palaeogeographic observations on the Cretaceous/Tertiary boundary in the Haymana-Polatli region (Central Turkey). *Lecture Notes in Earth Sci.* **8** : 385-396.

Geochemical characterisation of the Cretaceous-Tertiary Boundary sediments at Anjar, India

P.N. Shukla, A.D. Shukla and N. Bhandari

Shukla PN, Shukla AD & Bhandari N 1997. Geochemical characterisation of the Cretaceous-Tertiary Boundary sediments at Anjar, India. *Palaeobotanist* 46 (1,2) :127-132

Geochemical, geochronological, palaeomagnetic and palaeontological evidences that show that the third intertrappean bed at Anjar encompasses Cretaceous-Tertiary boundary are described. Presence of three well separated iridium rich horizons indicates multiple depositional events. Their origin in volcanic or multiple cometary impacts is discussed. The results are compared with the chemical anomalies observed in Um Sohryngkew River Section in Meghalaya.

Key-words—Cretaceous-Tertiary Boundary, Iridium anomaly, Kutch Basin, India.

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साराँश

भारत में अंजर की क्रीटेश्यस-टर्शियरी सीमा के अवसादों के भूरासायनिक लक्षण

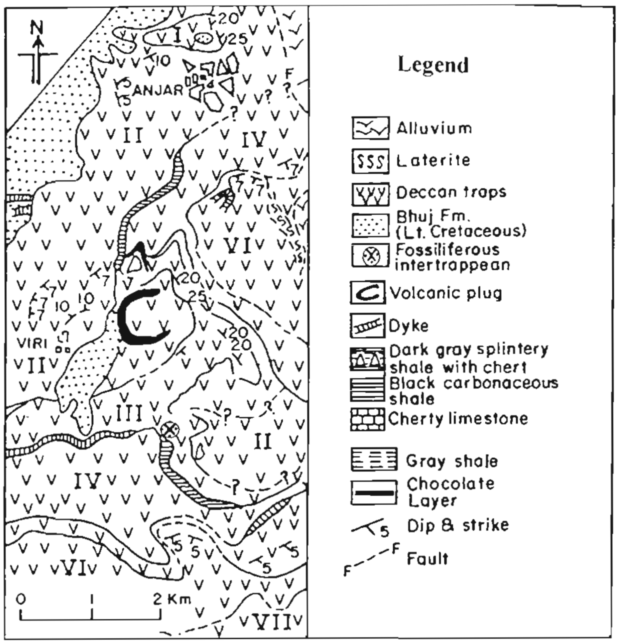
पी.एन. शुक्ल, ए.डी. शुक्ल एवं एन. भण्डारी

भूरासायनिक, भूकालानुक्रमिक, पुराचुम्बकीय एवं पुरातात्विक प्रमाणों जिनसे कि अंजर की तृतीय अन्तर्ट्रेपी संस्तर में क्रीटेश्यस-टर्शियरी सीमा की विद्यमानता व्यक्त होती है, का वर्णन किया गया है। तीन स्पष्ट पृथक इरीडियम से भरपूर संस्तरों की उपस्थिति से विविध निक्षेपणीय घटनायें प्रदर्शित होती हैं। ज्वालामुखीय अथवा विभिन्न धूमकेतु सम्बन्धी प्रभावों में इनकी उत्पत्ति की विवेचना की गई है। उपलब्ध परिणामों की तुलना मेघालय में उम्शौरिंगीव नदी खंड में प्रेक्षित रासायनिक विसंगतियों से की गई है।

THE Deccan volcanism, because of its magnitude (>10^6km^3), duration (0.5 to 3 Ma) and high frequency of flows, has played a significant role in the Cretaceous to Tertiary transition, about 65 Ma ago. The Cretaceous-Tertiary Boundary (KTB) is chemically marked by a global iridium rich layer (Alvarez *et al.*, 1980). Two sections within and close to the Deccan volcanic province, containing this characteristic iridium rich layer, have been identified and studied in our laboratory (Bhandari, Shukla & Pandey,1987; Bhandari, Gupta & Shukla, 1993a; Bhandari, Shukla & Castagnoli, 1993b; Bhandari *et al.*, 1994, 1995). One of them is located in a shallow marine section in the Um Sohryngkew River Basin in Meghalaya and the other one in a continental volcano-sedimentary section at Anjar, Kutch Basin. The Anjar section has given an opportunity to understand the sequential succession of events close to KTB with a high time resolution and their causative factors. In this paper, we describe chemical and sedimentary characteristics of this section. Upper Cretaceous fossils in this section have been described by Ghevariya (1988), Bajpai *et al*. (1993) and Bajpai (1996). In their high resolution study, Bhandari *et al.* (1996) found three iridium-rich layers, separated by about 25 - 30 cm from each other, in the third intertrappean samples. Here we describe the nature of sediments at the KT transition and also compare the main features of the two KT sections from India on the basis of their geochemical characteristics.

GEOLOGICAL SETTINGS

The volcano-sedimentary sequence at Anjar (23°15'N, 75 ° 15'E; Survey of India topo-sheet 41/I4) in Kutch region (Text-figure 1) consists of seven basalt flows (Ghevariya, 1988). The site is shown in satellite imagery in Plate 1. Between six of these flows (F I to F IV and F VI to F VII), there are several meters thick well-developed intertrappean (IT) sediments, whereas the Flow V is sandwiched between two red bole horizons. A variety of obser-



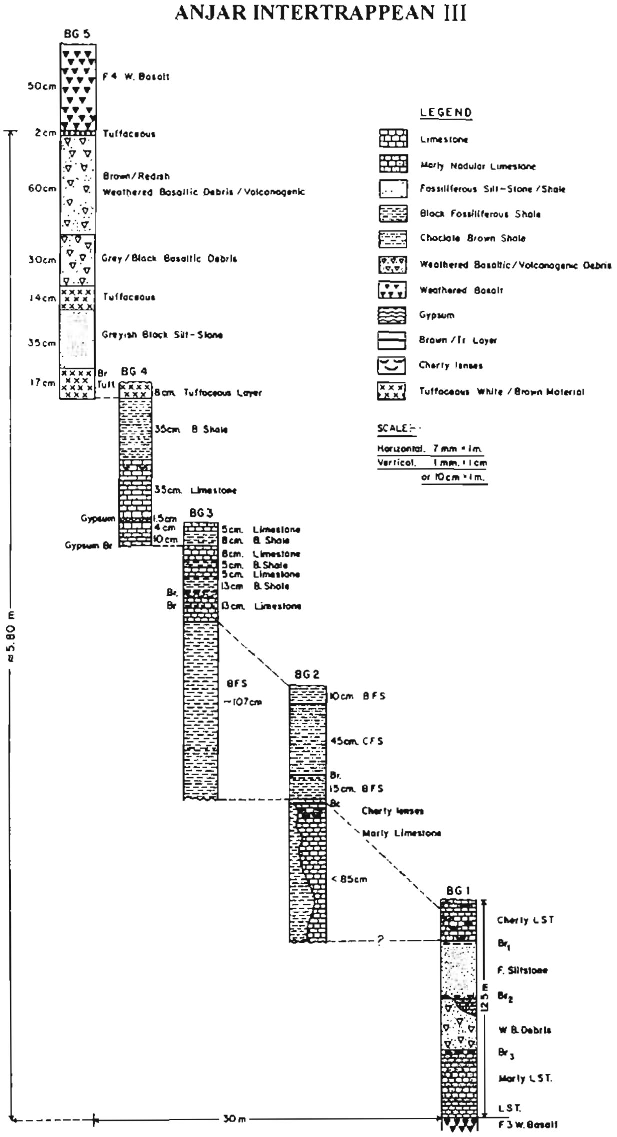
Text-figure 1— Location of Anjar volcano-sedimentary sequence (after Ghevariya, 1988). Various flow units are shown.

vations suggests that this sequence was emplaced during the uppermost Cretaceous. During November, 1995 a field workshop was held at Anjar in which participants from several institutions examined the sequence. Several pits were made through the intertrappean III in which iridium-rich layers have been observed. Text-figure 2 shows the composite litholog of the Intertrappean-III.

The IT-III is about 6 m thick and consists of clay, shales and limestone (Text-figure 2) in which the three thin and patchy horizons, rich in iridium have been identified. Limited search in other intertrappeans did not show any iridium enrichment. The 25 cm thick horizon between Layer I and Layer II is highly fossiliferous.

PALAEONTOLOGICAL OBSERVATIONS

Ghevariya (1988) and Bajpai *et al.* (1993) have reported the presence of dinosaur bones, egg shell fragments and other Upper Cretaceous fossils in the second and third (IT-II and IT-III) intertrappeans. Ghevariya (1988) also noted presence of invertebrate fossils in the V intertrappean bed. Palaeontological studies made in the II and III intertrappean sections suggest the presence of taxonomically diverse faunal and floral assemblages. In the intertrappean III, the fossils are abundant between Ir layer 1 and 2. These include bones, teeth and egg shells of sauropods and theropods, as well as ornithoid egg shells. Bulk screening of the third IT level has yielded isolated teeth, otoliths, scales of fishes, Geckonid (lacertilian) egg shells, ostracods and micro-pelecypods (Bajpai *et al.*, 1993; Bajpai, 1996). Fish teeth *Igdabatis* and *otoliths* (*Serranidae* and *Ariidae*) have also been reported by Bajpai (1996). The presence of stratigraphically important ostracod taxa such as "*Mongolianella*" and "*Altanicypris*" is also noticed. Initial palynological studies by R.K.Kar (Pers. Comm., 1996) suggest the presence of the latest Cretaceous (Maastrichtian) elements, including *Gabonisporites*. This fossil assemblage found in the horizon



Text-figure 2— Lithologs of Anjar Intertrappean III as constructed from study of five pits (BG1 to BG 5).

PLATE 1

Landsat imagery showing geological configuration around Anjar town. Several flows can be clearly seen. Location of the intertrappean III is shown by circle.

encompassed by iridium rich layer I and II is of Maastrichtian age. This horizon also contains significant amount of soot, presumably from forest fire.

GEOCHRONOLOGICAL FRAMEWORK

The seven basalt flows have been dated by ^{39}Ar-^{40}Ar method. Three of them FI (68.7 ±0.8 Ma), FII (66.6 ±0.6 Ma), FIII (65.3± 0.6 Ma) yield good plateau ages (Venkatesan *et al.*, 1996). Flows IV, V and VI do not yield good age plateaus but give integrated ages of 65.1±1.5, 65.9 ±1.6 and 65.0 ±1.2 million years (all errors are 2), which are consistent with their isochron ages. F VII also gives an apparent age of 61 ±1.6 Ma. The samples have also been dated by French Group (Hofmann *et al.*, 1997) and their results are essentially similar. The data indicate that the sequence was a prolonged one in time covering 7.7 ± 2 Ma but if Flow I and VI are excluded, than all the five flows were quickly laid between 65 Ma and 67 Ma, covering two million years or less. A finer time resolution is not possible because of uncertainties due to errors.

PALAEOMAGNETIC OBSERVATIONS

Palaeomagnetic studies carried out by S. Kusumgar (Pers. Comm., 1995) show that the secondary component is very prominent in most basalts. The three lower flows (F I, II and III) show a dominant normal magnetisation, most of it is secondary in nature, imprinted on a faint primary magnetisation whose direction could not be established with certainty. The secondary and primary components could be resolved in flow V, VI and VII and they show primary reverse magnetisation. Based on the geochronological and magnetic data, we place flows V and VI in Chron 29R. Flow IV gives erratic magnetisation and statistically poor data. The results so far indicate a N-R sequence but there is a contradiction between Mahabaleswar and Anjar data. Both of them represent the same time span 61-68 Ma (Venkatesan *et al.,* 1993) but Mahabaleswar flows show only a reverse chron. If there is a faint primary reversed component in the lower flows at Anjar, it needs to be confirmed by a more detailed study.

CHEMICAL ANOMALIES

The intertrappean sediments IT-III consist of a 6 m thick sequence of gypseous clays, splintery black-grey shales, cherty limestone and bedded chert. The grey and black shale contains three sub-centimeter thick, chocolate-coloured layers (Br 1, 2 & 3) separated by about 32 and 25 cm, respectively. All the three layers are patchy but are continuously traceable in pit BG1. The second layer, Br 2, is the most prominent and sometimes bifurcates into two closely spaced layers, 2A and 2B. Above each of these horizons, a white sub-centimeter thick continuous band, probably calcareous in nature, exists.

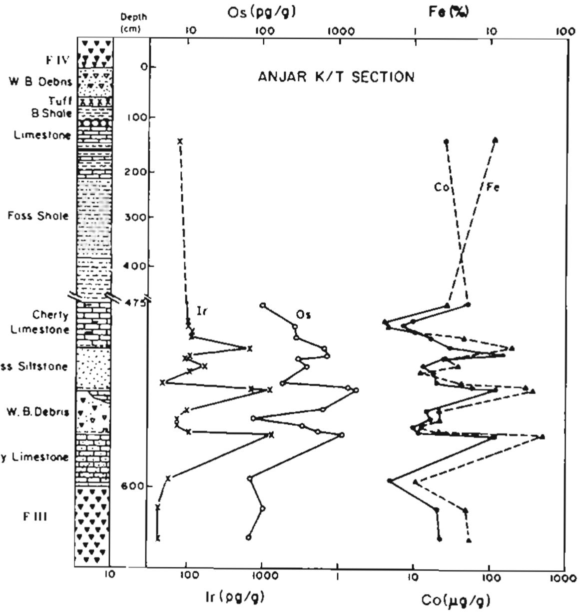
Concentration of several siderophiles (Fe, Co, Ni, Ir, Os), chalcophiles (Sb, Se, As Zn, Ag, Cu) and lithophiles (Al, Mg, Na, K, Ca, Ba, Sc, Hf, Th & 9 REE : La, Ce, Nd, Sm, Eu, Gd, Tb, Yb & Lu) has been determined using AAS INAA and RNAA procedures on closely spaced samples in IT-III. The elements which are characteristic of the KTB, e.g., platinum group elements like Ir and Os are enriched in the three layers together with chalcophile elements like Sb, As, Zn, Ag, etc.

The analyses indicate that the concentration of iridium in basalts, F III and F IV, is low,≤10 pg/g. The intertrappean III sediments generally contain iridium at ~100 pg/g, which is higher than the values found in other intertrappeans in Deccan (Bhandari, Gupta & Shukla, 1993a; Bhandari, Shukla & Castagnoli, 1993b). However, just above and below the uppermost horizon ,containing dinosaur fossils, the concentration of iridium increases abruptly reaching peak values of 700 to 1333 pg/g in the three layers. Text-figure 3 shows the depth profiles of some of these elements in the section. The high Ir is accompanied by unusually high Os, Fe, Co, Sb, Zn, Se, As and Ag. The peaks persist even when we correct for the clay content by normalizing to Sc. Thus the observed Ir enhancement appears unlikely to be due to secondary processes.

The concentrations of various siderophile and chalcophile elements in the layer Br 2, when compared with those in basalt FIII, show enhancement by large factors: Ir(>127), Fe(4.1), Co(2.6), Ni(1.8), Sb(795), Se(14.5), Zn(1.9) and Cu(1.8). Some lithophiles, i.e., Sc, Hf, Th, Mg, K and Na are relatively depleted by factors of 5 or more whereas others, i.e., Al, Cr, Mn and REE are depleted by factors of 1.5 to 22. The concentration of iridium in layer Br 2 is not only the highest amongst Anjar intertrappeans but also 10 to 20 times higher compared to several other intertrappean sediments studied so far, e.g., from nearby Bhachao site as well as far away sections from the eastern periphery of Deccan Plateau, i.e., from Nagpur, Jabalpur, Bargi and Padwar (Bhandari, Shukla & Castagnoli, 1993a). The Os/Ir ratio in the three layers is close to the meteoritic value of 1.

DISCUSSION

The occurrence of iridium-rich layers in the Anjar intertrappeans, deposited in lacustrine condition, above three basalt flows clearly ruled out the impact



Text-figure 3— Profiles of Ir, Os, Fe and Co in III intertrappean bed (pit BG1). **W. B.** is weathered basalt and **B.** is black.

origin of Deccan Volcanism proposed by Alt *et al.* (1988) and Rampino and Caldeira (1993). We have extensively searched other intertrappeans in the Deccan province for iridium-rich horizons (see Bhandari *et al.*,1993) but were not able to find any significantly enriched horizon except at Anjar. The other horizon in the Indian sub-continent where Ir rich layer exists is the shallow marine Um Sohryngkew River section in Meghalaya (Bhandari *et al.*, 1987). Palaeontological controls (Pandey,1990), Garg and Jain (1995) and presence of meteoric spinels (Robin *et al.*, 1997) clearly establish the presence of KTB in this section where Ir peak exists. Here the peak having concentration of Ir = 12.1 ng/g is much stronger than in Anjar (max. concentration 1.3 ng/g) but there is a significant difference. In Meghalaya, the peak is superimposed on a broad hump extending over 70 cm having Ir concentration of 0.1 ng/g whereas at Anjar three peaks of moderate Ir concentration occur on sediments which are also little bit enriched in Ir (0.1 ng/g). In spite of these differences in Ir profile which may be due to better resolution available at Anjar because of faster sedimentation rate, the integrated amount of Ir in the two sections is nearly the same ~70 ng/cm^2. This indicates identical source strength of Ir. If Ir originated in the Chicxulub impact of a bolide, similar fallout of Ir can be expected in far away locations as at Anjar and Meghalaya. Only a single Ir peak is expected from an asteroidal impact but observation of multiple peaks and enriched intervening sediments is consistent with multiple cometary impacts if there are no post-depositional disturbances. Graup and Spettel (1989) also found three iridium rich layers in Bavarian Alps K/T section. Volcanism can give rise to such a profile but absence of high iridium in other intertrappeans at Anjar and at other locations preclude such a possibility.

SUMMARY

The available geochronological, palaeomagnetic, geochemical and palaeontological data suggest that the Anjar Intertrappean III encompasses the K/T boundary. However, better palaeontological control is required to confirm this conclusion. Impact signatures such as shocked quartz, Ni-rich spinel, etc. have not yet been found in this section. Shocked quartz may not be expected since India was located in the forbidden zone of the fall-out ejecta of the Chicxulub impact according to the model of Alvarez *et al.* (1995). Absence of impact ejecta debris in Anjar intertrappeans does not confirm the suggestion of a giant 600 km impact crater at the India-Seychelles rift zone (Chatterjee & Rudra,1997), or another small crater proposed near Bombay (Negi *et al.*,1993) since the proximal ejecta expected at this site has not been found.

REFERENCES

Alt D, Sears JM & Hyndmann DW 1988. Terrestrial Maria : the origins of large basalt plateaus, hot spot tracks and spreading ridges. *J. Geol.* **96:** 647-662.

Alvarez LW, Alvarez W, Asaro F & Michel HV 1980. Extraterrestrial cause of the Cretaceous/Tertiary extinction. *Science* **208** : 1095-1108.

Alvarez W, Claeys P & Kieffer SW 1995. Emplacement of Cretaceous-Tertiary boundary shocked quartz from Chicxulub crater. *Science* **269** :930-935.

Bajpai S 1996. Iridium anomaly in Anjar intertrappean beds and the K/T boundary. *In*: Sahni A (Editor)—Cretaceous stratigraphy and palaeoenvironments. *Mem. geol. Soc. India* **37**: 313-320.

Bajpai S, Sahni A & Srinivasan A 1993. Ornithoid egg shell from Deccan intertrappean beds near Anjar (Kuchchh), western India. *Curr. Sci.* **64:** 42-45.

Bhandari N, Gupta M, Pandey J & Shukla PN 1994. Chemical profiles in K/T boundary section of Meghalaya, India: cometary, asteroidal or volcanic. *Chem. Geol.* **113** : 45-60.

Bhandari N, Gupta M & Shukla PN 1993a. Deccan volcanic contribution of Ir and other trace elements near the K/T boundary. *Chem. Geol.* **103** : 129-139.

Bhandari N, Shukla PN & Castagnoli GC 1993b. Geochemistry of some K/T sections in India. *Palaeogeogr. Palaeoclimtol. Palaeoecol.* **104**: 199-211.

Bhandari N, Shukla PN, Ghevariya ZG & Sundaram SM 1995. Impact did not trigger Deccan volcanism: evidence from Anjar K/T boundary intertrappean sediments. *Geophys. Res. Letts* **22 :** 433-436.

Bhandari N, Shukla PN, Ghevariya ZG & Sundaram SM 1996. K/T boundary layer in Deccan intertrappeans at Anjar, Kutch. *Geol. Soc. Am. Spec. Pap.* **(307):** 417-424.

Bhandari N, Shukla PN & Pandey J 1987. Iridium enrichment at Cretaceous-Tertiary boundary in Meghalaya. *Curr. Sci.* **56** : 1003-1005.

Chatterjee S & Rudra DK 1997. KT events in India; impact, rifting, volcanism and Dinosaur extinction. *Mem. Qld Mus.* **39 (3):**489-532.

Garg R & Jain KP 1995. Significance of terminal Cretaceous calcareous nannofossil marker *Micula prinsii* at the Cretaceous-Tertiary boundary in Um Sohryngkew section, Meghalaya. *Curr. Sci.* **69**: 1012-1017.

Ghevariya ZG 1988. Intertrappean dinosaurian fossils from Anjar area, Kachchh District, Gujarat. *Curr. Sci.* **57:** 248-251.

Graup G & Spettel B 1989. Mineralogy and phase chemistry of an Ir- enriched pre-K/T layer from the Lattengebirge, Bavarian Alps, and significance for the KTB problem. *Earth Planet. Sci. Letts* **95** : 271-290.

Hofmann C, Courtillot V, Bhandari N, Shukla PN, Kusumgar S, Ghevariya ZG, Gallet V, Fraud, G & Rocchia R 1997. Timing of bolide impact and flood basalt volcanism at the K/T boundary based on the study of Kutch sections. Abstract, 21/3 A06, E.G.S. Meeting, Strasboug.

Negi JG, Agrawal PK, Pandey OP & Singh AP 1993. A possible K-T boundary bolide impact site offshore near Bombay and triggering of rapid Deccan volcanism. *Phys. Earth Planet. Inter.* **76:** 189-197.

Pandey J 1990. Cretaceous/Tertiary boundary, iridium anomaly and foraminifer breaks in the Um Sohryngkew River section, Meghalaya. *Curr. Sci.* **59** : 570-575.

Rampino MR & Caldeira 1993. Major episodes of geological change : correlations, time structure and possible causes. *Earth planet. Sci. Letts* **114**: 215-227.

Robin E, Rocchia R, Bhandari N & Shukla PN 1997. Imprints of cosmic bolide in the Meghalaya K/T section (in preparation).

Venkatesan TR, Pande K & Ghevariya ZG 1996. ^{40}Ar/^{39}Ar ages of Anjar Traps, Western Deccan Province (India) and its relation to Cretaceous-Tertiary boundary events. *Curr. Sci.* **70** : 990-996.

Venkatesan TR, Pande K & Gopalan K 1993. Did Deccan volcanism predate the K/T transition? *Earth Planet. Sci. Letts* **119** : 181-189.

Ostracode fauna from the Patti Formation (Late Cretaceous) of Vridhachalam area, Tamil Nadu, India

S. Sugumaran, H.M. Nagaraj & U.B. Mallikarjuna

Sugumaran S, Nagaraj HM & Mallikarjuna UB 1997. Ostracode fauna from the Patti Formation (Late Cretaceous) of Vridhachalam area, Tamil Nadu, India. *Palaeobotanist* **46** (1,2) :133-140.

An ostracode fauna is recorded from the Patti Formation (Late Cretaceous) of Vridhachalam area, Tamil Nadu. The assemblage includes *Bairdia pentagonalis*, *B. cretacea*, *B. supplanata*, *Macrocypris limburgensis* and *Paracypris limburgensis*, which are typical of Maestrichtian age. The ostracodes show strong affinities with those recorded from the Ariyalur and Pondicherry areas, and those described from the type-Maestrichtian of Holland. The above assemblage and the presence of distinct Paleocene ostracodes in the overlying Pondicherry Formation throw light on K/T transition in the Vridhachalam area. The paper also discusses the stratigraphic distribution and zoogeographic affinities of the ostracode fauna with equivalent formations in India and the type-areas elsewhere.

Key-words—Ostracodes, Vridhachalam area, Patti Formation, Cretaceous-Tertiary transition, Maestrichtian, India.

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सारॉश

तमिलनाडु (भारत) में वृद्धाचलम् क्षेत्र के पट्टी शैल-समूह (अनंतिम क्रीटेश्यस) से ओस्ट्राकोड जीवजात

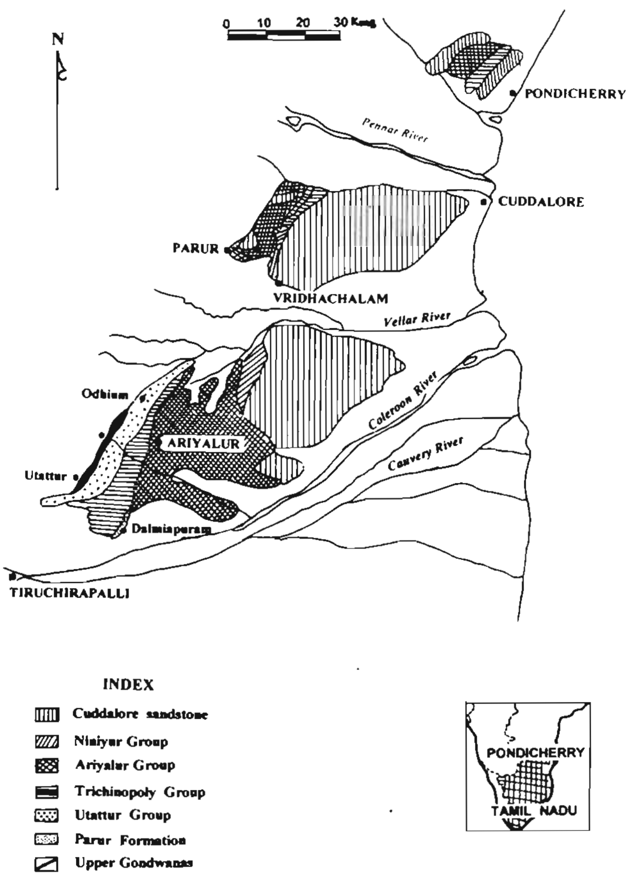
एस. सुगुमारन, एच. एम. नागराज एवं यू.बी. मल्लिकार्जुन

तमिलनाडु में वृद्धाचलम् क्षेत्र के पट्टी शैल-समूह (अनंतिम क्रीटेश्यस) से ओस्ट्राकोड जीवजात का वर्णन किया गया है। इस समुच्चय में *बेयर्डिआ पैंटागोनेलिस, बे. क्रीटेशिआ, बे. सप्लानाटा, मैक्रोसिप्रिस लिम्बर्जेन्सिस* एवं *पैरासिप्रिस लिम्बर्जेन्सिस* नामक वर्गक सम्मिलित हैं जो कि मॉस्ट्रिक्शियन आयु के हैं। प्राप्त ओस्ट्राकोड वर्गक अरियालूर एवं पाण्डिचेरी के विभिन्न क्षेत्रों तथा हालैंड के मास्ट्रिक्शियन आयु के हैं। प्राप्त ओस्ट्राकोड वर्गक अरियालूर एवं पाण्डिचेरी के विभिन्न क्षेत्रों तथा हालैंड के मास्ट्रिक्शियन कालीन वर्गकों से समानता प्रदर्शित करते हैं। उपर्युक्त समुच्चय तथा उपरिशायी पाण्डिचेरी शैल-समूह से प्राप्त पेलियोसीन ओस्ट्राकोडों से वृद्धाचलम् क्षेत्र में क्रीटेश्यस/टर्शियरी परिवर्तन के विषय में महत्वपूर्ण जानकारी प्रदान करते हैं। इस शोध-पत्र में ओस्ट्राकोड जीवजात के स्तरिकीय वितरण की विवेचना भारत एवं अन्य देशों के समतुल्य शैल-समूहों से भी की गई है।

THE Late Campanian-Maestrichtian sediments occur in narrow patches occupying the low country between Manimukta and Gadilum rivers (latitudes 11° 35' & 11° 45' N : longitudes 79° 15' & 79° 30' E), of Vridhachalam area. Though marine fossiliferous rocks of the area are limited in extent, their position between two disconnected larger exposures of Cretaceous in Tiruchirapalli and Pondicherry areas (Text-figure 1) makes them more interesting, both palaeontologically and stratigraphically. They are well exposed on the western margin and rest on the Archaean gneisses, and in turn are overlain by the Tertiary rocks of Paleocene-Miocene age.

The lower part of the sedimentary succession in the area comprises brownish to yellowish-grey, weathered gritty to coarse-grained sandstones of Parur Formation (= Sivaganga Formation). The Parur Formation is overlain by the Patti, Ariyalur and Palakkollai Formations in ascending order. This Mesozoic sequence is overlain by the Pondicherry Formation (Palaeocene) consisting mainly of yellowish-brown clay, weathered limestone and sandy marls. At the top of the succession rest Cuddalore Sandstone and Alluvium of Miocene to Recent age, respectively.

The Patti Formation mainly consists of indurated reddish-brown arenaceous limestone intercalated at places with marls, calcareous grits, sandstones and shales. The beds are more or less horizontal and occasionally show a gentle dip of less than 5°



Text-figure 1 — Map showing the Cretaceous-Tertiary succession in Tamil Nadu and Pondicherry.

towards east, along NE-SW trend. The name Patti Formation has been considered for the older fossiliferous series of Blanford of the Vridhachalam area with Patti Village, 10 km north-west of Vridhachalam town as its type locality (Rasheed & Govindan, 1966). The limestone is more conspicuous and rests unconformably on the Archaean rocks. Further north of Patti the beds are covered over by the sandstone patches and reappear at Pallipattu. The same beds of limestone can be traced up to Sendamangalam which forms the northern-most exposure of the Patti Formation. Lithologically, Patti Formation corresponds to the lower Ariyalur (= Sillakkudi Formation) of Tiruchirapalli area.

PREVIOUS WORK

Kaye and Cunliffe (1861, cited in unpublished Ph.D. Thesis; Govindan, 1965) made the first collection of fossils from the area. Later, Blanford (1865) gave the first elaborate account of the nature and deposition of Cretaceous rocks together with important fossil occurrences from different stratigraphic levels. The large collection of fossils made by him was later studied in detail by Stoliczka (1861-73). Govindan (1969) recorded 37 species of ostracode fauna belonging to 18 genera and 3 families, especially from the Patti, Erumanur and Mattur areas. He assigned Late Campanian to Maestrichtian age for these beds and inferred a littoral to shallow marine environment. Banerji (1970) recorded a total of 25 taxa, including 13 new species, from the Lower Ariyalur 'Stage' (Upper Turonian-Lower Maestrichtian).

MATERIAL

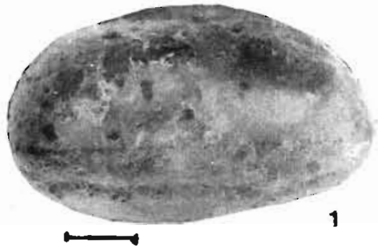
During 1993-95, about 50 samples were collected from the outcrops, stream sections and unlined dug wells. Best developed exposures can be seen just north of the town Vridhachalam in and around Reddikuppam Killanur, Patti and Sendamangalam. The geological map and sampling locations for the study of ostracodes are shown in the Text-figure 2. The samples have yielded well preserved ostracode fauna in addition to foraminiferal assemblage. The ostracode specimens are illustrated in Plates 1 and 2. The frequency distribution and stratigraphic range of ostracodes are shown in Tables 1 and 2, respectively.

PLATE 1

⟶

(In all cases the scale bar represents 100 μm)

1. *Cytherella ovata* (Roemer), Left valve view.
2. *Cytherelloidea* cf. *tricarinata* Sastri & Mamgain, right valve view.
3. *Bairdia* ex. gr. *B. pentagonalis* Veen, right valve view.
4. *Bairdia* ex. gr. *B. cretacea* Veen, right valve view.
5. *Bairdia supplanata* Veen, right valve view.
6. *Ovocytheridea ariyalurensis* Jain, left valve view.
7. *Veenidea limburgensis* Veen, right valve view.
8. *Cushmanidea pandei* Jain, right valve view.
9. *Neocytherideis elongata* (Sastri & Mamgain), left valve view.
10. *Neocytherideis reymenti* Jain, left valve view.
11. *Actinocythereis subelongata* Banerji, side view.
12. *Kikliocythere szczechurae* Jain, right valve view.
13. *Leguminocythereis subrectangulata* Singh & Porwal, right valve view.
14. *Leguminocythereis* sp. aff. *L. heistensis* (Keij), left valve view.
15. *Murrayina ariyalurensis* Jain, left valve view.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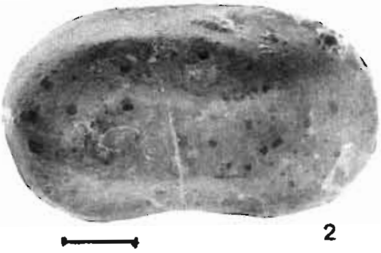
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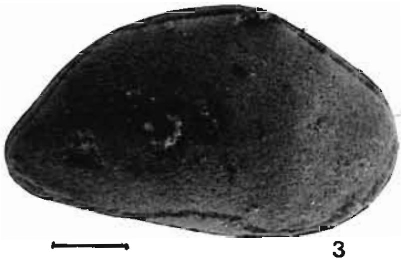
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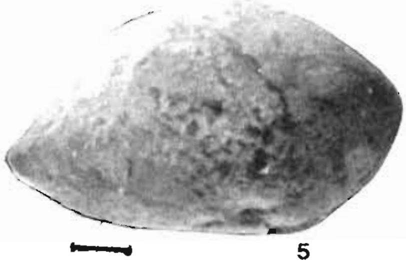
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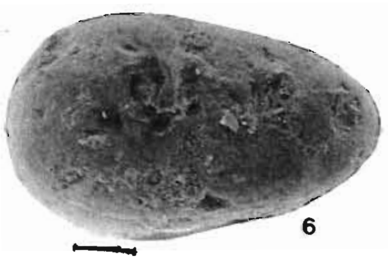
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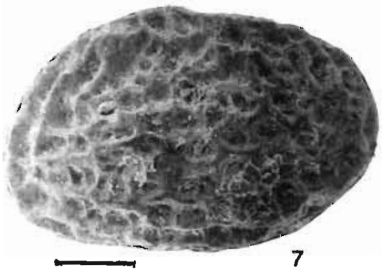
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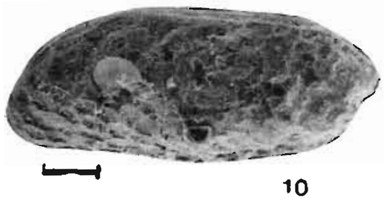
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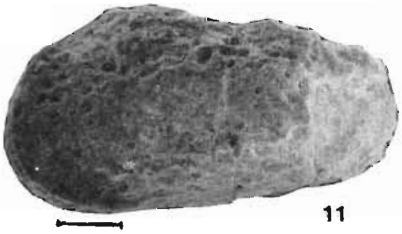
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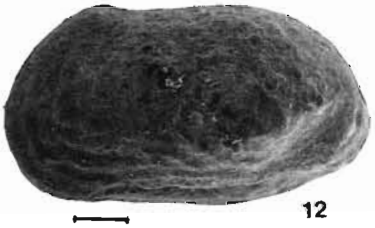
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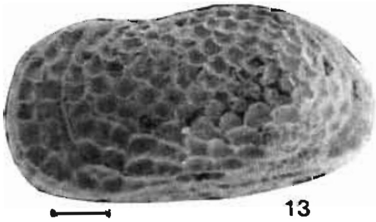
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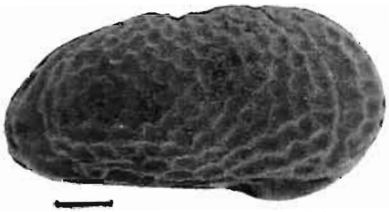
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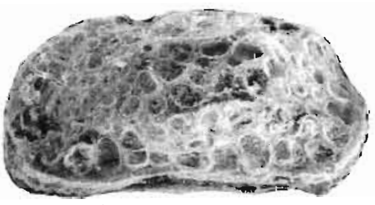
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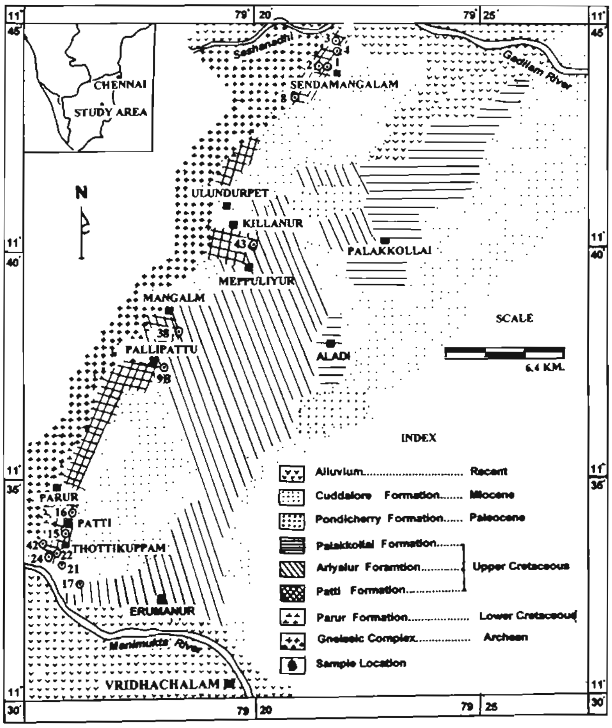
PLATE 1



Text-figure 2 — Geological map of Vridhachalam area showing sample locations (modified after Venkatachala & Sharma, 1974).

The principal reasons for interest in the study of ostracodes of the area are, (i) the Upper Cretaceous ostracodes of the Ariyalur area have been studied in detail, whereas the ostracodes from the Vridhachalam area have not received much attention, (ii) the ostracodes of the region have striking resemblance with forms known from the Upper Cretaceous sediments of the Indo-Pacific biogeographic province and thus suggest a possible route of migration, and (iii) the study will aid in better understanding of the faunal relationships of adjacent areas within and outside southern India.

COMPOSITION, DISTRIBUTION AND ZOOGEOGRAPHY OF THE FAUNA

A total of 21 ostracode taxa have been recorded, of which 5 were reported by earlier workers from the Vridhachalam area. Apart from ostracodes, foraminifera, fish fragments and molluscan shells are also common. The following is the check list of ostracodes recorded in the present study.

Table 1—The frequency distribution of Ostracodes from the Patti Formation of Vridhachalam area, southern India

PATTI															FORMATION
1	2	3	4	8	9B	13	15	16	17	21	22	38	42	43	SAMPLES / SPECIES
											R				*Cytherella ovata* (Roemer)
													R	+	*Cytherelloidea* cf. *tricarinata* Sastri & Mamgain
						X		X							*Bairdia pentagonalis* Veen
								X							*Bairdia cretacea* Veen
			+										X		*Bairdia supplanata* Veen
													R		*Ovocytheridea ariyalurensis* Jain
													X		*Veenidea limburgensis* Veen
											+		R		*Cushmanidea pandei* Jain
								R				R			*Neocytherideis elongata* (Sastri & Mamgain)
								X				R			*Neocytherideis reymenti* Jain
					+		R	R		+					*Actinocythereis subelongata* Banerji
							•						•		*Kikliocythere szczechurae* Jain
					X	R							R		*Leguminocythereis subrectangulata* Pratap, Singh & Porwal
						R							R		*Leguminocythereis* sp. aff. *L. heistensis* (Keij)
										+		R			*Murrayina ariyalurensis* Jain
		X				R				+		R		X	*Xestoleberis ovata* Bonnema
X			X	+											*Macrocypris limburgensis* Veen
X	+		+							X		X			*Paracypris limburgensis* Veen
						R						R			*Krithe boldyi* Banerji
										R				+	*Schuleridea bilobata* (Triebel)
							X	X							*Loxoconcha rugialvus* Crane

+	Very rare (1)
R	Rare (2-5)
X	Common (6-20)
•	Abundant (> 20)

Table 2—General stratigraphic range chart of Ostracode fauna of the Cretaceous-Tertiary succession of the Vridhachalam area (* Present work)

CAMPANIAN-MAESTRICHTIAN			PALAEOCENE	STAGE
PATTI	ARIYALUR	PALAKKOLLAI	PONDICHERRY	FORMATION / SPECIES
—		Unfossiliferous		*Cytherella ovata* (Roemer) *
—				*Cytherelloidea* cf. *tricarinata* Sastri & Mamgain *
—				*Bairdia pentagonalis* Veen *
—				*Bairdia cretacea* Veen *
—				*Bairdia supplanata* Veen *
—				*Ovocytheridea ariyalurensis* Jain *
—				*Neocytherideis reymenti* Jain *
—				*Kikliocythere szczechurae* Jain *
—				*Murrayina ariyalurensis* Jain *
—				*Xestoleberis ovata* Bonnema *
—				*Macrocypris limburgensis* Veen *
—				*Paracypris limburgensis* Veen *
—	—			*Actinocythereis subelongata* Banerji *
—	—			*Cushmanidea pandei* Jain *
—	—			*Krithe boldyi* Banerji *
—	—			*Veenidea limburgensis* Veen *
—	—			*Leguminocythereis subrectangulata* Pratap Singh & Porwal *
—	—			*Leguminocythereis* sp. aff. *L. heistensis* (Keij) *
—	—			*Loxoconcha rugialvus* Crane *
—	—			*Schuleridea bilobata* (Triebel) *
—	—			*Neocytherideis elongata* (Sastri & Mamgain) *
	—			*Bairdia ariyalurensis* Banerji
	—			*Bairdia binkhorsti* Veen
	—			*Bairdia decumana* Veen
	—			*Bairdia crespedesensis* Van den Bold
	—			*Brachycythere boldi* Pratap Singh & Porwal
	—			*Cytherella truncata* (Bosquet)
	—			*Cytherella renzi* Banerji
	—			*Cytheropteron harrisi* Skinner
	—			*Cytheropteron nealei* Jain
	—			*Xestoleberis perjensi* Veen
	—			*Pontocyprella jaini* Mallikarjuna
			—	*Cytherella rajuii* Guha & Shukla
			—	*Cytherella fusiforma* Ducasse
			—	*Cytherelloidea bhatiai* Guha & Shukla
			—	*Cytherelloidea vridhachalamensis* Guha & Shukla
			—	*Cyamocytheridea niniyurensis* Mallikarjuna
			—	*Schizocythere levinsoni* Rajagopalan
			—	*Bairdia talukdari* Guha & Shukla
			—	*Bairdopillata poddari* Lubimova *et al.*
			—	*Cuneocythere keiji* Guha & Shukla
			—	*Phalcocythere rete* Siddiqui
			—	*Phalcocythere dissenta* Siddiqui
			—	*Phalcocythere transquilis* Al Furaih
			—	*Acanthocythereis alacer* Al Furaih
			—	*Acanthocythereis* cf. *spongiosa* Al Furaih
			—	*Costa niniyurensis* Mallikarjuna
			—	*Kingmaina sastrii* Guha & Shukla
			—	*Echinocythereis multicostata* Deltel *et al.*
			—	*Brachycythere mckenjiei* Guha & Shukla
			—	*Hermanites scopes* Siddiqui
			—	*Xestoleberis rupnarayanalurensis* Guha & Shukla
			—	*Propontocypris (Expontocypris) khoslai* Bhandari
			—	*Occultocythereies indistincta* Siddiqui
			—	*Uroleberis gopurapuramensis* Guha & Shukla
			—	*Uroleberis reticulata* Guha & Shukla
			—	*Paracypris contracta* (Jones)

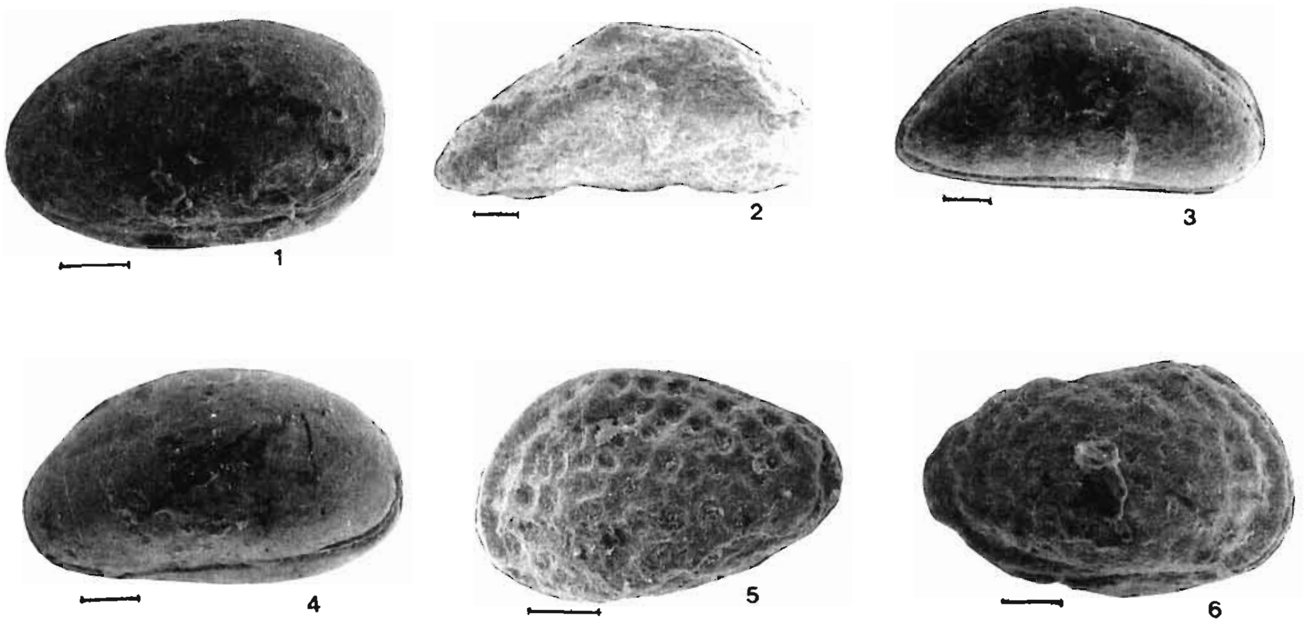


PLATE 2

(In all cases the scale bar represents 100 μm)

1. *Xestoleberis ovata* Bonnema, right valve view.
2. *Macrocypris limburgensis* Veen, right valve view.
3. *Paracypris limburgensis* Veen, right valve view.
4. *Krithe boldyi* Banerji, right valve view.
5. *Schuleridea bilobata* (Triebel) Banerji, right valve view.
6. *Loxoconcha rugialvus* Crane, right valve view.

Cytherella ovata (Roemer)
Cytherelloidea cf. *tricarinata* Sastri & Mamgain
Bairdia ex. gr. B. *pentagonalis* Veen
Bairdia ex. gr. B. *cretacea* Veen
Bairdia supplanata Veen
Ovocytheridea ariyalurensis Jain
Veenidea limburgensis Veen
Cushmanidea pandei Jain *Neocytherideis elongata* (Sastri & Mamgain)
Neocytherideis reymenti Jain
Actinocythereis subelongata Banerji
Kikliocythere szczechurae Jain
Leguminocythereis subrectangulata Singh & Porwal
Leguminocythereis sp. aff. *L. heistensis* (Keij)
Murrayina ariyalurensis Jain
Xestoleberis ovata Bonnema
Macrocypris limburgensis Veen
Paracypris limburgensis Veen *Krithe boldyi* Banerji
Schuleridea bilobata (Triebal)
Loxoconcha rugialvus Crane

Majority of the taxa recorded are from the arenaceous limestones of Patti Formation. The species restricted to this are : *Cytherella ovata, Cytherelloidea* cf. *tricarinata, Ovocytheridea ariyalurensis, Kikliocythere szczechurae, Murrayina ariyalurensis, Xestoleberis ovata, Macrocypris limburgensis, Paracypris limburgensis* and *Loxoconcha rugialvus.* Other dominant forms in the assemblage are: *Bairdia pentagonalis, B. cretacea, B. supplanata* and *Xestoleberis ovata.* Most of the forms are endemic and a few are cosmopolitan in nature. They can be compared well with the fauna of Pondicherry and Ariyalur areas.

Kikliocythere szczechurae, Bairdia cretacea, B. pentagonalis, B. supplanata, Veenidea limburgensis, Macrocypris limburgensis and *Paracypris limburgensis* are recorded for the first time. These species are known from Sillakkudi and Kallankurchchi Formations of the Ariyalur area, and also from the type-Maestrichtian of Holland. It is obvious that some species signify the cosmopolitan character of ostracodes of Vridhachalam area. However, species such as, *Krithe boldyi, Schuleridea bilobata* and *Loxoconcha rugialvus* are endemic in nature and restricted to the Patti Formation. It may be believed that there was a free movement of ostracode fauna between West Africa, North Africa, North America, West Europe and India during the Cretaceous times (Bhatia, 1984).

AGE IMPLICATION

The Patti Formation also records abundant and well-preserved planktic and benthic foraminifera, the presence of these being the main source of information for age determination. The occurrence of important keeled *Globotruncana* and *Rugoglobigerina* confirmed the Upper Campanian age for the Patti Formation (Govindan, 1969; Banerji, 1970). This correlates well with the *Karapadities karapadensis* Zone of ammonites (Upper Campanian) of the Ariyalur area (Sastry *et al.*, 1968). Therefore, the sedimentation initiated during Campanian times and not in Late Santonian to Early Campanian as was believed earlier. There are nine species of ostracodes which are common with the Sillakkudi Formation of the Ariyalur area. These are *Actinocythereis subelongata, Cushmanidea pandei, Krithe boldyi, Veenidea limburgensis, Leguminocythereis subrectangulata, L. heistensis, Loxoconcha rugialvus, Schuleridea bilobata* and *Neocytherideis elongata*. The species which extend their range into the overlying Ariyalur Formation are shown in Table 2 and bear similarity with European forms of Maestrichtian age. *Cytherella ovata,* a long ranging cosmopolitan species known from the Aptian-Albian (Oertli, 1958) and Cenomanian-Maestrichtian (Babinot, 1980) of France, occurs commonly in the Patti Formation. Therefore, its indicated age range from Aptian-Upper Campanian may not be of any help in the present work to consider age aspects of arenaceous unit of the Patti Formation. *Veenidea limburgensis* which is abundant in the collection is also known from the Maestrichtian of different parts of the world. Therefore, evidences furnished by the ostracode species suggest Upper Campanian-Lower Maestrichtian age for the Patti Formation of Vridhachalam area.

CRETACEOUS-TERTIARY TRANSITION

A few continuous sections across the boundary are known from the Cauvery Basin (Raju *et al.*, 1991), besides the well known section from Meghalaya (Bhandari *et al.*, 1987). The Cretaceous sea which deposited sediments in the Tiruchirappalli area from Upper Albian onwards had its maximum extension during Campanian-Maestrichtian time covering Vridhachalam and Pondicherry. It receded at the end of Maestrichtian and before long transgressed again introducing different fauna. The Patti and Ariyalur Formations have yielded typical Campanian and Maestrichtian ostracode assemblage and comparable to the same age of Western Europe (Sugumaran, 1997). The Palakkollai Formation overlies the Ariyalur Formation and yielded no ostracodes. The contact between the Ariyalur and Palakkollai Formations are gradual. On the basis of its sequence and unfossiliferous nature the Palakkollai Formation is assigned to Late Maestrichtian (Rasheed & Govindan, 1966). The Pondicherry Formation overlies the Palakkollai Formation and yielded typical Paleocene ostracodes (Nagaraj *et al.*, 1996) which are totally different from those of Patti and Ariyalur Formations (Late Cretaceous). Therefore, it is possible to place the KTB above the Palakkollai Formation (Late Maestrichtian) and below the Pondicherry Formation (Paleocene) in Vridhachalam area.

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REFERENCES

Babinot JF 1980. Les ostracodes du Crétacé supérieur de provence. *Unpubl. Ph.D. Thesis.* Univ. of France.

Banerji RK 1970. Marine Upper Cretaceous ostracode from the Lower Ariyalur stage of Vridhachalam, south India. *J. palaeont. Soc. India* **14** : 28-46.

Bhandari N, Shukla PN & Pandey J 1987. Iridium enrichment at Cretaceous/Tertiary Boundary in Meghalaya. *Curr. Sci.* **56** (19) : 1003-1005.

Bhatia SB 1984. Ostracode faunas of the Indian subcontinent, their palaeozoogeographic and palaeoecologic implications. *J. palaeont. Soc. India* **20** : 1-8.

Blanford HF 1865. On the Cretaceous and other rocks of the South Arcot and Trichinopoly districts. *Mem. geol. Surv. India* **4** (1) : 1-217.

Govindan A 1965. Palaeontological studies of the formations of Vridhachalam and Pondicherry areas of Madras State. *Unpubl. Ph.D Thesis.* Univ. of Madras.

Govindan A 1969. A preliminary note on the occurrence of ostracodes from the Upper Cretaceous rocks of Vridhachalam, south India. *Bull. geol. Soc. India* **6** (4) : 127-129.

Nagaraj HM, Sugumaran S & Mallikarjuna UB 1996. Ostracode fauna of the Pondicherry Formation (Paleocene) of Vridhachalam area, Tamil Nadu. *In* : Pandey J *et al.* (Editors) — *Contrs. XV Indian Colloq. Micropal. Stratigr., Debradun* : 421-427.

Oertli HJ 1958. Les ostracodes de l' Aptien-Albian d' Apt. *Rev. Inst. francaise Petrole* **13** (11) : 1494-1537.

Raju DSN, Ravindran CN, Misra PK & Singh J 1991. Cretaceous and Cenozoic foraminiferal zonal framework for East Coast sedimentary basins of India. *Geosci. J.* **12** (2) : 155-175.

Rasheed DA & Govindan A 1966. Stratigraphy of the Cretaceous rocks of Vridhachalam, south India. *Bull. geol. Soc. India* **3** : 3-4.

Sastri MVA, Rao BRJ & Mamgain VD 1968. Biostratigraphic zonation of the Upper Cretaceous formations of Trichinopoly District, south India. *Mem. geol. Soc. India* **40** (2) : 10-17.

Stoliczka F 1861-1873. Cretaceous fauna of south India. *Mem. geol. Surv. India* **1-4.**

Sugumaran S 1997. Geologic studies of the Cretaceous-Tertiary succession of the Vridhachalam area, Tamil Nadu, south India. *Unpubl. Ph.D Thesis.* Univ. of Bangalore.

Venkatachala BS & Sharma KD 1974. Palynology of the Cretaceous sediments from the subsurface of Vridhachalam area, Cauvery Basin. *Geophytology* **4** (2) : 153-183.

Physical and biological changes across the Jurassic/Cretaceous Boundary in northwestern Kutch Basin

Nageshwar Dubey & B. K. Chatterjee

Dubey N & Chatterjee BK 1997. Physical and biological changes across the Jurassic/Cretaceous Boundary in northwestern Kutch Basin. *Palaeobotanist* **46** (1, 2): 141-148.

In the northwestern part of the Kutch Basin, Lower Cretaceous shales and trigonid-bearing / bioturbated/ barren sandstones, overlie the glauconitic Upper Tithonian *Virgatosphinctes*-bearing "Umia Ammonite Bed" (138±20 Ma). During the lithofacies studies of this sequence, lithology, physical and biogenic sedimentary structures, bed geometry, palaeocurrent and fossil contents were given special attention. Laboratory investigations of heavy minerals, rock fragments and clay minerals revealed two distinct assemblages, one for the lower (Jurassic) and other for the upper (Cretaceous) part of the sequence. Lower part of the sequence is rich in low energy sedimentary structures, biogenic structures of sediment and deposit feeder, heavies and rock fragments of metamorphic province and clay minerals of marine origin. On the other hand, the upper part is rich in high energy sedimentary structures, biogenic structures of suspension feeders, heavies and rock fragments of granitic province and clay minerals of fresh to brackish water origin. These differences are of vital importance in delineating major changes such as shoreline orientation, changing provenance, relative sea level and tectonics during Jurassic/Cretaceous period in northwestern Kutch Basin.

Key-words—Sedimentology, Jurassic, Cretaceous, Kutch Basin, India.

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सारांश

उत्तर-पश्चिमी कच्छ द्रोणी में जुरेसिक/क्रीटेश्यस सीमा पर भौतिक एवं जैविक परिवर्तन

नागेश्वर दूबे एवं बिनय कुमार चटर्जी

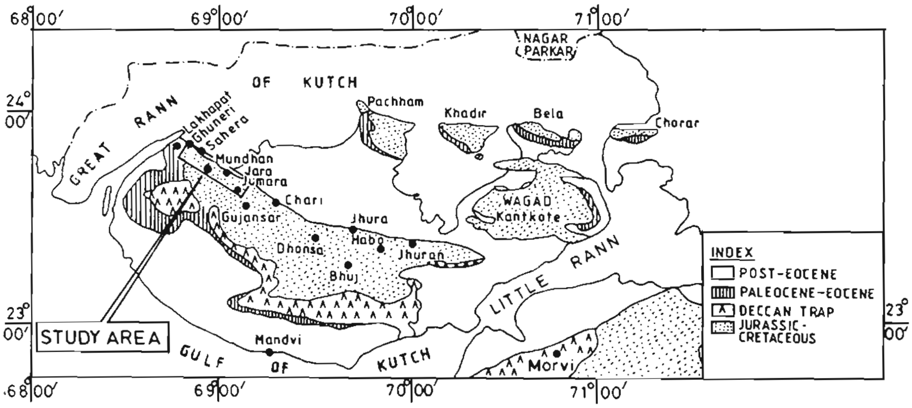
कच्छ द्रोणी के उत्तर-पश्चिमी भाग में अधरि क्रीटेश्यस शैल, ट्राइगोनिड-धारक/जैवजनित संरचना/जीवाश्म विहीन बलुआ पत्थर ग्लॉकॉनाइटी उपरि टिथोनियन *विरगेटोस्फिंक्टीस*-धारक ''उमिया अमोनाइट संस्तर'' (13.8±2.0 करोड़ वर्ष) के ऊपर विद्यमान हैं। इस अनुक्रम के शैल-लक्षणी अध्ययन के समय शैलविज्ञान, भौतिक एवं जैवजनित अवसादी संरचनाओं, संस्तर ज्यामिति, पुराधारा तथा जीवाश्मों की प्रचुरता पर विशेष ध्यान दिया गया है। भारी खनिजों, शैल खण्डों एवं मृदा खनिजों के विश्लेषण से दो विभिन्न समुच्चयों की उपस्थिति व्यक्त हुई है। जिनमें से एक अधरि (जुरेसिक) तथा अन्य उपरि (क्रीटेश्यस) है। अनुक्रम के निचले भाग में अल्पऊर्जा जनित अवसादी संरचनाओं, अवसाद व निक्षेप भोगी जैवजनित संरचनाओं, कायान्तरी प्रदेश के भारी खनिजों एवं शैल खण्डों तथा समुद्री उत्पत्ति के मृत्तिका खनिजों की प्रचुरता है। जबकि ऊपरी भाग में तीव्र ऊर्जा जनित अवसादी संरचनाओं, निलम्बन-भोगी जैव-जनित संरचनाओं, ग्रेनाइट के भारी खनिजों एवं शैल-खण्डों तथा खारे व अलवणीय जल में उत्पन्न मृत्तिका खनिजों की बाहुल्यता है। कच्छ द्रोणी में जूरेसिक-क्रीटेश्यस सीमा पर ये भेद प्रमुख परिवर्तनों जैसे पुरासमुद्ररेखीय सीमा, आनुपातिक समुद्री स्तर एवं विवर्तनिक गतिविधियों के अध्ययन में अत्यन्त महत्वपूर्ण सिद्ध हुए हैं।

WYNNE and Fedden (1872) divided the Mesozoic successions of Kutch Basin (Text-figure1) into a Lower (marine) and Upper (non-marine) unit. Later, Stoliczka (in Waagen, 1875) recognised four units, namely, Patcham, Chari, Katrol and Umia, in ascending order. This classification was followed by Rajnath (1932), Spath (1933) and later workers. Biswas (1977) classified the entire Mesozoic succession of the Kutch Basin into four lithostratigraphic units, i.e., Jhurio, Jumara, Jhuran and Bhuj Formations (Table 1).

A transgression of the epeiric sea produced argillaceous and calcareous, shallow marine, fossiliferous, tabular or sheet-like retrogradational succession (Jhurio, Jumara and partly Jhuran Formations) during Bajocian to Tithonian. This transgressive event reached its acme during Oxfordian, resulting in an aggradational succession of oolitic, fossiliferous hardground of limestone (Dhosa Oolite) in the upper part of Jumara Formation. Finally, major regression of Mesozoic sea produced wedge-shaped unit of coarsening and thickening upward, progradational succession partly Jhuran and Bhuj Formations) during Neocomian to Coniacian/ Turonian.

Table 1—Litho- and chrono-stratigraphical schemes of Mesozoic of Kutch with lithology of various units

WYNNE & FEDDEN (1872)	STOLICZKA in WAAGEN (1875)	RAJNATH (1932)		SPATH (1933)		BISWAS (1971, 77, 81)		PANDEY & DAVE (1993)	LITHOLOGY OF THE STUDY AREA	EPOCH AGE(Ma) SUCCESSION		PERIOD
UPPER (NON - MARINE)	UMIA GROUP	BHUJ SERIES	Palmoxylon beds Ptilophyllum beds Zamia beds	UMIA GROUP		BHUJ FORMATION	UPPER or BHUJ		Thick, coarse, friable sst., with thin glauconitic bands (capped by laterite). Alternating thin, ferruginous, hard sst. & shale, bioturbated sst., coarse friable sst. & shales leaf impression. Sand:Shale= 4:1	CONIACIAN ---89--- TURONIAN		CRETACEOUS
		UKRA BEDS	Calcareous shales		Ukra beds		MIDDLE or UKRA		TRIGONID bearing two/three coquina bands with giant symmetrical ripple; green, glauconitic shale and sst. with fossiliferous bands. Oölitic lst. with wood trunk. Sand:Shale= 1:1	PTIAN-ALBIAN ---112---		
		UMIA GROUP	Unfossiliferous mainly shales				LOWER or GHUNERI	MUNDHANIAN STAGE	Cyclic repetition of thick, maroom, hard, highly bioturbated sst., coarse, friable, cross-bedded yellow/pink sst., laminated shales (coal, carbonaceous shales & paleosol?) Silty/Sandy shale and argillaceous sandstone, leaf impression + wood. Sand:Shale= 3:1	—120—	PROGRADATIONAL (PS) NEOCOMIAN	
			Barren Sandstone		Barren beds	JHURAN FORMATION	KATESAR		Coarse, friable, greenish-yellow sandstone with abundant sedimentary structures, white gypsyferous shale with TRIGONID bearing thin bands of conglomeratic sandstones Oölitic sst. with leaf impression + wood. Sand:Shale= 2:1			
			TRIGONIA RIDGF Sandstone Barren sandstone Three green oolitic bands		TRIGONIA bearing sst. Green oolitic beds		UPPER		Coarse, friable, cross-bedded sandstone; flaggy sst., shale TRIGONIA RIDGE SANDSTONE (very hard, fossiliferous & hard barren, calcite cemented sst., conglomeritic base); Three green, glauconitic, poorly oolitic, fossiliferous limestone at the base. (VIRGATOSPHINCTES bearing Umia Ammonite Bed) Sand:Shale = 3:1	---138--- TITHONIAN		
	KATROL GROUP	KATROL GROUP	UPPER Mainly shales & sst	KATROL GROUP	Gajansar beds mainly shale Barren sst. Upper Katrol		MIDDLE	UMIAIAN	Thickly bedded, coarse, hard, compact, calcitecemented GRYPHAEA bed(Ridge), ferr., fossiliferous sst. silty/sandy shales. Locally coral bearing in JARA DOME, laterally extending and ridge forming. Thick shale beds producing valleys. Sand:Shale = 1:1	—140—	AGGRADATIONAL (AS)	
			MIDDLE Mainly sandstones LOWER Mainly shale		Middle Katrol Lower Katrol Kantcote sst.		LOWER	KATROLIAN	Thick, silty/sandy, poorly gypsiferous, grey-white shale with maroom nodules (sometimes enclosing fossils in their centers). Medium to coarse, hard, compact sandstones. Flaggy sandstone etc. forming small ridges. Sand:Shale = 1:2	KIMMERIDGIAN ---145---		
LOWER (MARINE)	CHARI GROUP	CHARI GROUP	Dhosa Oolite (bed no.1) Atheleta beds (bed no. 1a-3) Anceps beds (bed no. 4 & 5)	CHARI GROUP	Dhosa Oolite Atheleta beds	JUMARA FORMATION	UPPER	DHOSAIAN	Oolitic, (Dhosa Oölite) richly fossiliferous, glauco. lst. & (conglomeratic, intraformational), olive-green (khaki shale), (gypsiferous, nodule bearing, fossiliferous) & limestones (thick, yellow, fossiliferous, sandy, jointed). Shale predominates, shale > limestone	OXFORDIAN ---152---		JURASSIC
			Rehmani beds (bed no.6)		Anceps beds		MIDDLE	CHARIAN STAGE	Thick, very hard, highly fossiliferous, jointed, yellow small ridge forming limestone in thick olive green/ khaki shale, gypsiferous, with thin bands of biomicrite highly fossiliferous shale having nodules enclosing either ammonoids or septarian type). Shale predominates, shale > limestone			
			Zeilleria zone Shales & sandstones		Rehmanni beds		LOWER		Thick, gypsiferous, septarian & concretionary nodules bearing highly fossiliferous shale with thin bands of biomicrite (shell limestone), 'Golden Oölite' bearing fossiliferous limestone at KEERA DOME (East of study area). Shale predominates, shale > limestone		RETROGRADATIONAL (RS)	
	PATCHAM GROUP	PATCHAM GROUP	Bed no.22 cream coloured limestones Bed no.22 to 26 and more at PATCHAM Island		Macrocephalus beds	JHURIO FORMATION	UPPER	BADIAN STAGE	Grey-white, thick, pebbly/conglomeratic highly fossiliferous limestone, coral bearing limestone, white calcareous shale (marl), olive green-grey, gypseous shale Shale > limestone	CALLOVIAN ---157--- BATHONIAN		
				PATCHAM GROUP	Patcham coral beds Patcham Shell limestone		MIDDLE		Unexposed in the study area Thickly bedded, grey-yellow shales alternating with golden oölite			
					Patcham basal bed Kuar Bet Bed		LOWER		Thin beds of yellow and grey limestones with golden oölite in grey shale	---165---		
GORA DONGAR FORMATION KALA DONGAR FORMATION (encountered in Banni well no. 2 and Nirona - 1)								PATCHAMIAN BANNIAN	Mottled clay, claystone, shales, sst. with carb. matter, silty shale, minor limestone, lateritic clay, coarse sst., gravels, kaolinitic clay Sandstones, conglomerates, igneous wash etc.	BAJOCIAN ---171--- AALENIAN ---179---		



Text-figure 1—Geological map of the Kutch Basin with study area in northwestern part of Mainland.

Presence of well-preserved ammonites with other fauna facilitates high resolution chronological studies of Jurassic rocks whereas absence of mega index fauna in Cretaceous rocks (except Aptian-Albian, Ukra Member) makes it difficult to mark the base of Cretaceous. Three green, glauconitic, fossiliferous (Tithonian) oölitic, argillaceous limestone bands (1 m, 0.3 m & 0.1 m) alternating with grey, gypsiferous shale bands (1.5 m & 1 m), collectively known as 'Umia Ammonite Bed' mark the Jurassic/Cretaceous transition (Dubey & Chatterjee, 1996). This boundary roughly coincides with the Umiaian and Mundhanian stages of Pandey and Dave (1993). Glauconitic sample of middle band shows a radiometric age of 138 ± 20 Ma (Srivastava *et al.*, 1994). This age roughly coincides with global Jurassic/Cretaceous boundary. Among these three alternating glauconitic bands (1, 2, 3), bed thickness, glauconite and fossil content gradually decrease towards youngest (Figure 1). Occurrence of these glauconitic bands in the western part of the basin is totally facies dependent as they laterally pass into conglomeratic sandstone towards eastern part of the basin (continental side). The absence of glauconitic bands makes it difficult to demarcate the Jurassic/ Cretceous boundary in the central and eastern parts of the basin.

GEOLOGICAL BACKGROUND

Mesozoic sediments in the Kutch Basin directly overlie on Precambrian granitic/syenitic basement with an unconformity (Biswas & Deshpande, 1968).

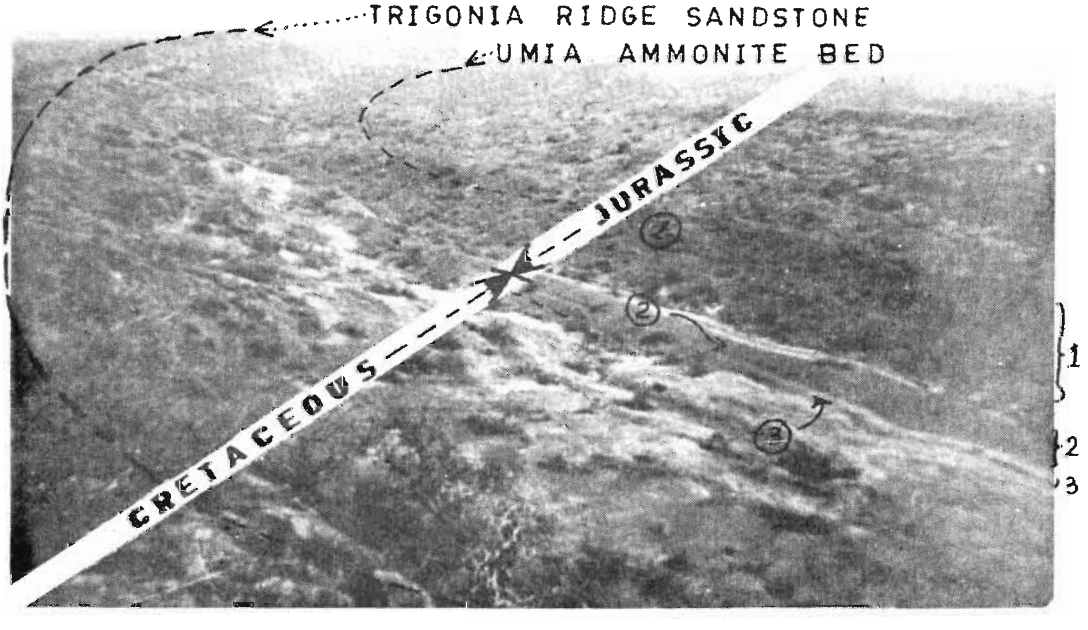
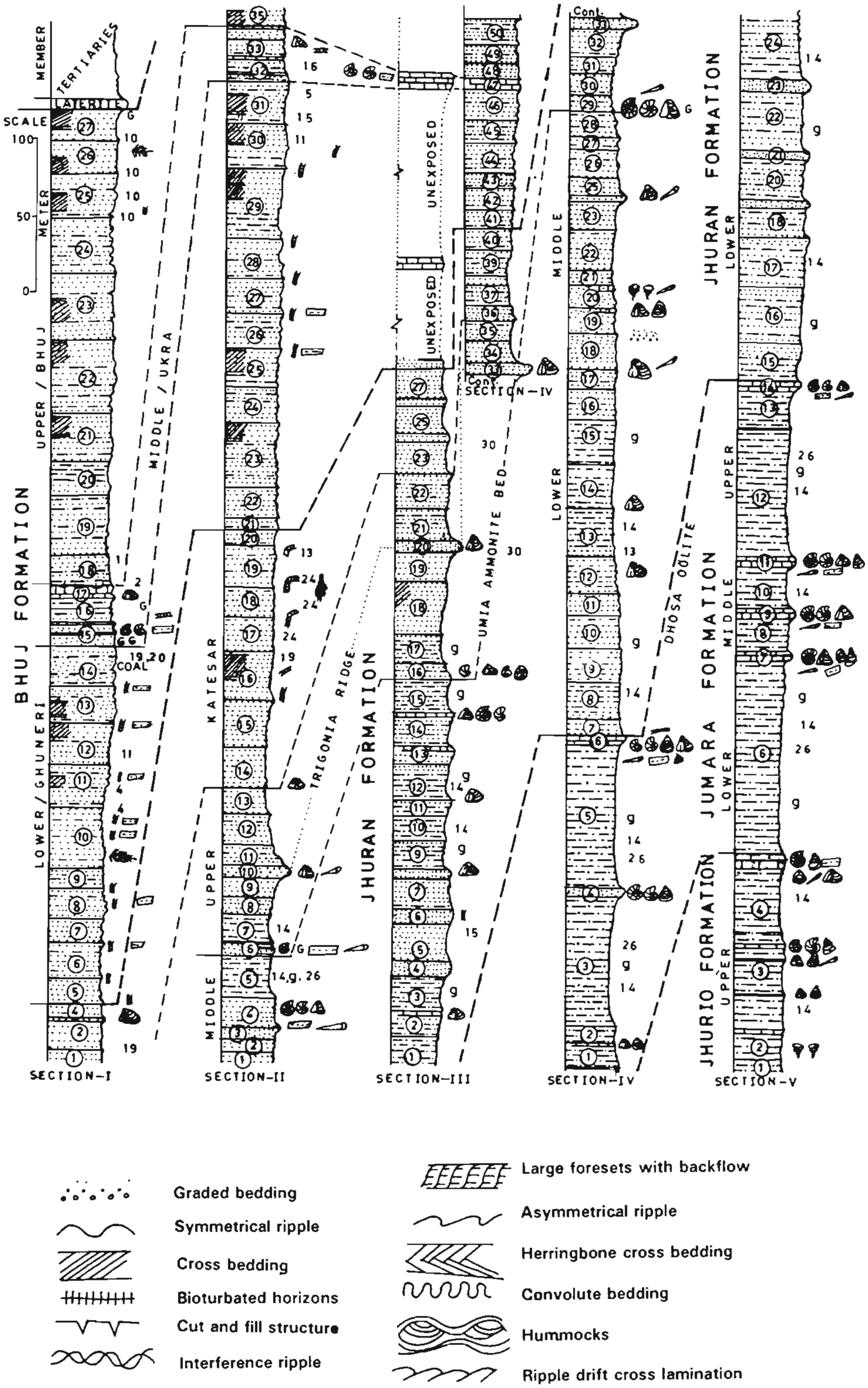


Figure 1—Field photograph showing three green glauconitic bands (1,2 & 3) at the base of Upper Member, Jhuran Formation (≃Umia Ammonite Bed) overlain by "*Trigonia* Ridge Sandstone" in Mundhan Anticline.

Three east-west trending asymmetrical anticlinal ridges, e.g.," the Island belt", Mainland and Katrol-Charwar in the south have domal outcrops with dome centers having oldest rocks and younger rocks near periphery. The study area lies between latitude N23°4' to 23°49' and longitude E68°50' to 69°06' (Text-figure 1). Five domes of the Mainland at Jumara, Jara, Mundhan, Sahera and Ghuneri were examined to get



Text- figure 2—Vertical lithocolumns with occurrence of physical and biological characters. Section I- Ghuneri dome; Section II- Sahera (Katesar) dome; Section III-Mundhan anticline; Section IV-Jara dome and Section V- Jumara dome.

a complete succession deposited during Middle Jurassic to Upper Cretaceous (Text- figure 2). Jurassic/ Cretaceous Boundary could easily be traced in glauconitic outcrops of Jara, Mundhan and Sahera domes. The oldest exposed rock (Bathonian) in present area of study lies in the centre of Jumara dome whereas the youngest (Coniacian/Turonian) occurs on the periphery of Ghuneri dome. Vertical litho-columns for each dome were prepared and sampled at close and regular intervals.

Mundhan Anticline

The Mundhan Anticline has an ideal exposure of Jurassic/Cretaceous rocks. A vertical profile was prepared by taking traverses from anticline center up to Mundhan Village (only bed no.8-21 are shown as sedimentary log in Text-figure 3), measuring more than 503 m of succession with thirty prominent beds. (Text-figure 2). It represents a composite sequence of Middle (bed no. 1 to 15; 265 m thick), Upper (bed no. 16 to 22; 143 m thick) and Katesar Member (bed no. 23 to 27; 75 m thick) of Jhuran Formation. Ghuneri Member, overlying on Jhuran Formation (bed no. 28 and other unexposed beds), followed by Ukra (M2) and Bhuj Members of Bhuj Formation, are well exposed in Sahera and Ghuneri domes, respectively (Dubey, 1992).

Lithologically silty shale, coarse friable sandstone, hard compact bivalve-bearing sandstone, ferruginous cemented well-sorted sandstone, oolitic, glauconitic, argillaceous limestones and olive green (khaki) shales are the main lithology. Tabular cross-bedding, herringbone cross-bedding, flaser and grad-

Table 2– List of common physical sedimentary structures encountered in Jurassic/Cretaceous succession of northwestern Kutch Basin(R= rare, C=common, and A=abundant)

Symbol in Fig. 4			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
AGE PERIOD	FORMATION	Sedimentary structure MEMBER	Current ripple	Mega wave ripple	Wave-current "	wave ripple with mud drape	Interfer. ripple	Massive beds	Parting lineation	Planar beds & transcurrent lamin.	Reactivation surfaces	Gradded bedding	Planar/tangential (tidal-bundle)	Tabular/trough/swash x-bedding	Ripple drift x-lamination	Flaser/lenticular beds	Herringbone x-bed	Hummocky/swaley x-bed & antidune?	Fining upward	Coarsening upward	Cut & fill stru.	Large channel, intraformat. congl.	Deformed x-beds	Slumps & slides	Flute mark	Convolute beds	Load cost, pseudonodules	Septarian nodules	Oriented Shells	Imbricated pebble	Box-work & mud cracks	Conglomerate
CRETACEOUS	BHUJ	UPPER or BHUJ	C	R	C	-	C	A	R	C	A	A	C	C	R	R	R	R	-	C	A	C	C	R	R	R	R	R	R	C	C	C
		MIDDLE or UKRA	-	R	R	R	C	C	R	C	R	C	-	-	R	R	R	C	C	-	R	-	R	-	R	R	R	R	C	R	-	R
		LOWER or GHUNERI	A	R	C	C	R	C	R	C	A	A	A	C	C	A	C	C	-	A	A	C	C	R	R	R	R	C	R	R	R	C
		KATESAR	A	R	A	-	R	C	C	C	A	A	C	C	R	R	C	C	-	A	A	C	C	C	R	C	R	R	R	R	R	A
138 (Ma)	JHURAN	UPPER	C	R	C	R	R	A	C	C	R	C	R	R	A	C	R	R	-	C	C	R	R	R	C	R	C	R	C	R	A	A
		MIDDLE	R	-	R	R	R	A	C	C	R	C	R	R	A	C	R	R	-	A	C	C	R	R	C	R	C	C	R	R	R	C
		LOWER	R	-	R	-	R	A	C	C	R	R	-	-	A	C	-	-	-	A	R	R	R	-	R	-	C	C	R	R	R	C
JURASSIC	JUMARA	UPPER	-	-	-	-	-	C	C	R	R	R	-	-	C	A	-	-	A	-	-	-	-	-	R	-	C	A	C	-	C	C
		MIDDLE	-	-	-	-	-	C	C	R	R	R	-	-	C	A	-	-	A	-	-	-	-	-	R	-	C	A	R	-	C	C
		LOWER	-	-	-	-	-	C	C	R	-	-	-	-	C	A	-	-	A	-	-	-	-	-	R	-	C	C	C	-	C	C
	JHURIO	UPPER	-	-	-	-	-	C	-	-	-	-	-	-	-	R	-	-	C	-	-	-	-	-	-	-	C	C	-	-	R	R

BASE NOT EXPOSED

ed bedding with load caste structures are common features (Table 2). The Upper Member of Jhuran Formation also includes " *Trigonia* Ridge Sandstone" in the middle. It constitutes three thick, very hard, compact, trigonid-bearing sandstone bands (F) alternating with coarse, rarely fossiliferous sandstone bands, i.e., D (Figure 2). Katesar Member shows conspicuous development of storm-induced low angle hummocks in sandstone and intraformational conglomerate. Vertical to subvertical tubes of meter length and few centimeter diameter are abundant in bioturbated, coarse, friable sandstone of this unit.

Physical changes across Jurassic/Cretaceous Boundary

Middle to Upper Jurassic period is marked by a world-wide sea-level rise reaching its acme during Oxfordian or Kimmeridgian (Vail & Todd, 1981; Hallam *et al.*, 1985), causing major transgression in many parts of the world. Mesozoic Kutch Basin also evolved at the same time as a combined result of eustasy and basinal/ provenance tectonics. In general, Jurassic transgression in the Kutch Basin deposited a retrogradational succession of muddy lithology (shale, limestone, argillaceous sandstone) characterised by fining upward cycles of uniform thickness and sandwitching "Dhosa Oolite" of Oxfordian age. It was deposited during still-stand phase of starved sedimentation, representing aggradational succession.

The beginning of the Cretaceous marks a global sea-level drop followed by gradual sea-level rise. Former is true for the Kutch Basin also, whereas the later was compensated by the uplift of provenance/ basin with high rate of sedimentation, resulting into regression. This deposited wedge-shaped coarser clastics (conglomeratic sandstone, sandy limestone and silty shale) of progradational succession of coarsening and thickening upward cycles.

Sedimentary structures–These commonly include both symmetrical and asymmetrical small and mega ripples, sandwaves, interference ripples, planar and trough cross-stratification, tidal bundles, hummocky cross-lamination, parting lineation, sole marks, herring-bone cross-bedding, flaser and lenticular bedding, large and small tidal channels (Table 2). Jurassic successions are characterised by low energy sedimentary structures like plane laminations, graded beddings, load casts, massive beds, etc., whereas Cretaceous successions are characterised by high energy sedimentary structures.

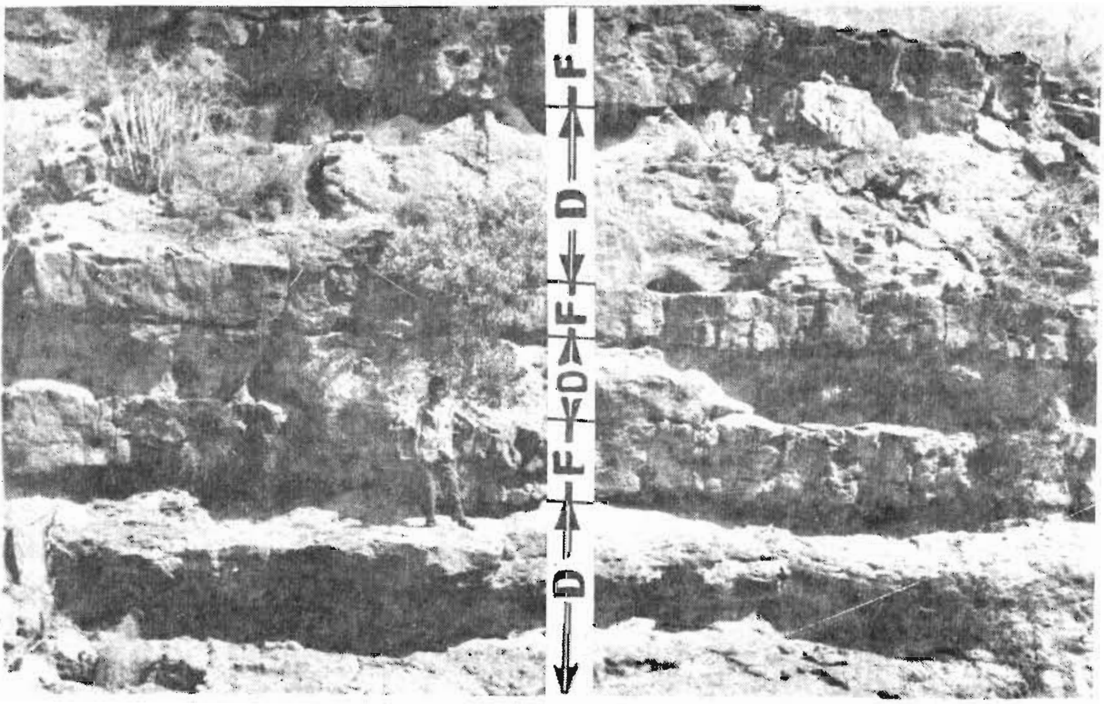


Figure 2—Field photograph showing vertical section of "*Trigonia* Ridge Sandstone" in Mundhan anticline. Distinct bands of hard, highly fossiliferous, granular, calcareous sandstone (F) and coarse, relatively friable, poorly fossiliferous sandstone (D) are alternating.

Bed geometry—Most of the beds deposited during Jurassic are tabular or sheet-like having almost equal thickness, whereas beds deposited during Cretaceous are wedge-shaped (Text- figure 2) generally thicker in offshore direction (West).

Heavy minerals—Both opaque and non-opaque heavies show variation in their abundance (Text-figure 3). Common heavy minerals are garnet, tourmaline, sillimanite, kyanite, monazite, andalusite, staurolite, zircon and rutile. Among the opaque heavies magnetite, ilmenite, leucoxene and hematite are common. There are two distinct assemblages, i.e., heavies of metamorphic affinity dominating in Jurassic, whereas heavies of granitic affinity dominate in Cretaceous.

Lithic/rock fragments—Chert, metaquartzite, quartz-mica schist, granite and silicified oolite are the main rock fragments (Text-figure 3). Similar to heavies, lithic fragments also show two distinct assemblages, i.e., metamorphic and granitic for Jurassic and Cretaceous, respectively.

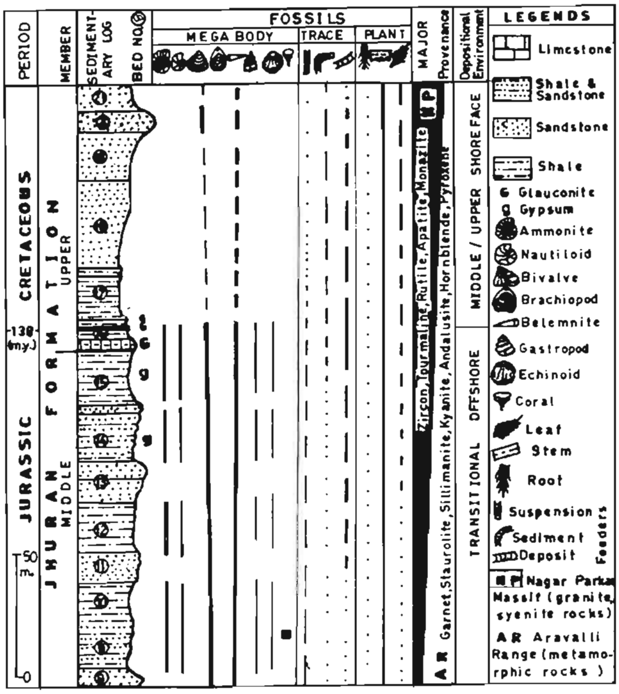
Clay minerals—Kaolinite, illite, chlorite and montmorillonite are the main clay minerals. Illite dominates in Jurassic of marine sediments, whereas kaolinite dominates gradually in Cretaceous indicating fresh to brackish water influence.

Palaeoshoreline—On the basis of palaeocurrent studies a changing scenario of palaeoshoreline emerged as north-south during Jurassic to northwest-southwest during Cretaceous.

Biological changes across Jurassic/ Cretaceous Boundary

The Jurassic succession is highly fossiliferous containing well-preserved cephalopods (ammonites, nautiloides, belemnites, etc.), gastropods, brachiopods, bivalves, echinoderms, corals and fossilised wood (Figure 2). Among the trace fossils, the *Cruziana - Zoophyços* ichnofacies predominates in the Jurassic sediments.

Gradual decrease in fossil content is prominent in Cretaceous part of the sequence, having either poor in body fossils or bioturbated sandstone bands. Bivalves and belemnites are preserved at certain levels only Figure 2. Among the ichnofossils *Skolithos - Arenicolites* ichnofacies predominates. However, the Ukra Member is similar in faunal content to the Jurassic succession, except for younger age and fossil dimensions alongwith *Cruziana - Teredolites* ichnofacies. The Bhuj Member lacks trace and body fossils. Well-preserved leaf-impressions common in this part of the Cretaceous succession. Sometimes wood pieces and root-like axes are also found. Thin coal bands occur at a few levels.



Text-figure 3—Variation of physical and biological characters across the Jurassic/ Cretaceous boundary. Sedimentary log shown in this figure is enlargement of lithocolumn of Mundhan anticline (bed no. 8-21; Section-III, Text-figure 2).

CONCLUSIONS

The Mesozoic sequence in this basin as a whole represents one major cycle of 2nd order (Vail *et al.*, 1977) having several mini-/para-cycles of smaller durations depending on the cumulative effect of sea-level fluctuations, basinal uplift and subsidence. The major transgressive phase commenced as early as pre-Bajocian (Jaitly & Singh, 1983), or Aalenian (Pandey & Dave, 1993) and continued up to Tithonian. During this time interval of more than 40 Ma, Jhurio (≃ Patcham) and Jumara (≃ Chari) and (Lower and Middle members) Jhuran (≃ Katrol) Formations were deposited.

The general regression of sea initiated during Neocomian, resulting into dominantly prograding barrier shoreline environments. During this interval of about 50 Ma, Jhuran (Upper and Katesar members) and Bhuj (≃ Umia) Formations were deposited. On the basis of the present study following differences between the Jurassic and Cretaceous sedimentation patterns have been observed.

1. Jurassic/ Cretaceous boundary lies between middle and upper bands of three green glauconitic bands at the base of Upper Member of Jhuran Formation. This is in accordance with the boundary established on the basis of microfossils (Umiaian/Mund hanian Stage boundary of Pandey & Dave, 1993).
2. Jurassic successions are dominated by carbonates and shales with minor sandstone (retrogradational and aggradational successions), with tabular geometry of uniform thickness, whereas Cretaceous is dominated by sandstones, shales with minor carbonates (progradational succession) of wedge-shaped geometry, thickening in offshore direction (West).
3. Rock/lithic fragments and heavy minerals of metamorphic affinity occur in abundance in the Jurassic as compared to Cretaceous, which contains heavies and lithic fragments of igneous origin.
4. Low energy sedimentary structures are common in the Jurassic, whereas high energy sedimentary structures frequently occur in the Cretaceous part of the sequence.
5. Undulose, polycrystalline, subrounded quartz characterises Jurassic, whereas non-undulose, subangular quartz grains are common in Cretaceous.
6. Amongst the clay minerals illite dominates in Jurassic indicating marine origin, whereas the presence of kaolinite in Cretaceous signifies fresh and brackish water influence.
7. Abundance of mega-, body fossils, including index fauna, characterises the Jurassic, whereas the Cretaceous is poor or sometimes barren in faunal content (except the Ukra Member and few trigonid-bearing thin bands).
8. Small pieces of fossilised wood occur throughout the sequence whereas coal seam, leaf-impressions and large wood trunks are preserved in Cretaceous.
9. Among the ichnofossils, Jurassic is dominated by sediment and deposit feeders whereas Cretaceous sediments are characterised by suspension feeders.
10. North-south palaeoshore line of Jurassic gradually changes to northwest-southwest during Cretaceous.
11. Aravalli range of Rajasthan situated in the east of the basin contributed much more sediments during Jurassic, whereas Nagar Parkar Massive of Pakistan from north and northeastern part contributed much during Cretaceous Period.

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REFERENCES

Biswas SK 1971. Note on the geology of Kutch *Q. Jl geol. Min. metall. Soc. India* **43** (4): 223-236.

Biswas SK 1977. Mesozoic rock stratigraphy of Kutch. *Q. Jl geol. Min. metall. Soc. India* **49** (3&4): 1-52.

Biswas SK 1981. Basin framework, palaeo- environment and depositional history of the Mesozoic sediments of Kutch Basin, western India. *Q. Jl geol. Min. metall. Soc. India* **53** (1&2): 56-85.

Biswas SK & Deshpande SV 1968. Basement of the Mesozoic sediments of Kutch, western India. *Bull. geol. Min. metall. Soc. India* **40:** 1-7.

Dubey N 1992. Mesozoic sedimentary sequences and their depositional environment in northwestern part of Kachchh Mainland, Gujarat. *Unpublished Ph.D. Thesis.* Banaras Hindu University, Varanasi.

Dubey N & Chatterjee BK 1996. The Cretaceous of Kachchh: their facies differentiation and depositional environments. *Natn. Sem. Cretaceous sedimentary environments, Madras. Abstracts:* 10.

Hallam A, Hancock JM, La Breque JL, Lowrie W & Channel JE 1985. The chronology of the geological record, Jurassic to Paleogene. Pt. 1 Jurassic and Cretaceous geochronology and Jurassic to Paleogene magnetostratigraphy. *In:* Snellying (Editor)–*Geol. Soc. Mem.* No. **10**: 118.

Jaitly AK & Singh CSP 1983. Discovery of the Late Bajocian *Leptosphinctes* Buckman (Jurassic Ammonitina) from Kachchh, western India. *N. Jb. geol. palaeont. Mh.* **2:** 91-96.

Pandey J & Dave A 1993. Studies in Mesozoic foraminifera and chronostratigraphy of western Kutch, Gujarat. *Mem. geol. Surv. India Paleont. indica* (1). Dehradun.

Rajnath 1932. A contribution to the stratigraphy of Kutch. *Q. Jl geol. Min. metall. Soc. India* **4** (4) : 161-174.

Singh IB 1989. Dhosa Oolite—a transgressive condensation horizon of Oxfordian age in Kachchh, western India. *J. geol. Soc. India* **34** (2): 152-160.

Spath LF 1933. Revision of the Jurassic cephalopod fauna of Kachh (Cutch). *Mem. geol. Surv. India Palaeont. indica* N.S 9 (2): 1-945.

Srivastava AP, Krishna JB, Rajagopalan G, Pathak DB & Ojha JR 1994. The first ever absolute age determination from the Jurassic of Kachchh, western India. *Geobios* **17**: 529-533.

Vail PR, Mitchum RM, Todd RG, Widmia JM, Thompson S, Sangree JB, Bubb JN & Hatelid WG 1977. Seismic stratigraphy and global changes of sea level. *In:* Payton CE (Editor)—*Stratigraphic interpretation of seismic data. Mem. Am. Assoc. Petroleum. Geol.* **26**: 49-212.

Waagen W 1875. Jurassic fauna of Cutch. *Mem. geol. Surv. India Palaeont. indica* ser. 9, **1**.

Wynne AB & Fedden F 1872. On the geology of Kutch. *Mem. geol. Surv. India* **9**:1-289.

A megaspore assemblage from the Athgarh Formation and its bearing on the age of the formation

B.N. Jana & Amit K. Ghosh

Jana BN & Ghosh AK 1997. A megaspore assemblage from the Athgarh Formation and its bearing on the age of the formation. *Palaeobotanist* **46** (1, 2) : 149-155.

Megaspores have been recorded from the Athgarh Formation of Mahanadi Basin. The megaspore assemblage comprises species of *Banksisporites*, *Bacutriletes*, *Erlansonisporites*, *Minerisporites*, *Saccarisporites*, *Paxillitriletes*, and seed structures referable to *Spermatites*. The megaspore assemblage has a preponderance of the genera *Paxillitriletes* and *Minerisporites* in association with other Early Cretaceous forms, and thus supports the age arrived at on the basis of megafloral data. Spore/pollen investigations had earlier revealed an age ranging between Upper Jurassic to Lower Cretaceous.

Key-words—Megaspores, Athgarh Formation, Mahanadi Basin, Lower Cretaceous, India.

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साराँश

अथगढ़ शैल-समूह से एक गुरुबीजाणु समुच्चय तथा शैल-समूह की आयु से इसका सम्बन्ध

बृजेन्द्र नाथ जाना एवं अमित कुमार घोष

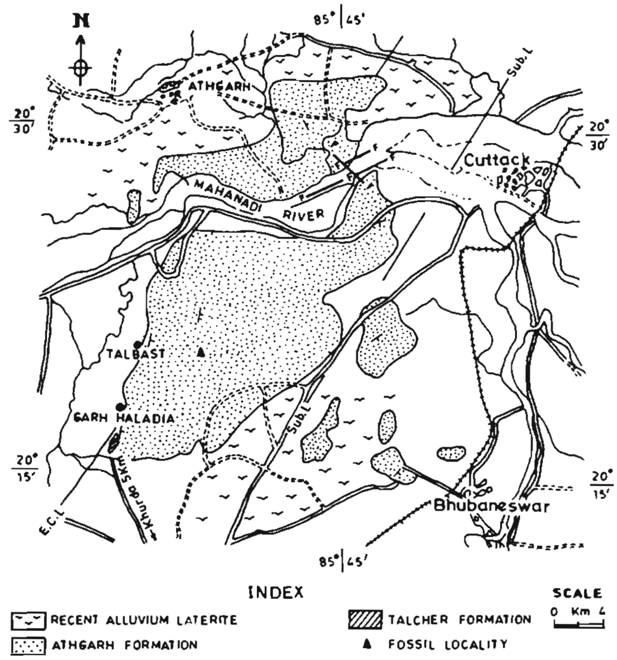
महानदी द्रोणी में अथगढ़ शैल-समूह से गुरुबीजाणु अभिलिखित किये गये हैं। इस गुरुबीजाणु समुच्चय में *बैंकसिस्पोराइटिस*, *बेक्युट्राइलिटीस*, *अर्लेन्सोनिस्पोराइटिस*, *माइनेरिस्पोराइटिस*, *सेक्केरिस्पोराइटिस*, *पैक्सीलीट्राइलिटीस* नामक प्रजातियों की जातियाँ तथा *स्पर्मेट्राइटिस* से तुलनीय बीज विद्यमान हैं जिनमें प्रारम्भिक क्रीटेशयस प्ररूपों के साहचर्य में *पैक्सीलीट्राइलिटीस* एवं *माइनेरिस्पोराइटिस* की पूर्व बाहुल्यता है। इस प्रकार यह समुच्चय भी गुरुवनस्पतिजात के आधार पर आँकी गई आयु की पुष्टी करती है। बीजाणु-परागकण अन्वेषण से इस शैल-समूह की उपरि जूरेसिक से अधरि क्रीटेश्यस आयु आँकी गई है।

THE Athgarh Formation, often referred to as 'Athgarh Sandstone', constitutes a part of the Mesozoic sedimentary sequences in Mahanadi Basin. The Mesozoic sediments in Mahanadi Basin lie unconformably over the Precambrian rocks or at places rest unconformably over the Permian sediments. The Athgarh Formation comprises conglomerates, grits, sandstones with intercalations of lenticular white, pink, yellow, dark grey clays and shales, ferruginous and carbonaceous shales and fireclay (Ball, 1877; Adyalkar & Rao, 1963; Patra, 1980). It is, in turn, overlain by laterite and alluvium. The estimated thickness of the formation is about 400 meters (Kumar & Bhandari, 1973).

Ball (1877) first collected plant megafossils from the Athgarh Formation; Feistmantel (1877) described these fossils. Subsequently, Athgarh megaflora has been worked out in detail by several workers. The megafloral assemblage is dominated by pteridophytes and conifers followed by cycadophytes and Bennettitales. Ginkgoales and Caytoniales are rarely represented in the assemblage.

Maheshwari (1975) recorded an *Araucariacites*-rich palynoassemblage of Athgarh Formation from Sidheshwar Hill, Cuttack District and Jagannath Prasad Quarry, Puri District. Jana and Tiwari (1986) and Patra (1990) further made palynological investigations of the sediments exposed in the Sidheshwar Hill. Jana (1990) recovered a palynoassemblage dominated by the genus *Murospora* from the Athgarh Formation near Talbast.

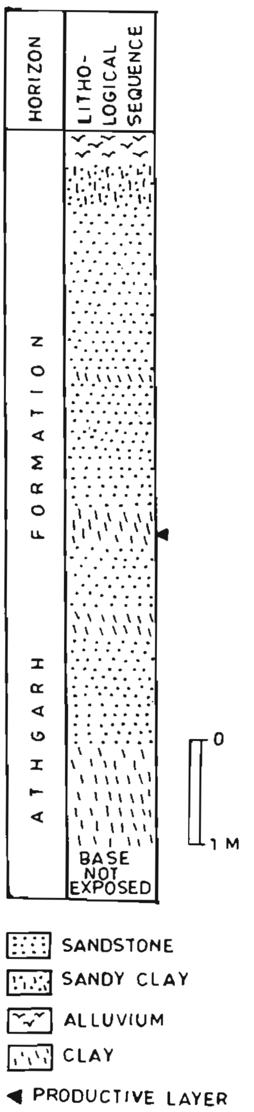
Samples for the present investigation on megaspores were collected from the exposure in an



Map 1—Geological map of a part of Athgarh Basin showing the fossil locality.

open cast 'Fire Clay Mine' in Talbast region. The mine is situated about 350 m east of Tata's Mine Guest House (Map 1). The section exposes alternate bands of sandstone and clay. Base of the section is not exposed and the top is covered by alluvium. The overall lithological sequence is represented in Text-figure 1. The megaspores were recovered from the 3rd clay band (from the base) which had earlier yielded miospores (Jana, 1990).

The megaspores were sorted out from the macerate which was collected over 150 sieve after treating the samples with hydrofluoric acid. The megaspores were dried and individual dry megaspore was studied and photographed under reflected light. The megaspore was then transferred to a covered petridish and oxidised in nitric acid. Sometimes, potassium chlorate was used to accelerate



Text-figure 1—Lithological sequence of Tata's Fireclay Mine at Talbast region showing the sampling site.

PLATE 1

⟶

(All figures X 100, unless otherwise mentioned)

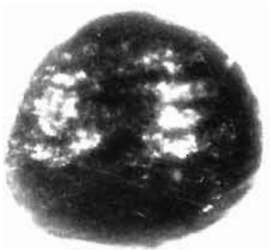
1, 2. *Banksisporites* sp. 1. Megaspore in dry state showing finely granulate exosporium; 2. Same megaspore after maceration showing disintegrated exosporium and dense mesosporium. Slide No. BSIP 11915.

3-5. *Erlansonisporites* sp. 3. Macerated megaspore in wet condition showing reticulate exosporium. Slide No. BSIP 11916; 4. Megaspore in dry state showing the reticulate ornamentation of exosporium; 5. Same megaspore in over-macerated condition. Slide No. BSIP 11917.

6. *Bacutriletes* sp. Megaspore in dry state showing well developed baculae on the proximal face. X 75; Slide No. BSIP 11918.

7-10. *Minerisporites auriculatus* Singh, Srivastava & Roy. 7. Megaspore in dry state showing distinct triradiate ridge and auriculi; 8. Same megaspore in wet condition after maceration; Slide No. BSIP 11919; 9. Another megaspore in dry state; 10. Same megaspore after overmaceration in wet condition. X 75. Slide No. BSIP 11920.

11, 12. *Minerisporites reticulatus* (Singh *et al.*) Banerji, Jana & Maheshwari; 11. A megaspore tetrad in dry state showing the proximal attachment of megaspores; 12. Same tetrad in wet condition showing a detached megaspore after maceration, remaining three are still proximally attached. X 75; Slide No. BSIP 11921.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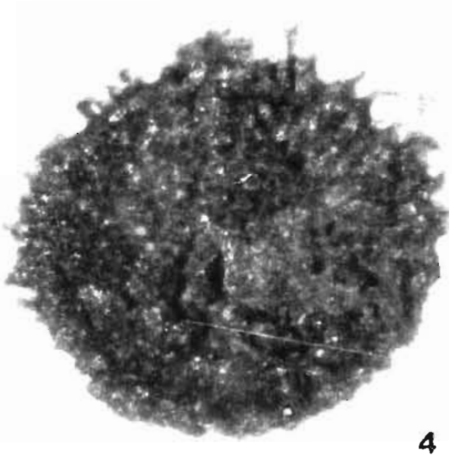
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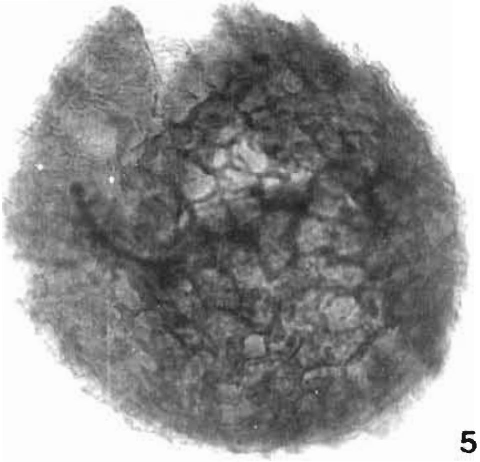
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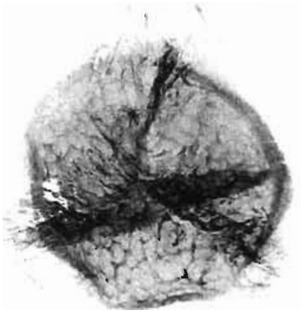
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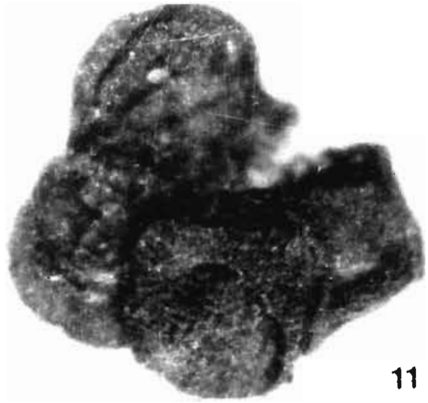
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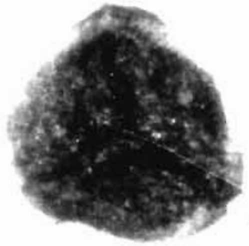
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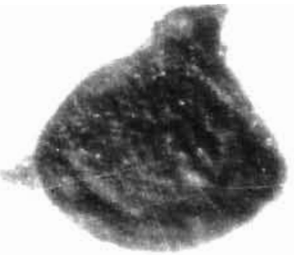
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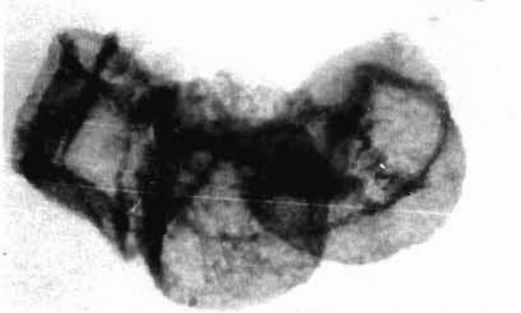
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PLATE 1

the oxidation process. After oxidation, the megaspores were digested, gradually, in dilute solution of potassium hydroxide and finally cleaned in water. During the gradual process of maceration photographs were taken in transmitted light. All the figured slides and negatives are preserved in the repository of Birbal Sahni Institute of Palaeobotany, Lucknow.

SYSTEMATIC DESCRIPTION

Anteturma — *Sporites* Potonié 1893
Turma — *Triletes* Reinsch emend. Potonié & Kremp 1954
Subturma — *Azonotriletes* Luber 1935
Infraturma — *Laevigati* Bennie & Kidston emend. Potonié 1956

Genus — Banksisporites Dettmann 1963 emend. Banerji, Kumaran & Maheshwari 1978

Banksisporites sp.
Pl. 1, figs 1-2

Description—Megaspores ± circular in outline, 310-325 µm in diameter in dry state and 350-385 µm in wet condition; triradiate mark and arcuate ridge not clearly discernible either in dry state or in wet condition; exosporium smooth to very finely granulate; mesosporium 320-350 µm in diameter.

Remarks—In overall appearance the specimens resemble those of *Banksisporites*, but in the absence of a distinct triradiate mark and arcuate ridge, these are not referable to any particular species of the genus.

Infraturma — *Apiculati* Bennie & Kidston 1854 emend Potonié 1956

Genus—*Bacutriletes* van der Hammen 1954 emend. Potonié 1956

Bacutriletes sp.
Pl. 1, fig. 6

Description—Megaspore ± circular, 510 X 550 µm in dry state and 580 X 640 µm in wet condition; triradiate mark not discernible in both dry state and wet condition; proximal face with well-developed, closely spaced, 6-13 µm long and 3-5 µm wide baculae; endosporium smooth, large and almost occupying the whole spore cavity.

Remarks—Due to restricted distribution pattern of baculae and absence of distinct triradiate mark the presently described specimen of *Bacutriletes* differs from those of known species, viz., *B. cutchensis* Singh *et al.*, *B. dijkstrae* Singh *et al.* and *B. srivastavae* Banerji *et al.* recorded from the Bhuj Formation of Kutch Basin.

Turma — *Zonales* (Bennie & Kidston 1886 ex Ibrahim) emend. Potonié 1956
Subturma — *Auritotriletes* Potonié & Kremp 1954
Infraturma — *Auriculati* Schopf ex Potonie & Kremp 1954

Genus — *Erlansonisporites* Potonié 1956

Erlansonisporites sp.
Pl. 1, figs 3-5

Description—Megaspores ± circular, 500-580 µm in dry state and 520-680 µm in wet condition, triradiate mark not clearly visible; exosporium ornamented with irregularly raised appendages, appendages anastomose to form reticula, meshes of reticula measuring 20 X 35 to 40 X 55 µm in wet condition.

Remarks—*Erlansonisporites* sp. apparently resembles *E. indicus* Banerji *et al.* from the Lower Cretaceous of Kutch Basin, but the former differs from the latter in having comparatively ill-developed appendages and indistinct triradiate mark.

PLATE 2

⟶

(All figures X 100, unless otherwise mentioned)

1. *Minerisporites reticulatus* (Singh *et al.*) Banerji, Jana & Maheshwari. Megaspore in overmacerated condition. X 75; Slide No. BSIP 11922.

2, 3. *Minerisporites auriculatus* Singh, Srivastava & Roy. 2. Megaspore in wet condition; Slide No. BSIP 11923; 3. Another megaspore in dry state showing well developed auriculi, Slide No. BSIP 11924.

4, 10. *Paxillitriletes maheshwarii* sp. nov. 4. Holotype in dry state; 5. Holotype after maceration showing reticulation on exosporium and webbed long branched and unbranched appendages; Slide No. BSIP 11925; 6. Another megaspore in wet condition after over-maceration; Slide No. BSIP 11926; 7. Same megaspore in dry state; 8. Megaspore in dry state; Slide No. BSIP 11927; 9. Another megaspore in dry state; 10. Same megaspore after maceration in wet condition; Slide No. BSIP 11928.

11, 12. *Saccarisporites* sp. 11. Megaspore in dry state. X 75; 12. Same magaspore after maceration. X 75; Slide No. BSIP 11929.

13, 14. *Spermatites* sp. 13. Specimen in dry state. X 75; 14. Same specimen after maceration in wet condition. X 75; Slide No. BSIP 11930.

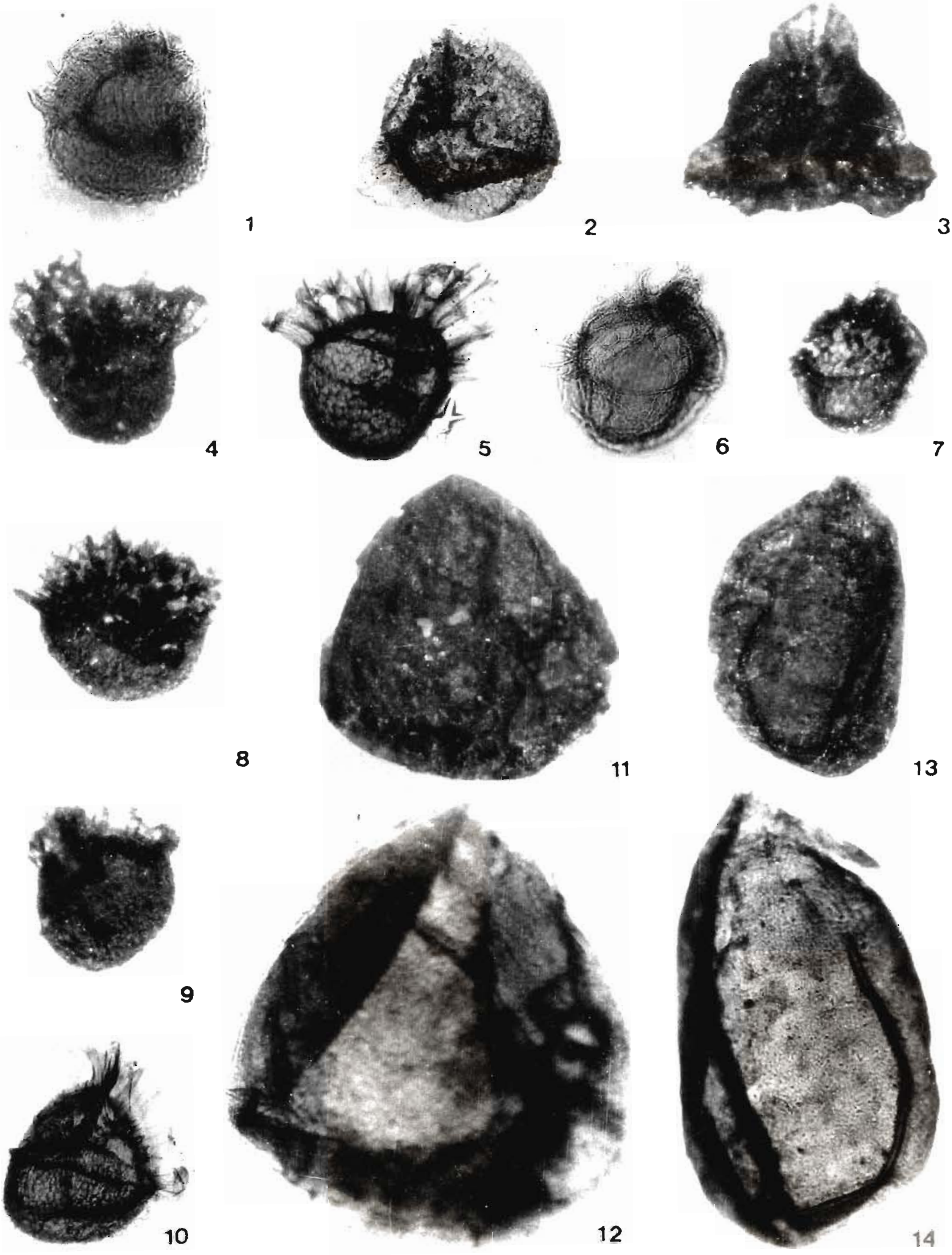

PLATE 2

Subturma — *Zonotriletes* Waltz 1935
Infraturma — *Zonati* Potonié & Kremp 1954

Genus — *Minerisporites* Potonié 1956

Minerisporites auriculatus Singh, Srivastava & Roy 1964
Pl. 1, figs 7-10; Pl. 2, figs 2-3

Remarks—In all available morphographic features and size, the specimens resemble those of *Minerisporites auriculatus* described by Singh, Srivastava and Roy (1964) from the Lower Cretaceous of Kutch Basin. The species is fairly rich in the present megaspore assemblage.

Minerisporites reticulatus (Singh, Srivastava & Roy 1964) Banerji, Jana & Maheshwari 1984
Pl. 1, figs 11-12; Pl. 2, fig. 1

Remarks–The present specimens found both in tetrad condition and dispersed condition resemble those of *Minerisporites reticulatus* recorded from the Lower Cretaceous of Kutch Basin.

Genus—*Paxillitriletes* Hall & Nicholson 1973

Paxillitriletes maheshwarii sp. nov.
Pl. 2, figs 4-10

Diagnosis–Megaspores trilete, amb ± circular in both equatorial and polar view, dimension 250-310 µm in dry state and 280-320 µm in wet condition; majority of the megaspores preserved laterally; trilete laesurae associated with a number of branched or unbranched appendages, appendages sometimes jointed at the base or throughout the whole length, measuring 50-150 µm in length in wet condition; exosporium reticulate, meshes of reticula measuring 10 X 14 µm to 15 X 20 µm, mesosporium not clearly discernible.

Comparison–*Paxillitriletes battenii* Banerji *et al.* is closely comparable to *P. maheshwarii* sp. nov. in overall shape and webbed nature of appendages, but the latter species is readily distinguishable in having spinose exosporium and comparatively larger size. *P. (Thomsonia) pseudotennella* (Dijkstra) Hall & Nicolson figured by Dijkstra (1951) differs from the present species in having conate exosporium.

Holotype–Pl. 2, figs 4 and 5, Slide No. BSIP 11925.

Type locality & age—Fireclay Quarry of Tata Refractories Ltd., Talbast, district Cuttack, Orissa; Athgarh Formation, Lower Cretaceous.

Derivation of name—The specific name is after Dr H. K. Maheshwari who has made significant contributions to the Indian Gondwana megaspores.

Genus—*Saccarisporites* Dev 1961

Saccarisporites sp.
Pl. 2, figs 11-12

Description—Megaspore subtriangular in outline, measuring 740 X 755 µm in dry state and 990 X 1020 µm in wet condition; exosporium very finely granulate with a few minor foldings.

Remarks—In overall shape and in exinal character the present specimen is comparable to *Saccarisporites* sp. recorded from the Jabalpur Formation by Dev (1961), but the present specimen is comparatively larger in size.

Incertae sedis

Genus—*Spermatites* Miner 1935

Spermatites sp.
Pl. 2, figs 13-14

Description—Elliptical to oval seed structure measuring 530 X 730 µm to 560 X 760 µm in dry state and 540 X 1020 µm to 580 X 1060 µm in wet condition, tapering on one end and broad at the other; surface finely granulose, sometimes with minor foldings but without any cellular structure.

Remarks—In overall appearance the seed structures are referable to *Spermatites*. In its shape the seed structures compare to some extent with *Spermatites indicus* Srivastava 1955 reported from the Barakar Formation of West Bokaro Coalfield. But no nucellar structure has been observed in the present specimens.

DISCUSSION

Among the known Late Mesozoic megaspore assemblages from Indian subcontinent, the Liassic assemblage from the Nammal Gorge, Pakistan (Sah & Jain, 1968) is characterised by the presence of *Banksisporites, Hughesisporites, Minerisporites* and *Nathorstisporites*. The megaspore assemblage from Sehora-on-Sher, Madhya Pradesh (Dev, 1961) is represented by the genera *Minerisporites, Saccarisporites* and *Dijkstraisporites*. Banerji *et al.* (1984) recorded 27 species of megaspores belonging to 11 genera from the Lower Cretaceous of Kutch and also reviewed the earlier work done by Singh *et al.* (1964). All the megaspore genera reported from the Sehora sediments of Madhya Pradesh (Dev, 1961) are also represented in the Kutch assemblage.

The present megaspore assemblage is closely comparable to that of Bhuj Formation (Kutch Basin) in having the presence of *Banksisporites, Bacutriletes, Erlansonisporites* and *Saccarisporites* along with the dominance of *Paxillitriletes* and *Minerisporites*. The Athgarh assemblage, however, is devoid of the genera *Hughesisporites, Verrutriletes, Horstisporites, Valvisisporites, Umiaspora* and *Dijkstraisporites*. The present megaspore assemblage may be assigned to the Assemblage Subzone B 2 of Maheshwari and Tewari (1988), though the genus *Dijkstraisporites* is not represented. The Athgarh megaspore assemblage shows the dominance of *Paxillitriletes* which is a very characteristic Lower Cretaceous form in The Netherlands, England and Canada (Dijkstra, 1949, 1951, 1959; Batten, 1969; Singh, 1964, 1971; Gunther & Hills, 1972).

Miofloral investigation on the Athgarh Formation was initiated by Maheshwari (1975). Jana and Tiwari (1986) reinvestigated the Athgarh palynoflora and assigned an Upper Jurassic age to it. But, the data on plant megafossils (Patra, 1980; Patra & Sahoo, 1995) indicate an Early Cretaceous age to the Athgarh Formation. The present megaspore assemblage conclusively points to a Lower Cretaceous age for the Athgarh Formation.

ACKNOWLEDGEMENTS

The authors are indeed thankful to Dr H.K. Maheshwari, Deputy Director, Birbal Sahni Institute of Palaeobotany for his useful comments and suggestions.

REFERENCES

Adyalkar PG & Rao CN 1963. Some new plant fossils from the Athgarh Stage, Upper Gondwanas, Orissa. *Rec. geol. Surv. India* **92**(2): 319-322.

Ball V 1877. On the 'Athgarh Sandstone' near Cuttack. *Rec. geol. Surv. India* **10**(2): 63-68.

Banerji J, Jana BN & Maheshwari HK 1984. The fossil floras of Kachchh. II - Mesozoic megaspores. *Palaeobotanist* **33**: 190-227.

Batten DJ 1969. Some British Wealden megaspores and their facies distribution. *Palaeontology* **12**(2): 333-350.

Dev S 1961. The fossil flora of the Jabalpur Series - 3. Spores and pollen grains. *Palaeobotanist* **8**: 43-56.

Dijkstra SJ 1949. Megaspores and some other fossils from the Aachenian (Senonian) in South Limburg, Netherlands. *Meded. Geol. Stichting.* n. ser. **3**: 19-32.

Dijkstra SJ 1951. Wealden megaspores and their stratigraphical value. *Meded. Geol. Stichting.* n. ser. **5**: 7-22.

Dijkstra SJ 1959. On megaspores, charophyta fruits and some other small fossils from the Cretaceous. *Palaeobotanist* **8**: 8-19.

Feistmantel O 1877. On some fossil plants from Athgarh Sandstones. *Rec. geol. Surv. India* **10**: 68-70.

Gunther PR & Hills LV 1972. Megaspores and other palynomorphs of the Brazeau Formation (Upper Cretaceous), Nordegg Area, Alberta. *Geosci. Man* **4**: 29-48.

Jana BN 1990. Palynology of Mesozoic outcrops of Athgarh Formation exposed near Talbast, Orissa. *In* : Jain KP & Tiwari RS (Editors)—*Vistas in Indian Palaeobotany, Palaeobotanist* **38**: 155-162.

Jana BN & Tiwari RS 1986. Further observations on the palynological assemblage from the Athgarh Formation, Sidheswar Hills, Orissa. *Q. Jl geol. Min. metall. Soc. India* **58**(3): 201-209.

Kumar S & Bhandari LL 1973. Palaeocurrent analysis of the Athgarh Sandstone. *Sediment. Geol.* **10**: 61-74.

Maheshwari HK 1975. Palynology of the Athgarh Formation near Cuttack, Orissa. *Palaeobotanist* **22**: 23-28.

Maheshwari HK & Tewari R 1988. Megaspore biostratigraphy of the Gondwana. *In* Venkatachala BS & Maheshwari HK (Editors)—*Concepts, limits and extension of the Indian Gondwana. Palaeobotanist* **36**: 102-105.

Patra BP 1980. Some ferns from East Coast Gondwana of Orissa with a note on the age. *Proc. 3rd Indian geol. Congr., Pune, 1980*: 57-68.

Patra BP 1990. Palaeofloristics of the Athgarh Sandstone, Orissa. *In*: Sahni A & Jolly A (Editors) — *Proc. Seminar-cum-Workshop- IGCP 216 & 245, Chandigarh, 1990*: 64-67.

Patra BP & Sahoo NK 1995. Some observations on the occurrence of Cycadophytes and Bennettitales in the East Coast Upper Gondwana Athgarh Sandstone, Cuttack and Khurda districts of Orissa, India. *Palaeobotanist* **44**: 139-151.

Sah SCD & Jain KP 1968. Lower Mesozoic megaspores from the Variegated Stage of Salt Range (West Pakistan). *Palaeobotanist* **16**: 288-291.

Singh C 1964. Microflora of the Lower Cretaceous Mannville Group, east-central Alberta. *Bull. Res. Coun. Alberta* **15**: 1-238.

Singh C 1971. Lower Cretaceous microfloras of the Peace River area, northwestern Alberta. *Bull. Res. Coun. Alberta* **28**(1): 1-229.

Singh HP, Srivastava SK & Roy SK 1964. Studies on the Upper Gondwana of Cutch - I, Mio- and macrospores. *Palaeobotanist* **12**(3): 282-306.

Change of micropaleontological assemblages at the Cretaceous-Paleogene Boundary in Western Siberia

V.M. Podobina, V.M. Kabanova & T.G. Kseneva

Podobina VM, Kabanova VM & Kseneva TG 1997. Change of micropaleontological assemblages at the Cretaceous-Paleogene Boundary in Western Siberia. *Palaeobotanist* 46(1,2): 156-160.

The foraminiferal and spore-pollen complexes were studied at the boundary of Maastrichtian-Danian (Cretaceous-Palaeogene) in Western Siberia. Terrigenic-argillaceous rocks with admixture of carbonaceous material from upper part of Gankinsky Suite and lower layers of Talitsky Suite belong to this stratigraphical interval. Carbonaceous secreted and secreted-agglutinated shells predominate among benthic Foraminifers. Planktonic forms were seldom and consist of representatives of the genera — *Rugoglobigerina* and *Guembelina* in the Maastrichtian and genera *Globigerina* and (rarely) *Globorotalia* in the Danian. At the Cretaceous-Palaeogene Boundary, palynocomplexes consist of group of angiosperm pollen. The flora producing *Triprojectacites* - type pollen became extinct in Late Maastrichtian. The active settling of western Siberia by "Norma" flora was confined to the beginning of the Palaeogene. Parallel with *Normapolles* representatives of Myricaceae, Fagaceae, Ulmaceae, Juglandaceae, Betulaceae, etc. originated and formed. They forced out the short-lived group of large-pollen "Norma" by the end of Paleocene.

Key-words—Cretaceous-Tertiary Boundary, Foraminiferal zones, Palynocomplex, Maastrichtian, Danian, Russia, Siberia.

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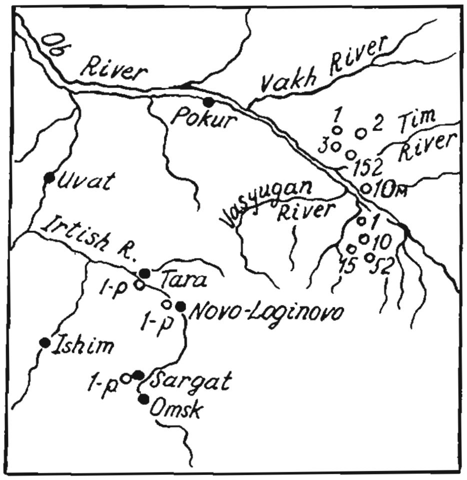
सारांश

पश्चिमी साइबेरिया में क्रीटेश्यस-पेलियोजीन सीमा पर सूक्ष्मपुरातात्विक समुच्चयों में परिवर्तन

वी.एम. पोडोबीना, वी.एम. काबानोवा एवं टी.जी. सेनेवा

पश्चिमी साइबेरिया में मास्ट्रिक्शियन-डेनियन (क्रीटेश्यस-पेलियोजीन) सीमा से प्राप्त फोरामिनीफरी एवं बीजाणु-परागकण समुच्चयों का अध्ययन किया गया है। गेनकिन्सकी के ऊपरी भाग तथा तालिस्की की निचली तहों से कार्बनमय सामग्री से युक्त स्थलजात-आर्जिलेसीय चट्टानें इस स्तरिक इकाई से सम्बद्ध हैं। बेन्थिक फोरामिनीफरों में कार्बनमय स्रावित एवं स्रावित एग्लूटिनेट शैलों की बाहुल्यता है। प्लवकीय प्ररूप काफी कम हैं तथा मास्ट्रिक्शियन काल में *रुगोग्लोबीजेरीना* एवं *गुएमबेलीना* नामक दो प्रजातियाँ मिलती हैं जबकि डेनियन काल में *ग्लोबीजेरीना* एवं *ग्लोबोरोटेलिया* (कम) नामक दो प्रजातियाँ विद्यमान हैं। क्रीटेश्यस-पेलियोजीन सीमा पर आवृतबीजी परागकण मिलते हैं। अनंतिम मास्ट्रिक्शियन काल में *ट्राइप्रोजेक्टेसाइटिस* प्रकार के परागकण विलुप्त हो गये थे। मिरिकेसी, फैगेसी, अल्मेसी, जुगलेन्डेसी, बिटुलेसी आदि कुलों के अवयव नोर्मापॉलिस के समानान्तर विकसित हुए तथा पेलियोजीन के अन्त तक इन्होंने "नोर्मा प्रकार" के बड़े परागकणों को समाप्त कर अपना प्रभुत्व स्थापित कर लिया था।

THE development of physical-geographical situation at the Cretaceous-Palaeogene (Maastrichtian-Danian) Boundary is mainly connected with the climatic factor. Two large palaeobiogeographical regions, viz., Boreal-Atlantic and Mediterranean, were distinguished by Podobina (1984) for this time interval on the Eurasia's territory. The first one which is of 'our interest, extends from the southern Scandinavia through the Polish Lowland to the East European Platform including western Siberia. Boreal basins within this region were under the influence of the northern Atlantic and the Arctic; chiefly terrigenic-carbonaceous and terrigenic rocks enclosing diverse palaeontological residues were accumulated there. In western Siberia, terrigenic-argillaceous rocks with an admixture of carbonaceous material occuring in the upper part of Gankinsky Suite and lower layers of Talitsky Suite, represent the Maastrichtain-Danian stratigraphic interval. The most widely spread foraminiferal and spore-pollen assemblages were selected for investigation among palaeontological residues found in these sediments. Danian deposits in this area were discovered only in the lows of relief, where they were preserved from the subsequent



Text-figure 1

erosion by water. Maastrichtian-Danian foraminifera and palynocomplexes within Omsk depression were investigated in subsurface sections, viz., near Sargat, borehole 1-p; near Novo-Loginovo, borehole 1-p; Tarskaya key-borehole 1-p; on the left bank of the Ob, in the basin of the Parbig, boreholes 1, 10, 15, 52; on the right bank of the Ob, in basins of the Tim and the Paidugina-boreholes 1, 2, 3, 152 (Ust-Tim depression) (Text-figure 1).

Maastrichtian-Danian palaeocoenoses of western Siberia had been formed under conditions of comparatively low temperature in epicontinental basins that were under the influence of Arctic. Waters of southern seas penetrating through the Turgai trough affected the formation of indicated palaeocoenoses to a lesser extent. They differ by the peculiar correlation between different types of benthic forms and almost by the complete absence of planktonic ones. Carbonaceous secreted and secreted-agglutinated shells of uncertain systematic position predominate among benthic forms; many taxa characteristic for European palaeocoenoses are absent. Planktonic forms are rare and consist of representatives of the genera — *Rugoglobigerina* and *Guembelina* in the Maastrichtian and *Globogerina* and *Globorotalia* (rarely) in the Danian. The change in ecological factors at the end of the Late Cretaceous, expressed by some fall in temperature and shallowing of the basin, led to considerable transformations in the systematic composition of the Danian palaeocoenosis in the southwestern part of the plain. The southeastern palaeocoenosis, on the contrary, is considerably impoverished in number of species as well as quantitatively; sharply differs from the underlying Maastrichtian palaeocoenoses. Investigated palaeocoenoses are from upper layers of Gankinsky Suite, including transitional or lower layers of Talitsky Suite. Late Maastrichtian foraminiferal palaeocoenosis with *Spiroplectammina kasanzevi* and *Bulimina rosenkrantzi* and the Danian palaeocoenosis with *Brotzenella praeacuta* on the southeast and *Bathysiphon nodosarieformis,* and *Glomospira charoides* on the southwest are distinguished among them. Late Maastrichtian palaeocoenoses differ considerably in composition and structure on the south and the north of western Siberia. The palaeocoenosis from the southern part of western Siberia consists approximately 80 per cent of carbonaceous secreted benthic forms; secreted-agglutinated forms account for 15 per cent and quartz-siliceous agglutinated forms only 5 per cent. On the north of western Siberia (to the north of latitudinal flow of the Ob), Late Maastrichtian palaeocoenosis is represented predominantly (up to 80-90 %) by secreted-agglutinated and (up to 10-12 %) quartz-siliceous forms. About 20 genera and 120 species comprise the southern palaeocoenosis and about one third or lesser of indicated taxa are present in the northern palaeocoenosis. The southwestern Danian palaeocoenosis with *Brotzenella praeacuta* consists of 38 genera and 57 species. Parallel with the disappearance of many benthic Maastrichtian species, Palaeocene species including new planktonic forms appeared for the first time in the indicated paleocoenosis. The latter are, however, single and west Siberian paleocoenoses differ from palaeocoenoses of the same age from other regions in this aspect, too. Carbonaceous secreted-agglutinated and secreted benthic species, viz., *Gaudryina gigantica* (Subbotina), *Clavulina parisiensis* Orb., *Parella lens* (Brotzen), *Cibicides spiropunctatus* Galloway et Morrey, *Anomalinoides danicus* (Brotzen), *Brotzenella praeacuta* (Vassilenko) and many other ones are present in rocks from borehole 1-p (int. 558.83-552.18 m), near Sargat that was chosen as the key-section for the Danian. As for planktonic forms, the presence of *Globigerina varianta* Subbotina, *G. trivialis* Subbotina, *Globorotalia pseudobulloides* Plummer, etc. must be noted. As a whole, according to ecological foraminiferal types, the Danian paleocoenosis in the southwest of the plain (Omsk depression) is closer to the underlying Maastrichtian one. Benthic carbonaceous secreted-agglutinated forms predominate here, as well as in the Late

Table 1

System	Series	Stage	Suite	Zones of Benthic Foraminifers	
				South Western region (Omsk depression)	Eastern region (Ust-Tim depression)
Paleogene	Paleocene	Selandian	Talitsky	*Ammoscalaria friabilis*	Layers with *Cyclammina coksuvorovae*
				Brotzenella praeacuta	Layers with *Bathysiphon nodosarieformis*, *Glomospira charoides*
		Danian			
Cretaceous	Upper	Maastrichtian	Gankinsky	*Spiroplectammina kasanzevi*, *Bulimina rosenkrantzi*	

Maastrichtian of the southern palaeocoenosis (borehole 1-p, near Sargat, int. 558.83-552.18 m; borehole 1-p, near Novo-Loginovo, int. 607.15-602.55 m; borehole 1-p, near Tara, depth 595 m).

On the east (the right bank of the Ob, Ust-Timskaya depression), the other palaeocoenosis, (probably Danian) with *Bathysiphon nodosarieformis, Glomospira charoides* was found. In addition to the above species, more highly organised representatives of *Trochammina* aff. *proteus* Karrer, met in Palaeocene, and *Spiroplectammina* aff. *kasanzevi* Dain of Late Maastrichtian age were discovered there.

The palaeocoenosis of mixed systematic composition, consisting of relict Maastrichtian and appearing Palaeocene species, is usually characteristic for the Danian in western Siberia too. However, here primitive quartz-siliceous agglutinated forms predominate (Ust-Tim depression, basins of the Tim and Paidugina, borehole 1, int. 470-460 m; borehole 2, int. 484-480 m; borehole 3, int. 413-390 m; borehole 152, int. 420-418 m) indicating more shallow- and cold-water basin. Consequently, the considerable change of foraminiferal palaeocoenoses at the Late Cretaceous-Danian boundary was caused by substantial alterations of environment, by reconstruction of physical-geographical conditions at the latitudinal distribution because of change in climatic zonality and the revival of tectonic regime to the beginning of Palaeocene.

Table 2

System	Series	Stage	Suite	Palynocomplexes of eastern region
				Basin of Parbig River
Paleogene	Paleocene	Selandian	Talitsky	Predominant: Taxodiaceae, Pinaceae, Normapolles Characteristic: *Extratriporopollenites* spp., *Trudopollis menneri*, *T. conrector*, *Nudopollis endangulatus*, *N. thirgartii*, *Oculopollis sibirica*, *Basopollis* sp., *B. vestibulatus*, Myricaceae, Ulmaceae, Juglandaceae, Betulaceae.
		Danian		Predominant: Taxodiaceae, Pinaceae Characteristic: *Orbiculapollis globosus*, *Ulmoideipites tricostatus*, *Trudopollis nonperfectus*, *T. conrector*, *T. fossulotrudens*, *Oculopollis sibirica*, *Anacolosidites* sp., *Triporopollenites robustus*, *Myrica* spp., *Triatriopollenites* spp. *Rare: Mancicorpus*, *Aquilapollenites*.
Cretaceous	Upper	Maastrichtian	Gankinsky	Predominant: Pinaceae, Taxodiaceae Characteristic: *Orbiculapollis globosus*, *Wodehouseia* spp., *Tricolporites gracilis*, *Aquilapollenites* spp., *Ulmoideipites* spp., *Ephedra* sp. Rare: Normapolles. Abundant: *Membranosphera maastrichtica* and *Deflandrea bakeri*.

Late Maastrichtian palynocomplex, controlled by *Spiroplectammina kasanzevi-Bulimina rosenkrantzi* Zone (Podobina, 1988), is distinguished by the authors on the left bank of the Ob in the section of Parbigskaya borehole 52 (int. 262-254 m) in the lower part of the Gankinsky Suite. It is represented by dark-grey, rarely black or greenish-grey, clay with interlayers containing glauconite and sideritic concretions. The palynocomplex is poor in spore content. *Sphagnum* (*S. regium* Drozh., *S. australe* (Ñook.) Drozh.) and monolete spores of Polypodiaceae are appreciably represented. Spores of *Gleichenia* sp., *Cyathea* sp., *Matonia* sp., *Osmunda* sp. etc. are very rare. Among the gymnosperms, pollen of Taxodiaceae predominate. *Pinus* spp. and *Cedrus* spp. are found more often, *Pinus aralica* Bolchovitina is sparse. *Dacrydiumites* sp. and *Ephedra* are represented by single specimens. Pollen of angiosperms is diverse; there is no prevalence. The participation of *Quercites sparsus* (Mart.) Samoilovich is noticeable. The following common Upper Cretaceous forms are present : *Liliacidites*, *Myrica* spp., Myrtaceae, Hamammelidaceae, *Corylopsis compacta* (Mart.) Samoil., *Platanus*, Loranthaceae, *Engelhardtia* sp., *Celtis* sp., *Ulmoideipites tricostatus* And., *Tricolpopollenites* spp., *Triatriopollenites* spp., *Triporopollenites* spp., *Tricolporopollenites* spp., *Aquilapollenites* spp., *Triprojectus* sp., *Parviprojectus striatus* Mtchedishirili, *Orbiculapollis globosus* Chlonova and *Orbiculapollis lucidus* Chlonova. A single grain of *Castanea* sp. was found. Aquatic forms of *Membranosphera maastrichtica* Samoilovich-type, and various dinocysts are abundant including *Deflandrea bakeri* Defl. Higher in the section (int. 220-206 m) in the same suite of clays (but not characterized by fauna), a palynocomplex is distinguished which is similar to the known Danian palynocomplex (Zaklinskaya, 1977). Here *Triprojectacites* with accompanying list of Late Cretaceous plants is still found, but the percentage of *Ulmoideipites* And. increases, *Orbiculapollis globosus* Chlonova was also found in considerable numbers; the diversity of *Normapolles* (*Trudopollis nonperfectus* Pflug., *Trudopollis pompeckji* Pflug, *Oculopollis baculotrudens* (Pflug) Zaklinskaya) and *Triatriopollenites* spp. increases. *Membranosphaera maastrichtica* Samoilovich and *Deflandrea bakery* Deflandre are very rare. Shrinking of the marine basin had apprarently occurred. Similar regularity was observed in the section of Vasuganskaya borehole 10-I (the mouth of the Vasugan, the left tributary of the Ob), where in palynospectra from the upper layers of Gankinsky Suite the percentage of representatives of Ulmaceae (*Ulmoideipites* And.), Myricaceae, Juglandaceae, Betulaceae increases; the flash of *Orbiculapollis* Chlonova and *Ephedra* is marked against a background of the sharp lowering role of *Triprojectacites* (Grigoryeva, 1970).

An Early Palaeogene palynocomplex (Danian, by convention) has been distinguished from 15 m thick dark-grey clay in the cover of Gankinsky Suite (Parbigskaya borehole 15). Deposits within the interval of 258-232 m are datable by foraminiferal-*Spiroplectammina kasanzevi-Bulimina rosenkrantzi* Zone and layers with Late Maastrichtian palynocomplex. In rocks from depth 223 m, the palynocomplex was described, where the spore part and the composition of gymnosperm pollen hadn't undergone alteration. Notable changes in the direction of increasing quantity and pollen diversity of stemma Normapollis had occurred in the composition of angiosperms. *Trudopollis* spp., *T. fossulotrudens* Pflug, *T. conrector* Pflug, and *Oculopollis sibirica* Zaklinskaya (amounting to 4.5-9.0 %) are marked here. *Alnus* sp., *Myrica* spp., *Comptonia* sp., *Carya* sp., *Pterocarya* sp., *Castanea* sp., *Quercus* sp., Caprifoliaceae (cf. *Lonicera*), *Ulmoideipites tricostatus* And., *Anacolosidites* sp., *Nyssa* sp., *Tricolpopollenites* sp., *Triatriopollenites* spp., *Triporopollenites robustus* Pflug and *Tricolporopollenites* sp. are associated forms. *Aquilapollenites* sp. and *Mancicorpus* sp. are met sporadically. Layers with analogical complex, of Lower Paleocene age by convention, was traced in the base of Palaeogene section, Parbig area (boreholes 1, 10, 52). Early Palaeocene *Triporopollenites robustus-Ulmoideipites* palynocomplex has been established (Nagorskaya *et al.*, 1978) in Orlovsky layers which are scantily developed in the cover of Symsky Suite (continental analogue of Gankinsky Suite) on the right bank of the Ob.

Layers with *Trudopollis menneri-Nudopollis endangulatus-Oculopollis gigantheus* palynocomplex (Early Palaeocene, Zelandian ?) were distinguished by Ilyenok (1968) in lower subsuite of Talitsky Suite (Oàzovsky borehole 1-D). In the upper layers of underlying deposits (Gankinsky Suite, int. 439.9-396.5 m), Late Maastrichtian *Spiroplectammina kasanzevi* Zone had been distinguished by Kiselman (1974). Foraminiferal assemblage with *Parella lens* (Brotz.) (Danian, by convention) was defined by her above these rocks within the interval of 371.6-369.0 m. A palynocomplex was described from deposits in the interval of 390.5-298.0 m. The spore pollen composition does not show any change. Characteristic Cretaceous relicts were observed as before among angiosperms, the percentage of *Quercites sparsus* (Mart.) Samoilovich is noticeable. The role of diverse pollen, attributed to stemma Normapolles (28 %) - *Extratriporopollenites* sp., *Trudopollis conrector* Pflug, *T. proparvus* Pflug, *Oculopollis* spp., *Basopollis* sp., *B. vestibulatus* Zaklinskaya, *Nudopollis endangulatus* Pflug, *N. thiergartii* Pflug increased significantly. Palaeocene (Zelandian) *Ammoscalaria friabilis* Zone was distinguished by Podobina in the lower half of Talitsky Suite.

The successive comparative analysis of palynocomplexes at the Cretaceous-Palaeogene Boundary shows that Late Maastrichtian and Maastrichtian to Danian palynocomplexes characterize the upper part of Gankinsky Suite having marine and coastal-marine genesis. It confirms greatly the conclusions of Zaklinskaya (1960, 1977), Mtchedlishvili (1961), Grigoryeva (1968), and Khlonova (1974). The palynocomplex of dismembered Maastrichtian was distinguished for the upper subsuite of Symsky Suite. Early Palaeocene palynocomplex (Danian, by convention) was traced discretely in boundary layers in the cover of Gankinsky and Symsky suites - lower part of Talitsky Suite and its continental analogues. *Trudopollis menneri - Nudopollis endangulatus-Oculapollis gigantheus* palynocomplex of Early Palaeocene (Zelandian ?) age is confined to the lower subsuite of Talitsky Suite.

The most noticeable changes in the development of Late Cretaceous-Palaeogene flora occurred in the composition of representatives of angiosperms. Their rise, mass settling and decline covered just this restricted time interval. In Late Maastrichtian flora "Aquila", plants producing *Triprojectacites* pollen died out. The active settling of western Siberia by flora "Norma" was confined to the beginning of the Palaeogene. The reduction of marine basin was probably favourable to this process during the Danian regression. Parallel with Normapollis representatives of Myricaceae, Fagaceae, Ulmaceae, Juglandaceae, Betulaceae, Salicaceae, etc. originated and formed; they forced out short-lived group of large-pollen "Norma" by the end of Palaeocene.

REFERENCES

Brotzen F 1948. The Swedish Paleocene and its foraminiferal fauna. *Sver. Geol. Undersok.*, Ser. C, **42** (2): 1-140.

Freiman EV 1962. Paleocene foraminifera assemblages of West Siberian plain. *Materials on paleontology and stratigraphy of Western Siberia:* 52-65. Gostoptechizdat Press, Leningrad.

Grigoryeva KN 1968. Spore-pollen complexes of Maastrichtian deposits of West Siberian lowland. *Palynological method in stratigraphy:* 131-150. Leningrad

Grigoryeva KN 1970. Palynological basing of stratigraphical subdivision of Senonian deposits in eastern and southeastern part of West Siberian lowland: 1-19. *Autoref. dissert. for a candidate degree.* Tomsk.

Iljenok LL 1968. Palynological characteristic of Paleocene in Western Siberia. *Paleopalynological method in stratigraphy:* 188-198. Moscow.

Khlonova AF 1974. *Palynology of Cretaceous deposits in Siberia and the Far East.* Nauka Press, Novosibirsk .

Kiselman EN 1974. Upper Maastrichtian foraminiferal assemblages of *Spiroplectammina kasanzevi* Zone in the eastern part of West Siberian plain. *Materials on stratigraphy and paleontology of Siberia* : 122-127.

Mtchedlishvili ND 1961. Palynological characteristic of Cretaceous deposits in Western Siberia. Maastrichtian-Danian. *Pollen and spores of Western Siberia. Jurassic-Paleocene* : 329-333.

Nagorskaya EP, Aleksandrova A & Iljenok LL 1975. Palaeocene and Eocene of Ketsky Priobje. *Paleogene and Neogene of Siberia* :93-100. Nauka Press, Novosibirsk.

Podobina VM 1975. *Upper Cretaceous and Paleogene foraminifera in West Siberian plain and their significance for stratigraphy.* Univ. of Tomsk Press, Tomsk.

Podobina VM 1984. *Paleozoogeographical regionalization of Late Cretaceous basins of Western Siberia and other aquatoria of the Northern hemisphere by data of foraminiferal investigation.* Univ. of Tomsk Press, Tomsk.

Podobina VM 1988. New data on distribution of Late Maastrichtian foraminiferal zone in the southeast of Western Siberia. *Materials on paleontology and stratigraphy of Western Siberia:* 109-114. Univ. of Tomsk Press, Tomsk.

Podobina VM 1989. *Foraminifera and zonal stratigraphy of the Upper Cretaceous in Western Siberia.* Univ. of Tomsk Press, Tomsk.

Podobina VM 1992. The Danian stage of Western Siberia. *Materials on paleontology and stratigraphy of Western Siberia:* 80-83. Univ. of Tomsk Press, Tomsk.

Podobina VM 1994. Foraminifera of Cretaceous-Paleogene boundary deposits in Western Siberia (Kaimysovsky vault). *Problems of geology in Siberia:* 4-6. Univ. of Tomsk Press, Tomsk.

Podobina VM & Bessonenko EA 1988. New data on biostratigraphy of the Senonian in the southeast of Western Siberia. *Materials on paleontology and stratigraphy of Western Siberia* : 100-108. Univ. of Tomsk Press, Tomsk.

Podobina VM & Kseneva TG 1989. Microfaunal characteristic of boundary Cretaceous-Paleogene deposits in Western Siberia. *Rational usage of natural resourses of Siberia:* 79-80. Univ. of Tomsk Press, Tomsk.

Subbotina NN 1950. Microfauna and stratigraphy of Elburgansky horizon and the horizon of Goratchy klutch. Microfauna of USSR. sb.IV. *Trudy VNIGRI,* new ser. (57): 5-112.

Subbotina NN & Alekceitchik LS *et al.* 1964. *Foraminifera of Cretaceous and Paleogene deposits of West Siberian lowland.* Nedra Press, Leningrad.

Zaklinskaya ED 1960. The subdivision of Maastrichtian-Danian-Paleocene deposits of Western Siberia on the base of spore-pollen analysis data. *The boundary of Cretaceous and Tertiary deposits:* 181-190. Nauka Press, Moskow.

Zaklinskaya ED 1977. *The development of flora at Mesozoic-Cenozoic boundary.* Nauka Press, Moskow.

Significance of calcareous algae across the Cretaceous-Tertiary sequence of Cauvery Basin in Tiruchirapalli District, Tamil Nadu

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Ghosh AK, Jana BN & Maithy PK 1997. Significance of calcareous algae across the Cretaceous-Tertiary sequence of Cauvery Basin in Tiruchirapalli District, Tamil Nadu. *Palaeobotanist* **46** (1,2) : 161-167.

Calcareous skeletal algae belonging to Cyanophyta (Cyanobacteria), Chlorophyta and Rhodophyta are known from Uttatur, Trichinopoly, Ariyalur and Niniyur groups of Tiruchirapalli District, Tamil Nadu. An attempt has been made to analyse the algal assemblages across the Cretaceous-Tertiary sequence in Tiruchirapalli District, Tamil Nadu. The distribution pattern of algal taxa indicates that there is a gradual change in algal flora from Cretaceous to Tertiary.

Key-words--Calcareous algae, Distribution pattern, Cretaceous -Tertiary sequence, India.

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सारांश

तमिलनाडु के तिरुचिरापल्ली जनपद में कावेरी द्रोणी के क्रीटेश्यस-टर्शियरी अनुक्रम में चूनामय शैवालों का महत्व

अमित कुमार घोष, बृजेन्द्र नाथ जाना एवं प्रभात कुमार माइती

तमिलनाडु के तिरुचिरापल्ली जनपद में उतातुर, त्रिचनापल्ली, अरियालूर एवं निनियूर नामक समूहों से सियनोजीवाणु, क्लोरोफाइटा एवं रोडोफाइटा नामक मंडलों से सम्बद्ध चूनामय मेखलीय शैवाल ज्ञात हैं। इस जनपद में क्रीटेश्यस-टर्शियरी अनुक्रम से उपलब्ध शैवालीय समुच्चयों का विश्लेषण करने का प्रयास किया गया है। शैवालीय वर्गकों के वितरण से उक्त काल में शैवालीय वनस्पतिजात में शनैः शनैः परिवर्तन प्रदर्शित होता है।

SINCE 1931, calcareous algae have been reported from the Cretaceous-Tertiary sediments of Tiruchirapalli District, Tamil Nadu. Rama Rao and Prasannakumar (1932) described *Lithothamnium* from the Kallakkudi (Dalmiapuram) limestone mines (Dalmiapuram Formation) belonging to Uttatur Group. Narayan Rao (1944, 1946) reported two new species, namely, *Solenopora coromandelensis* and *S. jurassica* and Rama Rao and Gowda (1954) described *Solenopora sahnii* and *Sporolithon (Archaeolithothamnium) lugeonii* (*sensu* Ghosh & Maithy, 1996) from the same beds. Gowda (1978) recorded *Solenopora* sp. and *Amphiroa* sp. from the Varagapaudy Limestone of Uttatur Group. Varma (1952), for the first time, reported the occurrence of *Clypenia sahnii* from the Trichinopoly Group of rocks. In recent times, Misra and Kumar (1988) investigated the Varagur limestones of Trichinopolly Group and reported 31 species of fossil algae belonging to 17 genera of Cyanophyta (Cyanobacteria), Chlorophyta and Rhodophyta. From the Ariyalur Group, Mamgain *et al.* (1968) have reported *Sporolithon (Archaeolithothamnium)* sp., *Lithothamnium* sp. and *Mesophyllum* sp. from south-west of Ariyalur town. Porostromata algae consisting of *Rivularia lissaviensis, R. piae, R. theodori, Rivularia* sp. cf. *R. dianae* and *Garwoodia toomeyi* have been described by Ghosh and Maithy (1995) from the Cretaceous sediments of Sendurai, Tiruchirapalli District. Rama Rao (1931) reported *Sporolithon (Archaeolithothamnium) torulosum* from Niniyur beds. In the classical contribution on fossil algae from Niniyur Group, Rama Rao and Pia (1936) described 11 taxa belonging to Dasycladaceae, Chaetophoraceae, Solenoporaceae and Corallinaceae. Rama Rao (1938, 1956, 1958) described few dasyclads from the Niniyur Group and reviewed the previous work done on fossil algae from this group. Varma (1952, 1954) reported *Clypenia, Neomeris* and *Acicularia* (Dasycladaceae) and Gowda (1953, 1959) described *Holosporella* and *Piania niniyurensis* from the Niniyur beds. From the Palaeocene (Danian) of Niniyur Group, Rama Rao and Gowda (1954) reported *Solenopora tiruchiensis,* and Pal (1972) reported *Sporolithon (Archaeolithothamnium) pondicherriensis, S. zonatum* and *Distichoplax raoi.* In the present paper an attempt has been made to analyse the algal assemblages from different outcrop areas of Cretaceous-Tertiary sequence in Tiruchirapalli District and to ascertain the significance of calcareous algae in biostratigraphy.

GEOLOGICAL SETTING

Cretaceous-Tertiary sediments in the Cauvery Basin, classified into four groups, viz., Uttatur, Trichinopoly, Ariyalur and Niniyur, occur as isolated patches outcropping in the western margin fringing the Archaean (charnokite/gneiss) basement. The first geological mapping of the area was carried out by Blanford (1862). Later, significant contributions on micropalaeontology and sedimentology (Rama Rao, 1956; Pascoe, 1959; Sastry *et al.,* 1968, 1972; Sundaram & Rao, 1966; Banerji, 1966, 1972, 1973; Chiplonkar & Tapaswi, 1975; Jain, 1977; Govindan, 1977, Govindan *et al.,* 1996, and others) along with detailed geological mapping and band-by-band aerial photomapping (Venkataraman & Rangaraju 1965, in Govindan *et al.,* 1996) gave a clear picture of the stratigraphy of Tiruchirapalli area.

The marine Cretaceous-Tertiary sequence of Cauvery Basin in Tiruchirapalli District is represented at its base by Uttatur Group which lies unconformably over the Kaolinite-Smectite dominant Therani plant beds of Upper Gondwana (Therani Bed lies unconformably over the Archaean). Lithologically the Uttatur Group comprises basal conglomerates, grey shale (Subbaraman, 1968), algal-coralline limestone (Banerji, 1972) and Karai Shale. Govindan *et al.* (1996) identified Maravathur Clay as a facies variation of Karai Shale and grouped it in Uttatur. An unconformity of small duration exists between the Uttatur Group and basal Paravay Formation of Trichinopoly Group. The Paravay Formation comprising calcareous sandstone, argillaceous limestone and limestone is overlain unconformably by the Garudamangalam Formation which consists of ferruginous sandstone, grey shale, limestone and, in turn, is followed by current bedded sandstone. The Trichinopoly Group is unconformably overlain by Ariyalur Group, consisting two sandstone bodies separated by a limestone. The basal Sillakkudi Formation of Ariyalur Group comprises ferruginous arkosic sandstone and limestone bands. The overlying Kallankurichi Formation consists of grainstone to wackestone with *Lepidorbitoides* bryozoans, echinoid and molluscan shells. The lower part of the upper sandstone body, composed of megafaunal rich buff coloured calcareous sandstone is well developed in the central part which is designated as Ottakovil Formation (Sastry *et al.,* 1972). The upper part comprising argillaceous sandstone and ferruginous claystone of continental origin is known as Kallamedu Sandstone. The topmost lithohorizon of the Cretaceous-Tertiary Sequence, conformably overlying the Ariyalur Group is represented by Niniyur Group of Danian age and is characterised by fossiliferous, white to cream coloured marls and calcareous clays.

A generalised lithostratigraphic sequence is represented in Table 1 (modified after Govindan *et al.,* 1996)

ALGAL ASSEMBLAGES FROM CRETACEOUS-TERTIARY SUCCESSION OF TIRUCHIRAPALLI AREA

A. Algal Assemblage from the Uttatur Group

Cyanophyceae (Cyanobacteria)

Rivularia (Cayeuxia) fruticulosa, Rivularia sp.

Dasycladaceae

Acicularia antiqua, Larvaria occidentalis, Neomeris sp., *Halimeda* sp.

Solenoporaceae

Solenopora jurassica, S. coromandelensis, S. sahnii and *Sporolithon (Archaeolithothamnium) lugeonii.*

In addition to the above listed algal taxa recorded from the Kallakkudi Limestone (Dalmiapuram Formation), from Varagapaudy Limestone of Uttatur Group Gowda (1978) reported the occurrence of

Table 1

AGE	GROUP	OUTCROP AREA FORMATION
DANIAN	NINIYUR	NINIYUR
MAASTRICHTIAN	ARIYALUR	KALLAMEDU Sandstone
		OTTAKOVIL
		KALLANKURICHI Limestone
		SILLAKKUDI
CAMPANIAN	TRICHINOPOLY	GARUDAMANGALAM
SANTONIAN		PARAVAY
CONIACIAN		MARAVATTUR Clay
TURONIAN	UTTATUR	KARAI Shale
CENOMANIAN		KALLAKUDDI Limestone
ALBIAN		Grey Shale
APTIAN		Conglomerate
EARLY CRETACEOUS LATE JURASSIC		THERANI PLANT BEDS
ARCHAEAN CRYSTALLINES		

Red algae *Solenopora* belonging to Solenoporaceae and *Amphiroa* belonging to Corallinaceae (Corallinoideae, articulated corallines).

B. Algal Assemblage from the Trichinopoly group

Cyanophyceae (Cyanobacteria)

Rivularia sp. cf. *R. kurdistanensis*, *Palaeomastigocladus indicus*.

Siphonocladaceae

Pycnoporidium lobatum.

Dasycladaceae

Clypenia sahnii, *Cylindroporella* sp. cf. *C. sugdenii*, *Indopolia* sp. cf. *I. satyavanti*, cf. *Larvaria* sp., *Neomeris cretaceae*.

Solenoporaceae

Solenopora filiformis, *S. tiruchiensis*, cf. *Solenopora* sp. A., *Solenopora* sp., *Parachaetetes* sp., *P. asvapatii*, *Thaumatoporella incrustrata*.

Squamariaceae

Ethelia sp., *E. alba*.

Corallinaceae (Melobesoideae, Crustose Corallines)

Sporolithon (*Archaeolithothamnium*) *lugeonii*, *S. nonsteinensis*, *S. parisiense*, *S. rude*, cf. *Sporolithon* sp., *Mesophyllum* sp. cf. *M. daviesi*, *M. varians*, cf. *Archaeolithophyllum* sp., *Lithophyllum* sp. A., *Lithophyllum* sp. B., cf. *Lithophyllum* sp., *Distichoplax biseriales*.

Corallinoideae, articulated coral-lines

Amphiroa elliotii, *A. guatemalense*, *A. varagurense*.

C. Algal Assemblage from the Ariyalur group

From the Ariyalur Group Rama Rao (1931) and Mamgain *et al.* (1968) reported the occurrence of *Lithothamnium*, *Sporolithon* (*Archaeolithothamnium*) and *Mesophyllum* belonging to Corallinaceae (Melobesoideae, Crustose Corallines) of Rhodophyta. Recently Porostromata algae have been recorded by Ghosh and Maithy (1995) from the Cretaceous sediments (equivalent to Ariyalur Group) of Sendurai, Tiruchirapalli District. The assemblage consists of the following taxa :

Cyanophyceae (Cyanobacteria)

Rivularia lissaviensis, *R. piae*, *R. theodori*, *Rivularia* sp. cf. *R. dianae*.

Codiaceae

Garwoodia toomeyi.

D. Algal Assemblage from the Niniyur Group

Dasycladaceae

Acicularia sp., *A. dyumatsenae*, *A. indica*, *Acitabularia* sp., *Clypenia sahnii*, *Disocladella* sp., *D. undulata*, *D. savitriae*, *Indopolia satyavanti*, *Neomeria* sp., *Orioporella malaviae* and *Piania niniyurensis*.

Cheatophoraceae

Palaeochlya sp.

Solenoporaceae

Parachaetetes asvapatii, Solenopora tiruchiensis.

Corallinaceae (Melobesoideae, Crustose Corallines)

Sporolithon (Archaeolithothamnium) lugeonii, S. torulosum, Sporolithon sp. cf. *S. lycoperdioides, Sporolithon* aff. *provinciale, Distichoplax raoi.*

Corallinoideae, Articulated coral-lines

Corallina raoi.

DISCUSSION

It is evident from the distribution pattern (Table 2) that in the marine rocks of Tiruchirapalli District, many Cretaceous algal taxa extend up to the Tertiary (Danian) time, though apparent extinction of many algal forms is also visualised during the Cretaceous, accompanied by the appearance of new algal species in the Niniyur Group (Danian). In view of this situation it is difficult to recognise the biostratigraphic zonation on the basis of algal assemblages. Earlier it has been implied by Rama Rao and Pia (1936) that algae are most helpful in stratigraphic correlation based on index fossils. But recent analysis indicates that it is indeed very problematical to use algae as biostratigraphic marker mainly because of following two reasons :

1. the algal taxa which were used earlier as index fossils are now proved to be long ranging; and
2. many of the forms which were regarded earlier as index algal fossils are doubtful as well as controversial and in some cases are considered as animal remains.

It may not be out of context to mention here that *Distichoplax biseriales*, which is still considered as an index fossil for the rocks having Palaeocene-Lower Eocene age, is present in the Trichinopoly Group (Misra & Kumar, 1988). Pal (1972) reported *Distichoplax* from the Niniyur Group (Danian) and it is stratigraphically quite justified. However, it should be mentioned here that validity of *Distichoplax* as an alga had been questioned by Lemoine (1958) and Lemoine (1961-62). They have shown analogies between chitinous parts of living and fossil Pterobranchia belonging to *Rhabdopleura*, and suggested that *Distichoplax* should not be considered as an alga. Rama Rao and Pia (1936) expressed their view that presence of *Sporolithon (Archaeolithothamnium) lugeonii* in the Niniyur Group is indicative of Tertiary age, but the taxon is now known to occur in Uttatur and Trichinoploy groups (Rama Rao & Gowda, 1954; Misra & Kumar, 1988). The genus *Corallina* which is known to be restricted to Tertiary everywhere is found in the Dalmiapuram Formation of Uttatur Group (Gowda, 1978). Eventually, it appears that no marker algal taxa in true sense is available to date the Cretaceous-Tertiary rocks of Tiruchirapalli District. However, from the distribution pattern (Table 2) it is evident that there are certain algal taxa which are significantly absent, or present or rich in any particular horizon. These are enumerated below.

The reefoidal limestone of Kallakkudi Limestone (Dalmiapuram Formation) and Varagapaudy Limestone belonging to Uttatur Group contains algae. The algal assemblage from the Dalmiapuram Formation is significantly devoid of Corallinoideae (Articulated Corallines). But the Varagapaudy Limestone which occurs at the base of Uttatur Group (Gowda, 1978) contains the articulated coralline red alga *Amphiroa* in association with *Solenopora* (Solenoporaceae). The latter genus ranges beyond Jurassic (Rama Rao & Gowda, 1954; Gowda, 1976) up to Danian (Keijzer, 1945; Rama Rao & Gowda, 1954).

Majority of the algal taxa described from the Varagur Limestone of Trichinopoly Group (Misra & Kumar, 1988) are Upper Cretaceous forms, but some of them are also known from the deposits older than Jurassic, Jurassic to Middle Cretaceous and Palaeocene to Miocene.

Rama Rao (1931) and Mamgain *et al.* (1968) reported the occurrence of crustose coralline red algae from the Ariyalur Group of rocks. Recently Ghosh and Maithy (1995) described Porostromata algae from the Cretaceous rocks of Sendurai belonging to Ariyalur Group. According to Rama Rao and Pia (1936) the Niniyur algal flora indicates a transitional position between the Cretaceous and Tertiary. The Niniyur algal assemblage (Rama Rao & Pia, 1936) is rich in well calcified Chlorophyta and coralline Rhodophyta. Majority of the algal species in the Niniyur Group are new and the preliminary indications given by their affinities are contradictory. The Niniyur Group may be included in the Mesozoic due to the presence of *Parachaetetes* and absence of specialised

Table 2—Distribution pattern of calcareous algae

TAXA	DISTRIBUTION IN DIFFERENT GROUPS			
	UTTATUR	TRICHINOPOLY	ARIYALUR	NINIYUR
Clypenia sahnii	—			—
Neomeris sp.	—			—
Sporolithon lugeonii	—	—		—
Sporolithon nonsteinensis	—	—		—
Acicularia antiqua	—	—		
Halimeda sp.	—			
Larvaria occidentalis	—			
Rivularia fruticulosa	—			
Rivularia sp.	—			
Solenopora jurassica	—			
Solenopora coromandelensis	—			
Solenopora sahnii	—			
Amphiroa sp.	—			
Solenopora sp. A	—			
Solenopora sp. B	—			
Amphiroa elliottii		—		
Amphiroa guatemalense		—		
Amphiroa varagurense		—		
Cylindroporella sp. cf. *C. sugdeni*		—		
Rivularia sp. cf. *kurdistanensis*		—		
Ethelia alba		—		
Ethelia sp.		—		
Indopolia sp. cf. *I. satyavanti*		—		
cf. *Larvaria* sp.		—		
Lithophyllum sp. A		—		
Lithophyllum sp. B		—		
cf. *Lithophyllum* sp.		—		
Neomeris cretaceae		—		
Mesophyllum sp. cf. *M. daviesi*		—		
Mesophyllum varians		—		
Palaeomastigocladus indicus		—		
Pycnoporidium lobatum		—		
Solenopora filiformis		—		
Solenopora sp.		—		
cf. *Solenopora* sp. A		—		
Sporolithon parisiense		—		
Sporolithon rude		—		
Thaumatoporella incrustata		—		
Parachaetetes sp.		—		
Distichoplax biseriales		—		
Parachaetetes asvapatii		—		
Lithothamnium sp.			—	
Lithophyllum sp.			—	
Mesophyllum sp.			—	
Sporolithon sp.			—	
Rivularia sp. cf. *Rivularia dianae*			—	
Rivularia lissaviensis			—	
Rivularia piae			—	
Rivularia theodori			—	
Garwoodia toomeyi			—	
Acicularia dyumatsenae				—
Acicularia indica				—
Acicularia sp.				—
Acitabularia sp.				—
Corallina raoi				—
Disocladella savitriae				—
Disocladella sp.				—
Disocladella undulata				—
Distichoplax raoi				—
Indopolia satyavanti				—
Orioporella malaviae				—
Piania niniyurensis				—
Solenopora tiruchiensis				—
Sporolithon aff. *provinciale*				—
Sporolithon pondicherriensis				—
Sporolithon sp. cf. *lycoperdioides*				—
Sporolithon torulosum				—
Sporolithon zonatum				—
Palaeochlya sp.				—

Melobesoideae in the Niniyur assemblage. On the other hand, presence of *Sporolithon* (*Archaeolithothamnium*) *lugeonii* and *Orioporella* would point to a Tertiary age of the Niniyur Group.

Therefore, Rama Rao and Pia (1936) expressed that algae can not play any significant role in the stratigraphic zonation in south India. However, the authors while discussing the age of Niniyur Group based on fossil algal assemblage stated that the Niniyur rocks must be given an age towards the close of Upper Cretaceous, for they overlie the Ariyalur Group.

A perusal of the foregoing discussion reveals that algae can not be used as an important tool to demarcate the K/T boundary. However, a critical evaluation of the distribution pattern of calcareous algae from the Cretaceous-Tertiary sediments of Tiruchirapalli District allows us to draw the following conclusions :

1. The Cretaceous algal assemblages consist of Cyanophyta or Cyanobacteria (10%), Chlorophyta (20-25%) and Rhodophyta (60-65%), whereas, the Tertiary assemblages consist of Chlorophyta (40-45%) and Rhodophyta (50-55%).
2. Calcified Cyanophyta (Cyanobacteria) which are frequent forms in the Cretaceous, are not present in the Tertiary algal assemblage recovered from the Niniyur Group.
3. The green algae like *Acicularia, Disocladella, Orioporella* and *Piania* are only known from the Niniyur Group, whereas, forms like *Cylindroporella, Clypenia, Halimeda,* etc. are only recorded from the underlying Cretaceous deposits. Codiaceae are poorly represented in the Tertiary deposits.
4. Gymnocodiaceae and Solenoporaceae (Rhodophyta) significantly contribute to the algal assemblages of Cretaceous deposits, whereas, their presence in the Tertiary deposits is unimportant. Among the crustose corallines, frequency of occurrence and morphological variations of the alga *Sporolithon* (*Archaeolithothamnium*) increases in the Tertiary sediments in comparison to those of Cretaceous.
5. In the Tertiary deposits (Niniyur Group, Danian) a majority of the algal species are new (viz., *Acicularia dyumatsenae, A. indica, Disocladella savitriae, Indopolia satyavanti, Piania niniyurensis*). Apparent extinction of many algal forms (viz., *Halimeda* sp., *Lithophyllum* sp., *Lithothamnium* sp., *Mesophyllum* sp., *Larvaria occidentalis, Rivularia* spp. and *Amphiroa* spp.) is also noticed from Cretaceous to Tertiary. These are indicative of the fact that there is a gradual change in algal flora from Cretaceous to Tertiary, due to which preponderance of new species is visualised in the algal assemblage of Niniyur Group (Danian).

REFERENCES

Banerji RK 1966. The genus *Globotruncana* and biostratigraphy of the Lower Ariyalur Stage (Upper Cretaceous) of Vridhachalam, south India. *J. geol. Soc. India* **7**: 51-69.

Banerji RK 1972. On the stratigraphy and micropalaeontology of Dalmiapuram Formation (Lower Cretaceous) - a new rock-stratigraphic unit of south India. *J. palaeont. Soc. India* **15**: 32-41.

Banerji RK 1973. Stratigraphy and micropalaeontology of the Cauvery Basin. Part I. Exposed area. *J. palaeont. Soc. India* **17**: 7-30.

Blanford HF 1862. On the Cretaceous and other rocks of south Arcot and Trichinopoly districts. *Mem. geol. Surv. India* **4**(1): 1-217.

Chiplonkar GW & Tapaswi PM 1975. Biostratigraphy of the Inoceramids in the Upper Cretaceous of Trichinopoly District, south India. *Biovigyanam* **1**: 11-15.

Ghosh AK & Maithy PK 1995. Porostromata algae from the Cretaceous of Sendurai, Tiruchiraplli District, Tamil Nadu, India. *J. palaeont. Soc. India* **40**: 49-53.

Ghosh AK & Maithy PK 1996. On the present status of Coralline red alga *Archaeolithothamnium* Roth. from India. *Palaeobotanist* **45**: 64-70.

Govindan A 1977. Late Cretaceous and Lower Tertiary foraminiferal genus *Bolivinoides* from the Cauvery Basin, south India and its palaeobiogeographical significance. *J. geol. Soc. India* **18**: 459-476.

Govindan A, Ravindran CN & Rangaraju MK 1996. Cretaceous stratigraphy and planktonic foraminiferal zonation of Cauvery Basin, south India. *Mem. geol. Soc. India* **37**: 155-187.

Gowda SS 1953. Occurrence of *Holosporella* in the Niniyur Group (Danian) of Trichinopolly, Cretaceous of south India. *Curr. Sci.* **22**(6): 169-170.

Gowda SS 1959. *Piania niniyurensis*, a new dasycladaceous alga from the Niniyur Group (Danian) of the Trichinopolly Cretaceous, south India. *J. geol. Soc. India* **1**: 152-155.

Gowda SS 1978. Fossil algae *Solenopora* and *Amphiroa* from the Trichinopolly Cretaceous rocks of south India. *Curr. Sci.* **47**(14): 502-503.

Jain KP 1977. Additional dinoflagellates and acritarchs from grey shale member of Dalmiapuram Formation, south India. *Palaeobotanist* **24**(3): 170-194.

Keijzer FG 1945. *Geogr. Geol. Meded.* **2** : 6.

Lemoine M 1961-62. Comparison de *Distichoplax biserialis* et des Rhabdopleura fossils et actuels. *Rev. Micropaleont.* **3**(2): 95-102.

Lemoine P 1952. Sur L'attribution du *Distichoplax biserialis* (Diet.) Pia aux pterobranches (Rhabdopleura) *C. r. Acad. Sci. Paris* **246**(14): 2145-2148.

Mamgain VD, Gururaja MN & Sastry MVA 1968. Fossil algae from Ariyalur Group (Upper Cretaceous), south India. *Indian Min.* **22**(1): 53-56.

Misra PK & Kumar P 1988. Fossil algae from the Cretaceous of Varagur, Tiruchirapalli District, Tamil Nadu. *Palaeobotanist* **37**: 36-51.

Narayan Rao SR 1944. Upper Jurassic marine algae from Trichinopoly, south India. *Curr. Sci.* **13**: 101-102.

Narayan Rao SR 1946. On two species of *Solenopora* from the Cullygoody Limestone of the Trichinopoly District, south India. *J. Indian bot. Soc. (M.O.P. Iyenger Comm. Vol.)*: 331-337.

Pal AK 1972. Further discovery of fossil algae in the Niniyur Group (Palaeocene) of the type area. *In* : Ghosh AK *et. al.* (Editors)—*Proceedings of the Seminar on Paleopalynology and Indian Stratigraphy* : 243-247. Calcutta University, Calcutta.

Pascoe EH 1959. *A manual of geology of India and Burma-* **2**. 3rd Ed., Calcutta.

Rama Rao L 1931. On the occurrence of *Lithothamnium* in south Indian Cretaceous. *Nature* **128**: 225-226.

Rama Rao L 1938. Recent discoveries of fossil algae in the Cretaceous rocks of south India. *Curr. Sci.* **7** : 1-6.

Rama Rao L 1956. Recent contribution to our knowledge of the Cretaceous rocks of south India. *Proc. Indian Acad. Sci.* **B41**: 185-245.

Rama Rao L 1958. Fossil algae in India. *Nature* **181**: 544-545.

Rama Rao L & Gowda SS 1953. Occurrence of *Clypeina* (Dasycladaceae) in the Niniyur Group (Danian) of the south Indian Cretaceous. *Curr. Sci.* **22**: 332-333.

Rama Rao L & Gowda SS 1954. Solenoporaceae from the Cretaceous rocks of south India. *Curr. Sci.* **23**(6): 177-179.

Rama Rao L & Pia J 1936. Fossil algae from the uppermost Cretaceous beds (the Niniyur Group) of the Trichinopoly District, south India. *Mem. geol. Surv. India, Palaeont indica*, n. ser., **21**(4): 1-49.

Rama Rao L & Prasanna Kumar C 1932. Occurrence of *Lithothamnium* in the south Indian Cretaceous. *Nature* **129**: 776-777.

Sastry MVA, Mamgain VD & Rao BRJ 1972. Ostracod fauna from the Ariyalur Group (Upper Cretaceous), Trichinopoly District, south India. *Mem. geol. Surv. India, Palaeont. indica*, n. ser., **40**: 1-59.

Sastry MVA, Rao BRJ & Mamgain VD 1968. Biostratigraphic zonation of the Trichinopoly District, south India. *Mem. geol. Soc. India* **2**: 10-17.

Subbaraman JV 1968. Surface and subsurface geology of the area around Dalmiapuram, Trichinopoly District. *Mem. geol. Soc. India* **2**: 92-98.

Sundaram R & Rao PS 1966. Lithostratigraphy of Cretaceous and Palaeocene rocks of Trichirapalli District, Tamil Nadu, south India. *Rec. geol. Surv. India* **115** (5): 9-23.

Varma CP 1952. *Clypenia* (Dasycladaceae) from the Cretaceous of S. India. *Palaeobotanist* **1**: 339-341.

Varma CP 1954. On the algal genera *Neomeris* and *Acicularia* from the Niniyur (Danian) beds, Trichinopoly (south India). *Proc. natn. Inst. Sci. India* **20**: 298-304.

Palynological changes across subsurface Palaeocene-Eocene sediments at Barmer, Rajasthan, India

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Tripathi SKM 1997. Palynological changes across subsurface Palaeocene-Eocene sediments at Barmer, Rajasthan, India. *Palaeobotanist* **46** (1,2) : 168-171.

Palynofloras recovered from core samples from two bore-holes MK 327 and MK 332 drilled near Kapurdi, Barmer, Rajasthan are rich and diversified. Restricted occurrence of *Matanomadhiasulcites maximus* and *Triangulorites pachyexinus* alongwith other long-ranging taxa demarcates the Palaeocene sediments from those of Eocene. Presence of Eocene sediments in the studied bore-holes is indicated by the restricted occurrence of *Meliapollis pachydermis, M. symplex, Lygodiumsporites lakiensis* and *Foveotricolporites reticuloidus.* Two palynological zones, Assemblage Zone A indicating Late Palaeocene age and Assemblage Zone B indicating Early Eocene age, have been identified in the bore-hole sequences and sediments representing these zones have been correlated with Akli and Mataji Ka Dungar formations, respectively of the Barmer Basin.

Key-words—Palynology, Palaeocene, Eocene, Rajasthan, India.

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सारॅांश

राजस्थान (भारत) में ब्राड़मेर के समीपस्थ उपसतही पेलियोसीन-ईओसीन अवसादों में परागाणविक परिवर्तन

सूर्यकान्तमणि त्रिपाठी

राजस्थान में बाड़मेर के समीप कपूर्ड़ी से एम.के. 327 एवं एम.के. 332 नामक दो वेध-छिद्रों के नमूनों से प्राप्त परागााणुवनस्पतिजात सघन एवं विविधता युक्त हैं। अन्य दीर्घकालिक वर्गकों सहित *मातानोमढ़ियासल्फाइटिस मेक्सिमस* एवं *ट्राएंगुलोराइटिस पेकिएक्साइनस* की सीमित उपस्थिति से पेलियोसीन एवं ईओसीन अवसादों को सीमाबद्ध किया जा सका है । *मिलियापोलिस पेकिडर्मिस, मि. सिम्पलेक्स, लाइगोडियमस्पोराइटिस लाकीयेन्सिस* एवं *फोवियोट्राइकॉल्पोराइटिस रेटिकुलोइड्स* की सीमित उपस्थिति से वेध-छिद्रों में ईओसीन कालीन अवसादों की उपस्थिति व्यक्त होती है। दो परागााणविक मंडल--समुच्चय मंडल ए. एवं समुच्चय मंडल बी., जो क्रमशः अनंतिम पेलियोसीन तथा प्रारम्भिक आदिनूतन आयु इंगित करते हैं, अभिनिर्धारित किये गये हैं तथा अकली एवं माताजी का डुंगर शैल-समूहों से इन अवसादों की तुलना की गई है।

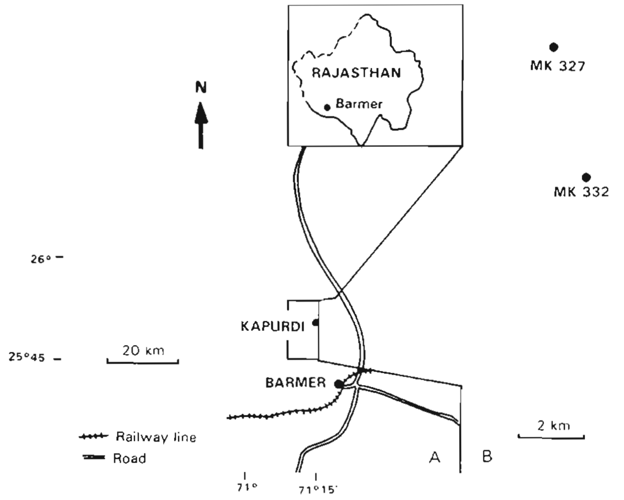
PRESENT paper deals with the critical assessment of palynofloral assemblages recorded from two bore-hole sections situated near Kapurdi, Barmer District, Rajasthan (Text-figure 1). These bore-holes were drilled by Mineral Exploration Corporation Limited. Lithocolumn of the bore-holes alongwith position of samples is given in Text-figure 2. The palynofloras are rich and diversified and comprise algal cysts, fungal remains, pteridophytic spores and angiospermous pollen. Taking into consideration the distribution pattern and frequency of different palynotaxa the studied sequences were dated as Palaeocene-Eocene in age (Tripathi, 1994, 1995).

The palynoassemblages were compared with those from other contemporaneous sediments and the perceptible change was observed in the distribution of palynotaxa that enables demarcation of the Palaeocene and Eocene strata.

GEOLOGICAL SETTING AND GENERAL LITHO-STRATIGRAPHY OF THE AREA

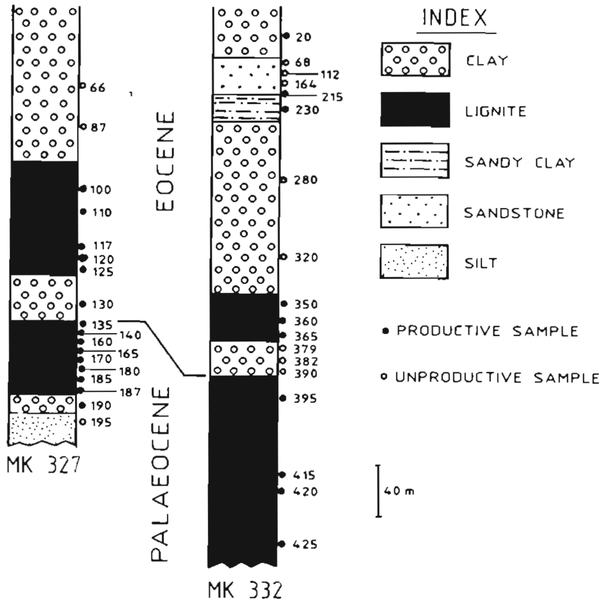
The sedimentary sequences in Rajasthan are predominantly intracratonic type. These sediments, forming a part of western Rajasthan shelf, comprise Middle Jurassic to Early Eocene rocks in a north-south trending graben (Dasgupta, 1977).

Palaeocene-Eocene rocks in Barmer Basin are divided into Fategarh, Barmer, Akli, Mataji Ka Dungar and Kapurdi formations, in ascending order. Fategarh Formation is made up of sandstone mixed with clay



Text-figure 1—A, Map showing the area of investigation; **B,** location of bore-hole sections.

bands and gastropod casts at the top. Based on lithological similarity this formation is correlated with nonmarine sandstone member of subsurface Sanu Formation of Jaisalmer Basin (Dasgupta, 1977). The lower part of the overlying Barmer Formation is represented by fluviatile sediments, whereas its upper part is marine in nature. Based on palynological studies the lower part of Barmer Formation is dated as Palaeocene in age. The Akli Formation unconformably overlies the Barmer Formation. Lower part of this formation is made up of a sandstone-lignite sequence whereas the upper part is a volcanogenic bentonite sequence. Mataji Ka Dungar Formation is dominantly represented by coarse and ferruginous sandstone with pisolite and pebbly sandstone. The Kapurdi Formation is constituted by Fuller's Earth deposits interbedded with marine bioclastic limestone.



Text-figure 2—Lithosuccession of studied bore-hole sections and sample position.

PREVIOUS PALYNOLOGICAL WORK

Palynological data from Rajasthan Basin are available from Barmer (Bose, 1952; Jain *et al.*, 1973; Naskar & Baksi, 1978; Tripathi, 1994, 1995), Bikaner (Singh & Dogra, 1988; Ambwani & Singh, 1996; Kar, 1996a) and Palana beds (Rao & Vimal, 1950, 1952; Sah & Kar, 1974). Inter-relationship of these sequences is not clearly understood. Singh and Dogra (1988) reviewed the Palaeocene and Early Eocene spore/pollen assemblages from Indian sedimentary sequences and identified five palynological zones, viz., Zones SP-1 and SP-2 representing Early Palaeocene, SP-3 and SP-4 representing Late Palaeocene and SP-5 representing Early Eocene. These Palynological zones were correlated with planktonic foraminiferal zones and were found to persist in Meghalaya, West Bengal, Cauvery and Kutch basins (Singh & Dogra, 1988). The SP-3 Zone (Singh & Dogra, 1988) marks the beginning of Upper Palaeocene in India. This zone is characterised by the dominance of *Dandotiaspora* spp., subdominance of *Proxapertites* spp., *Triangulorites* spp., and restricted occurrence of *Retipilonapites cenozoicus* and *Palaeosantalaceaepites dinoflagellatus.* SP-4 Zone is distinguished by the predominance of near-shore pollen and dinoflagellate cysts. Persistent occurrence of arecaceous pollen assignable to *Palmidites, Spinizonocolpites* and *Neocouperipollis* in high frequency is noticed in Late Palaeocene sediments of Meghalaya, Assam, Himalayan foothills, Kutch and Rajasthan. SP-5 Zone is characterised by the dominance of tricolpate, tricolporate and triporate pollen and rare occurrence of *Proxapertites, Dandotiaspora, Lycopodiumsporites* and polycolpate grains.

PRESENT STUDY

Angiosperm pollen in general dominate the assemblage recorded from bore-holes MK 327 and MK 332. Pollen having affinities with the families Arecaceae, Liliaceae, Oleaceae, Bombacaceae, Caesalpiniacae, Proteaceae, Rubiaceae, Onagraceae, Caprifoliaceae, Clusiaceae and Lamiaceae have been documented in the assemblage in fairly good number. Pteridophytic spores assignable to the families Osmundaceae, Matoniaceae, Polypodiaceae, Lycopodiaceae, and Schizaeaceae are well-represented. Distribution of stratigraphically significant spore/ pollen taxa is given in Table 1. These two sections show almost similar patterns with regard to distribution and frequency of different palynotaxa. Salient features of the assemblages are: good representation of *Proxapertites* spp., *Matanomadhiasulcites kutchensis, Spinizonocolpites echinatus, Tricolpites retibaculatus, Liliacidites microreticulatus, Granustephanocolpites sahii, Dandotiaspora* spp., *Lycopodiumsporites* spp., *Triangulorites bellus* and *T. pachyexinous* and comparatively less representation of *Kielmeyerapollenites eocenicus* and *Tricolpites retibaculatus*. Distribution and frequency of palynotaxa enable identification of two zones in the assemblage which are informally designated as Assemblage Zone A and Assemblage Zone B. Assemblage Zone A is characterised by the dominance of *Dandotiaspora dilata, Lycopodiumsporites* spp., *Proxapertites* spp., *Triangulorites bellus, Liliacidites microreticulatus, Granustephanocolpites sahii* and *Palmidites* spp. and restricted occurrence of *Matanomadhiasulcites maximus* and *Triangulorites pachyexinus*. In bore-hole MK 327 depth 135 to 190 m and in bore-hole MK 332 depth 395 to 425 m represent Assemblage Zone A. The palynofloral composition and palynotaxa frequency indicate that this zone can be correlated to SP-3 and SP-4 zones proposed by Singh and Dogra (1988). The assemblage Zone B is marked with increased frequency of *Tricolporopollis rubra, Spinizonocolpites echinatus, Kielmeyerapollenites eocenicus* and *Matanomadhiasulcites kutchensis* and restricted occurrence of *Meliapollis pachydermis, M. simplex, Foveotricolporites reticuloidus, Lygodiumsporites lakiensis* and *Bombacacidites* sp.

Table 1—Palynotaxa distribution in bore-hole sections

TAXA	ASSEMBLAGE ZONE A	ASSEMBLAGE ZONE B
Matanomadhiasulcites maximus	----	
Triangulorites pachyexinous	----	
Dandotiaspora dilata	——	----
D. telonata	----	----
Lycopodiumsporites palaeocenicus	——	----
L. umstewensis	----	----
Proxapretites assamicus	——	----
P. cursus	——	----
P. microreticulatus	——	----
Liliacidites microreticulatus	——	----
L. major	----	----
L. magnus	----	----
Palmidites plicatus	——	----
P. naviculus	----	
P. excellens	——	----
Triangulorites bellus	——	----
Granustephanocolpites sahii	——	----
Spinizonocolpites echinatus	----	——
Tricolporopollis rubra	----	——
Kielmeyerapollenites eocenicus	----	——
Matanomadhiasulcites kutchensis	----	——
Meliapollis pachydermis		----
M. simplex		----
Foveotricolporites reticuloides		----
Lygodiumsporites lakiensis		——
Bombacacidites sp.		----

—— Frequent
---- Rare

In bore-hole MK 327 depth 100 to 130 m and in bore-hole MK 332 depth 20 to 365 m represent Assemblage Zone B. This zone is correlatable to SP-5 Zone of Singh and Dogra (1988).

DISCUSSION

Demarcation of Palaeocene and Eocene sediments based on palynotaxa distribution is rather difficult as most of the taxa are long ranging. However, the change in frequency of some palynotaxa plays a crucial role in determining the boundary.

In India, the Early Palaeocene assemblage is characterised by the dominance of *Proxapertites operculatus, P. cursus, Matanomadhiasulcites maximus, Spinizonocolpites echinatus, Saturna enigmaticus* and *Terscissus grandis*. The Late Palaeocene assemblage shows the dominance of *Dandotiaspora* spp., *Lycopodiumsporites* spp., *Palmaepollenites eocenicus, Neocouperipollis* spp., *Spinizonocolpites* spp., *Palmidites* spp., *Psilastephanocolporites* spp., *Retistephanocolporites* spp. and *Granustephanocolpites*. These forms either disappear or are rarely found in Early Eocene (Kar, 1996b). The Palaeocene palynotaxa continuing in Early Eocene are: *Matanomadhiasulcites*, *Triangulorites, Lakiapollis, Tricolporopollis, Palmaepollenites* and *Neocouperipollis.*

The Early Eocene assemblage is marked with increased frequency of *Tricolporopollis matanomadhensis, Meliapollis ramanujamii, M. pachydermis, M. simplex, Umbelliferoipollenites ovatus, Pellicieroipollis langenheimii* and *Lygodiumsporites lakiensis.* In bore-hole MK 327, in the samples from the depth 135 to 190 m, largely representing the lignite sequence, the dominant taxa are: *Proxapertites, Matanomadhiasulcites, Liliacidites, Dandotiaspora, Triangulorites* and *Granustephanocolpites.* The assemblage belongs to Assemblage Zone A and sediments yielding these forms have been dated as Palaeocene. Samples from the depth 100 to 125 m of this bore-hole, representing clay and lignite, have yielded an assemblage identifiable as Assemblage Zone B and is characterised by the presence of *Meliapollis pachydermis, Meliapollis simplex, Foveotricolporites reticuloidus* and *Lygodiumsporites lakiensis.* These palynotaxa are restricted to Early Eocene. Low frequency of *Dandotiaspora, Lycopodiumsporites* and *Proxapertites* is also noticed in this assemblage which again indicates Early Eocene age. Similar pattern of palynotaxa distribution is observed in the samples of bore-hole MK 332 in which samples from the depth 395 to 425 m have yielded a palynoflora matching that of Assemblage Zone A indicating Palaeocene age whereas, samples from depth 20 to 365 m have yielded an assemblage similar to that recorded from Assemblage Zone B indicating Early Eocene age.

Considering the stratigraphical distribution of palynotaxa and their frequency Palaeocene and Eocene sediments have been demarcated in two bore-holes MK 327 and MK 332 and the boundary is marked at the top of a lignite sequence (Text-figure 2) and sediments representing Assemblage Zone A have been correlated with Akli Formation whereas, those representing Assemblage Zone B are correlated with Mataji Ka Dungar Formation.

REFERENCES

Ambwani K & Singh RS 1996. *Clavadiporopollenites raneriensis* gen. et sp. nov. from the Tertiary sediments of Bikaner District, Rajasthan, India. *Palaeobotanist* **43**(3): 139-142.

Bose MN 1952. Plant remains from Barmer District, Rajasthan. *J. scient. Indian Res.* **11B**(5) : 185-190.

Dasgupta SK 1977. The stratigraphy of the West Rajasthan Shelf. *Proc. 4th Colloq. Indian Micropalaeontol. Stratigr.* : 219-233.

Jain KP, Kar RK & Sah SCD 1973. A palynological assemblage from Barmer, Rajasthan. *Geophytology* **3**(2) : 150-165.

Kar RK 1996a. On the Indian origin of *Ocimum* (Lamiaceae) : a palynological approach. *Palaeobotanist* **43**(3) : 43-50.

Kar RK 1996b. Late Cretaceous and Tertiary palynological succession in India. *Palaeobotanist* **45** : 71-80.

Naskar P & Baksi SK 1978. Palynological investigation of Akli lignite, Rajasthan. *Palaeobotanist* **25** : 314-329.

Rao AR & Vimal KP 1950. Plant microfossils from Palana lignite (Eocene), Bikaner. *Curr. Sci.* **19** : 82-84.

Rao AR & Vimal KP 1952. Tertiary pollen from lignites of Palana (Eocene), Bikaner. *Proc. natn. inst. Sci. India* **18**(6) : 595-601.

Sah SCD & Kar RK 1974. Palynology of the Tertiary sediments of Palana, Rajasthan. *Palaeobotanist* **21**(2) : 163-188.

Singh RY & Dogra NN 1988. Palynological zonation of Palaeocene in India with special reference to western Rajasthan. *In* : Maheshwari HK (Editor)—*Palaeocene of India : Proceedings of the Symposium on Palaeocene of India : limits and subdivisions, Lucknow, 1986* : 51-64. Indian Association of Palynostratigraphers, Lucknow.

Tripathi SKM 1994. New angiosperm pollen from subsurface Early Palaeogene sediments of Barmer District, Rajasthan, India. *Palaeobotanist* **42**(1) : 61-65.

Tripathi SKM 1995. Palynology of subsurface Palaeocene-Eocene sediments near Kapurdi, Barmer District, Rajasthan, India. *Palaeobotanist* **43**(1) : 45-53.

Distribution of palynofossils across the Palaeocene-Eocene Boundary in north-east and western India

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Mandal J & Kumar M 1997. Distribution of palynofossils across the Palaeocene-Eocene Boundary in north-east and western India. *Palaeobotanist* **46** (1, 2) : 172-176.

Late Palaeocene-Early Eocene palynoassemblages of north-east and western India have been analysed to assess the behaviour of palynotaxa during the transition. More than 50 per cent of the taxa continue from Palaeocene to Eocene while some are restricted only to Palaeocene. A number of palynotaxa appear at Early Eocene that may be considered as marker. A critical study on the distribution pattern of these palynotaxa indicates that there is no sharp or abrupt change during Palaeocene-Eocene instead majority of taxa are common and differ only in percentage frequency.

Key-words—Palynology, Palaeocene-Eocene transition, North-east and western India.

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सारांश

उत्तर-पूर्व एवं पश्चिमी भारत में पेलियोजीन-ईओसीन सीमा पर परागाणविकरूपकों का वितरण

जगन्नाथ प्रसाद मंडल एवं माधव कुमार

अनंतिम पेलियोसीन-प्रारम्भिक ईओसीन परिवर्तन के समय परागाणुवर्गकों की प्रकृति का मूल्यांकन करने के लिए उत्तर-पूर्व एवं पश्चिमी भारत से उपलब्ध समुच्चयों का विश्लेषण किया गया है। ऐसा देखा गया है कि लगभग 50 प्रतिशत वर्गक उसी प्रकार मिलते हैं जबकि कुछ वर्गक केवल पेलियोसीन काल तक ही मिलते हैं प्रारम्भिक ईओसीन काल में मिलने वाले वर्गक-सूचक वर्गक जाने जाते हैं । इन परागाणुवर्गकों के वितरण के स्वरूप के विशेष अध्ययन से प्रदर्शित होता है कि पेलियोसीन-ईओसीन काल में कोई आकस्मिक अथवा विशेष परिवर्तन नहीं हुआ है तथा अधिकतर वर्गक सामान्य हैं तथा केवल प्रतिशत बारम्बारता में विभिन्नता प्रदर्शित करते हैं।

DISTRIBUTION pattern of palynoflora at Palaeocene-Eocene transition on the Indian subcontinent has not so far been evaluated, however, Palaeocene and Eocene palynoassemblages have been critically assessed (Sah & Kar, 1972; Venkatachala *et al.*, 1989; Kar, 1992; Kar & Bhattacharya, 1991). The present study is based on the analyses of Upper Palaeocene palynoflora of Kutch and Meghalaya and Early Eocene of Kutch and Cambay basins. The floral change across P/E is explained on the basis of taxa restricted only to Palaeocene, common flora during Palaeocene-Eocene transition and rapid increase of palynotaxa at Early Eocene.

DISCUSSION

The Late Palaeocene in Meghalaya is represented by coal-bearing Lakadong Sandstone Member of Sylhet Limestone Formation. The Tura Formation in Garo Hill is time transgressive unit and equivalent to Sylhet Limestone Formation. The middle and upper members of Tura Formation are correlated on lithological characters with Lakadong Sandstone and Umlatdoh Limestone members respectively (Raja Rao, 1981).

In Meghalaya, Late Palaeocene sediments are deposited in shallow marine environment. Very rich palynofossils are documented from these strata (Biswas, 1962; Baksi, 1962; Salujha *et al.*, 1972, 1974; Singh, 1977; Sah & Dutta, 1967,1974; Dutta & Sah, 1970; Singh & Singh, 1978; Kar & Kumar, 1986; Mandal, 1986, 1990). The Early Eocene strata in Khasi Hills are represented by limestone facies (Umlatdoh Limestone Member) which are devoid of pollen-spores.

In Kutch Basin, Matanomadh Formation is deposited in lacustrine environment and Palaeocene in age. The Gypseous Shale Member, lowermost member of overlying Naredi Formation, is dated to Early Eocene (Biswas, 1992). The palynological data from Matanomadh and Naredi formations also favour Late Palaeocene and Early Eocene ages respectively (Mathur, 1966; Mathur & Pant, 1973; Saxena, 1980; Sah & Kar, 1972; Kar, 1985). The palynoassemblages of Matanomadh Formation and Lakadong Sandstone Member are almost identical. Both the assemblages possess *Dandotiaspora dilata, D. telonata, D. plicata, Matanomadhiasulcites maximus, M. kutchensis, Neocouperipollis kutchensis, Palmaepollenites kutchensis, Lakiapollis ovatus, Retitribrevicolporites matanomadhensis, Meliapollis ramanujamii, Triangulorites bellus, Tricolpites crassireticulatus*, etc. (Kar & Kumar, 1986; Saxena, 1980; Kar, 1985).

The lignite-bearing horizon of Tarkeshwar Formation in Cambay Basin has common palynoflora with the Naredi Formation and palynologically dated as Early Eocene (Rawat *et al.*, 1977; Koshal & Uniyal, 1986; Kar & Bhattacharya, 1992; Kumar, 1996).

In both the areas luxuriant vegetation flourished under the influence of tropical climate occupying roughly same latitudinal position (Broin, 1987). The assemblages, on analysis, reveal that Late Palaeocene flora is represented by 61 genera and 132 species, out of which 17 genera and 45 species belong to pteridophytes and 44 genera and 87 species represent angiosperms. Early Eocene palynoassemblage consists of 90 genera and 162 species. The study also reveals that 77 per cent of genera and 43 per cent of species of pteridophytes and 50 per cent genera and 38 per cent species of angiosperm pollen are common to Late Palaeocene and Early Eocene assemblages. During this transition significant increase of angiosperm taxa is evident while the pteridophytic spores decrease quantitatively at specific level. This is due to the disappearance of many species of the dominant genera like *Lycopodiumsporites, Dandotiaspora, Proxapertites* and *Neocouperipollis* during Early Eocene and increase of the number of species, e.g., *Palmaepollenites* as shown in the following Table:

	Palaeocene	Eocene
Dandotiaspora dilata	+	-
D. densicarpa	+	-
D. plicata	+	+
D. telonata	+	+
D. pseudoauriculata	+	+
Lycopodiumsporites speciosus	+	-
L. umstewensis	+	-
L. compartmentus	+	-
L. palaeocenicus	+	-
L. concavus	-	-
L. duttae	+	-
L. sabii	+	-
L. bellus	+	-
L. parvireticulatus	+	+
Proxapertites emendatus	+	-
P. crassimurus	+	-
P. assamica	+	+
P. microreticulatus	+	+
P. reticulatus	-	+
Neocouperipollis magnus	+	-
N. spinorobustus	+	-
N. robustus	+	-
N. wodehousei	+	-
N. brevispinosus	+	+
N. rarispinosus	+	+
N. perspinosus	+	+
N. echinatus	+	+
N. kutchensis	+	+
Palmaepollenites plicatus	+	+
P. nadhamunii	+	+
P. ovatus	+	+
P. kutchensis	+	+
P. magnus	-	+

(+ present; - absent)

It is certain that at the P/E transition, more than 50 per cent taxa continue from Palaeocene to Eocene. However, some palynofossils disappear at the end of Palaeocene while a number of taxa appear during Early Eocene. These first appeared elements of Early Eocene are much more in number than the taxa disappeared at the end of Palaeocene. The common elements vary in occurrence at both the times, they are either abundant in Palaeocene or Eocene. Therefore, four categories of palynotaxa emerged at the transition level are (i) palynotaxa restricted in Palaeocene, (ii) abundant in Late Palaeocene but rare in Early Eocene, (iii) rare in Late Palaeocene and abundant in Early Eocene, and (iv) appearance of new taxa in Eocene (Text-figure 1). The following are some of the commonly occurred significant taxa representing the following four categories.

Text-figure 1—The chart shows four categories of palynotaxa during the P/E transition.

1. Palynotaxa restricted in Palaeocene

Dandotiaspora dilata, Proxapertites emendatus, Kielmeyerapollenites syncolporatus, Droseridites major, Densiverrupollenites eocenicus, Lycopodiumsporites speciosus, L. umstewensis and *Matanomadhiasulcites maximus.*

2. Abundant in Late Palaeocene but rare in Early Eocene

Dandotiaspora telonata, Lycopodiumsporites palaeocenicus, Proxapertites assamica, Matanomadhiasulcites kutchensis, Neocouperipollis kutchensis, N. brevispinosus, Triangulorites bellus, T. pachyexinus, Spinizonocolpites echinatus, Tribrevicolporites eocenicus and *Psilastephanocolporites subcircularis.*

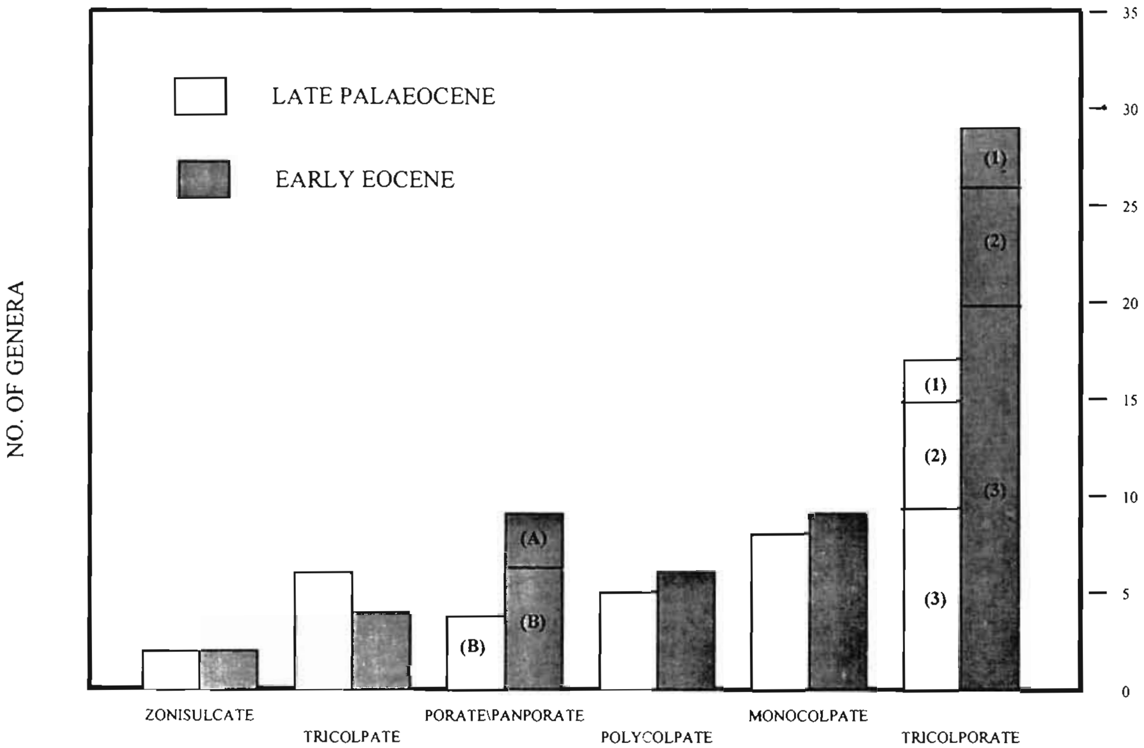
3. Rare in Late Palaeocene and abundant in Early Eocene

Lakiapollis ovatus, Meliapollis spp., *Racemonocolpites thanjinathensis, Margocolporites tsukadai, Retitri-brevicolporites matanomadhensis, Dermatobrevicolporites triangulus, D. exaltus, Striacolporites cephalus* and *Polymargocolporites mawlensis.*

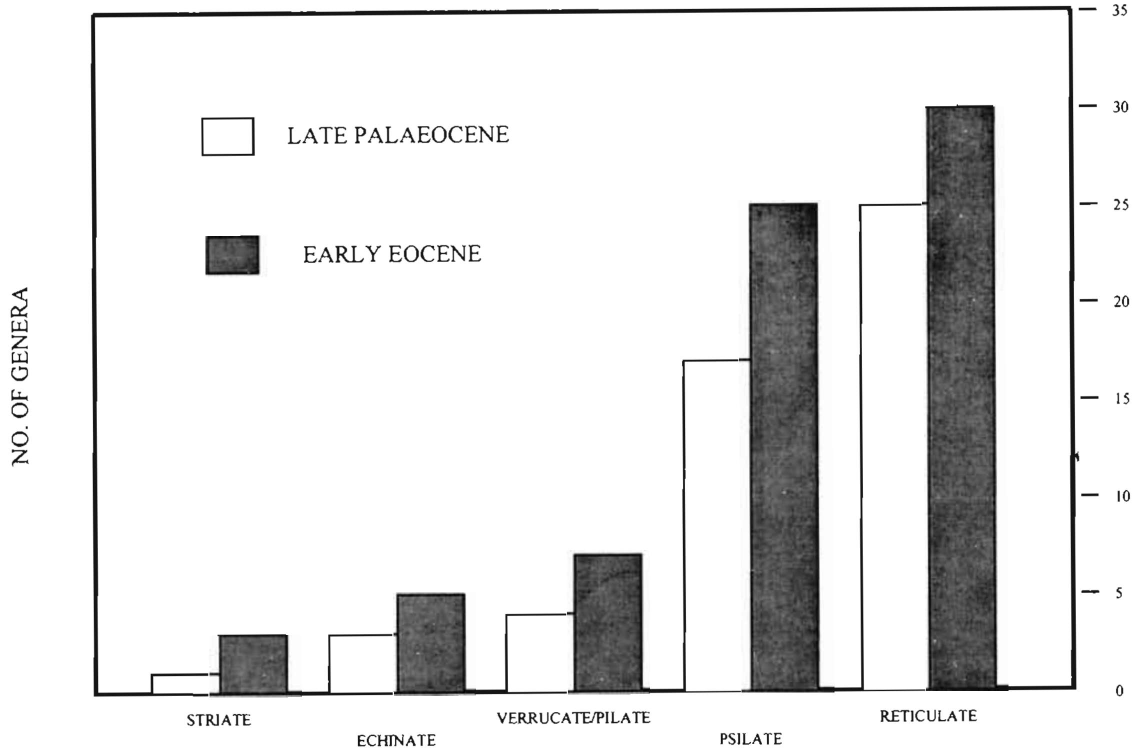
4. Taxa appeared in Eocene

Cheilanthoidspora monoleta, C. enigmata, Pellicieroipollis langenheimii, Lanagiopollis rugularis, Acanthotricolpites bulbospinosus, Tricolporopilites robustus, Marginipollis kutchensis, Arengapollenites achinatus, Umbelliferoipollenites ovatus, U. constrictus, Retitrilatiporites kutchensis, Retitetrabrevicolporites granulatus, Longapertites retipilatus, Angulocolporites microreticulatus, Clavaperiporites clavatus, and *Minutitricolporites minutus.*

The above mentioned distribution and analyses of palynomorphs demonstrate that Palaeocene-Eocene transition is not marked by the drastic change of palynofossils. This is rather characterized by common elements having different percentage representation. However, restricted palynotaxa to Palaeocene are not at the generic level but they are only at the specific rank. The taxa *Dandotiaspora dilata* and *Matanomadhiasulcites maximus* restricted in Palaeocene and occurring uniformly in both the areas can suitably be used as Late Palaeocene marker. The other stratigraphically restricted taxa, viz., *Kielmeyerapollenites syncolporatus, Polycolporites indicus* and *Droseridites major* are confined to Meghalaya (Kar & Kumar, 1986), while *Sonneratiapollis bellus, Psilastephanocolporites guaduensis* and *Osmundacidites microgranifer* are restricted in Kutch (Kar, 1992). The taxa *Lycopodiumsporites speciosus* and *Proxapertites emendatus* are more common in Meghalaya than Kutch. The notable event during this transition is the appearance of angiosperm taxa of various families in Early Eocene. The introduced palynotaxa which can definitely be tagged with the modern families are Arecaceae (*Arengapollenites*), Alangiaceae (*Lanagiopollis, Tricolporocolumellites, Tricolporopilites, Pellicieroipollis*), Barringtoniaceae (*Marginipollis*), Linaceae (*Clavaperiporites*), and Apiaceae (*Umbelliferoipollenites*). The definite modern affinity of some other taxa, e.g., *Dermatobrevicolporites, Striatricolpites, Cheilanthoidspora,*



Text-figure 2—Histogram shows the relative frequencies of aperture types (**A**- panporate; **B**- triporate; **1**- syncolporate; **2**- brevicolporate; **3**- (longi-)colporate).



Text-figure 3—Bars show the comparison of different kinds of exinal features of angiosperm taxa.

Acanthotricolpites, Minutitricolporites of Early Eocene could not be ascertained.

Palm pollen are rich both in variety and number during Eocene which is an universal feature of that time because of maximum development and extension of the tropical climate (Traverse, 1988). Polycolpate forms are also common along with palm pollen but quantitatively more rich during Palaeocene. However the distinction of Late Palaeocene and Early Eocene assemblages on the basis of abundance of polycolpate and palm pollen, can only be possible when both the assemblages are studied side by side.

Apart from the assessment of palynological distribution, an analysis on the morphological characters of palynomorphs has been made. This analysis has revealed that some changes have occured in the aperture type during the Early Eocene. The apertures like monosulcate, zonisulcate, tricolpate and colporate types are common in Palaeocene-Eocene palynoassociation. The dominant aperture type during Late Palaeocene is tricolpate while colporate in Early Eocene. It is also observed that the triporate aperture are uncommon during Palaeocene but quite a few taxa have been recorded in later time along with panporate type which appears at the Early Eocene (Text-figure 2). However, no change has been noticed in the sculptural features on the pollen exine (Text-figure 3).

CONCLUSIONS

1. No sharp palynofloral change is observed during Palaeocene-Eocene interval but is marked by transition of flora.
2. Disappearance of *Dandotiaspora dilata, Proxapertites emendatus, Kielmeyerapollenites syncolporatus* and *Lycopodiumsporites speciosus* marks the end of Palaeocene.
3. Several new angiospermic taxa have appeared at Early Eocene.
4. Angiosperm families Alangiaceae, Barringtoniaceae, Apiaceae and 'panporate' aperture are introduced at Early Eocene.

REFERENCES

Baksi SK 1962. Palynological investigation of Simsang River Tertiaries, South Shillong Front, Assam. *Bull. geol. Min. metall. Soc. India* **26** : 1-22.

Biswas B 1962. Stratigraphy of the Mahadeo, Langpar, Cherra and Tura formations, Assam, India. *Bull. geol. Min. metall. Soc. India* **25** : 1-48.

Biswas SK 1992. Tertiary stratigraphy of Kutch. *J. palaeont. Soc. India* **37** : 1-29.

Broin F de 1987. Les Tortues et le Gondwana. *Bull. Groupe Francais Gondwana* **10** : 71-86.

Dutta SK & Sah SCD 1970. Palynostratigraphy of the Tertiary sedimentary formations of Assam : 5. Stratigraphy and palynology of South Shillong Plateau. *Palaeontographica* **B131** : 1-62.

Kar RK 1985. The fossil floras of Kachchh-IV. Tertiary palynostratigraphy. *Palaeobotanist* **34** : 1-279.

Kar RK 1992. Stratigraphical implications of Tertiary palynological succession in north-eastern and western India. *Palaeobotanist* **40** : 336-344.

Kar RK & Bhattacharya M 1992. Palynology of Rajpardi Lignite, Cambay Basin, Gujra Dam and Akri Lignite, Kutch Basin. *Palaeobotanist* **39**(2) : 250-263.

Kar RK & Kumar M 1986. Palaeocene palynostratigraphy of Meghalaya, India. *Pollen Spores* **28** : 177-218.

Koshal VN & Uniyal SN 1986. Palynostratigraphy of the Cenozoic succession of Cambay Basin, Gujarat. *Bull. geol. Min. metall. Soc. India* **54** : 208-226.

Kumar M 1996. Palynostratigraphy and palaeoecology of Early Eocene palynoflora of Rajpardi lignite, Bharuch District, Gujarat. *Palaeobotanist* **43** : 110-121.

Mandal J 1986. Palynological study of Sutunga coal seam, Jaintia Hills, Meghalaya. *Palaeobotanist* **35** : 196-199.

Mandal J 1990. Palynological investigation of Palaeocene sediments from Thanjinath, Meghalaya. *Palaeobotanist* **37** : 324-330.

Mathur YK 1966. On the microflora in the Supra Trappeans of western Kutch, India. *Q. Jl geol. Min. metall. Soc. India* **38** : 33-51.

Mathur YK & Pant J 1973. Plant microfossils of Palaeocene-Eocene age from the Wagad region, Kutch. *Curr. Sci.* **42** : 857-859.

Raja Rao CS 1981. Coalfields of India : Vol. 1. Coalfields of north eastern India. *Bull. geol. Surv. India* ser. A **45** : 1-74.

Rawat MS, Mukherjee J & Venkatachala BS 1977. Palynology of Kadi Formation, Cambay Basin, India. *In* : BS Venkatachala BS & Sastri VV (Editors)—*Proc. IV Colloq. Indian Micropaleontol. Stratigr., Dehradun* : 179-192.

Sah SCD & Dutta SK 1967. Palynostratigraphy of the Tertiary formations of Assam : 2. Stratigraphic significance of spores and pollen in the Tertiary succession of Assam. *Palaeobotanist* **16** : 177-195.

Sah SCD & Dutta SK 1974. Palynostratigraphy of the Tertiary formations of Assam : 3. Biostratigraphic zonation of the Cherra Formation of South Shillong Plateau. *Palaeobotanist* **21** : 42-47.

Sah SCD & Kar RK 1972. Palynostratigraphic evaluation of the Lower Eocene sediments of India. *In* : Ghosh AK *et al.* (Editors)—*Proc. Sem. Paleopalynol. Indian Stratigr., Calcutta, 1971* : 255-265.

Salujha SK, Kindra GS & Rehman K 1972. Palynology of the South Shillong Front. Part 1. The Palaeogene of Garo Hills. *In* : Ghosh AK *et al.* (Editors)--*Proc. Sem. Paleopalynol. Indian Stratigr., Calcutta 1971* : 265-291.

Salujha SK, Kindra GS & Rehman K 1974.Palynology of the South Shillong Front. Part II. The Palaeogene of Khasi and Jaintia hills. *Palaeobotanist* **21** : 267-284.

Saxena RK 1980. Palynology of the Matanomadh Formation in the type area, north western Kutch, India (Part 2). Systematic description of gymnospermous and angiospermic pollen grains. *Palaeobotanist* **26** : 130-143.

Singh RY 1977. Stratigraphy and palynology of the Tura Formation in the type area (part III). Discussion. *Palaeobotanist* **24** : 1-12.

Singh RY & Singh HP 1978. Morphological observations on some spores and pollen grains from the Palaeocene subsurface assemblages of Garo Hills, Meghalaya. *Palaeobotanist* **25** : 475-480.

Traverse A 1988. *Palaeopalynology*. Unwin Hyman, Boston.

Venkatachala BS, Caratini C, Tissot C & Kar RK 1988. Palaeocene-Eocene marker pollen from India and tropical Africa. *Palaeobotanist* **37** : 1-25.

Palaeocene foraminifera from the Ariyalur area, southern India

N. Malarkodi & H.M. Nagaraj

Malarkodi N & Nagaraj HM 1997. Palaeocene foraminifera from the Ariyalur area, southern India. *Palaeobotanist* **46** (1, 2) : 177-185.

The Palaeocene sediments of the Ariyalur area, spread over 80 sq km, are exposed as isolated outcrops and consist mainly of marls, shelly and cream-coloured limestones on the northeastern part of Tiruchirapalli Cretaceous. The present study records well-preserved smaller foraminifera of both benthic and planktic nature. The planktic species suggest a Palaeocene age for the Niniyur Formation. The foraminiferal fauna in general reflects shallow marine to brackish water conditions of deposition. The paper also discusses stratigraphic distribution and zoogeographic affinities of foraminifera of the Niniyur Formation with respect to equivalent horizons in India and abroad.

Key-words— Foraminifera, Palaeocene, Niniyur Formation, India.

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साराँश

दक्षिणी भारत में अरियालूर क्षेत्र से पेलियोसीन फोरामिनीफर

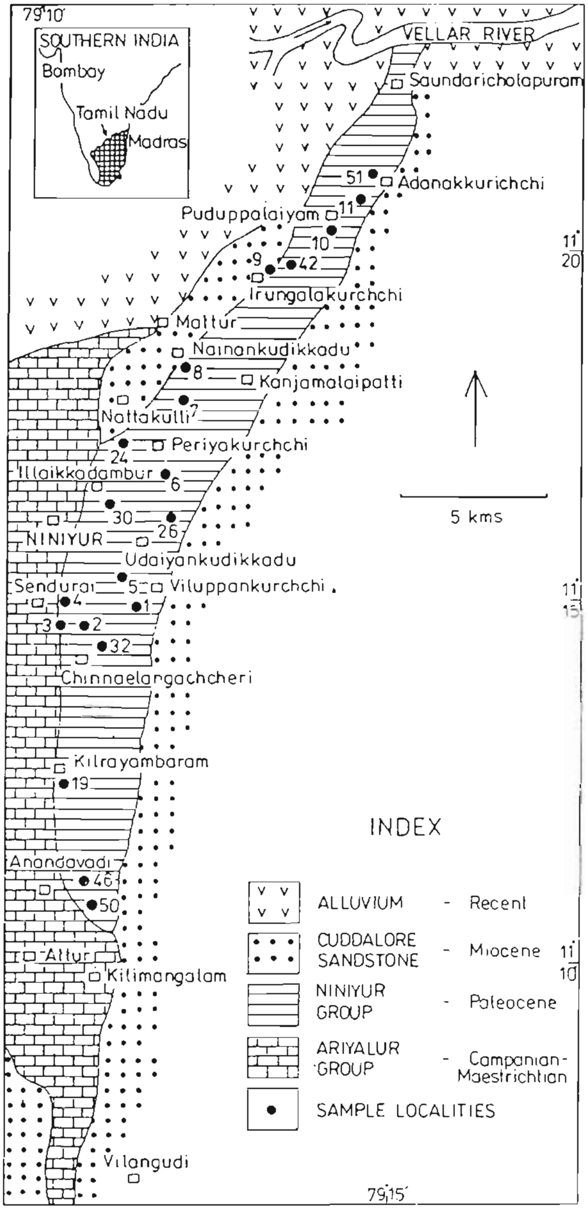
एन. मलारकोडी एवं एच. एम. नागराज

लगभग 80 वर्ग किलोमीटर क्षेत्र में अरियालूर क्षेत्र के पेलियोसीन कालीन अवसाद पृथक दृश्यांसों के रूप में अनावरित हैं तथा त्रिचुरापल्ली के क्रीटेश्यस कालीन उत्तर-पूर्वी भाग में शैली, क्रीम रंग के चूनापत्थरों से युक्त हैं। प्रस्तुत अध्ययन में बेन्थिक एवं प्लवकी प्रकृति के छोटे फोरामिनीफरों का वर्णन किया गया है। प्राप्त फोरामिनीफर निक्षेपण के समय छिछली समुद्री से लवणीय जलवाली परिस्थितियाँ प्रदर्शित करते हैं। इसी शोध-पत्र में निनियूर शैल-समूह के समतुल्य संस्तरों से प्राप्त फोरामिनीफरों के स्तरिकीय वितरण आदि पर भी विवेचना की गई है।

THE Niniyur Formation (Palaeocene) overlying the Ariyalur Group (Campanian-Maastrichtian) is exposed as isolated outcrops along a NNE-SSW trend, between Vellar River in the north and Kavanur in the south, over a strike length of 26 km on the northeastern part of Tiruchirapalli Cretaceous area (Text-figure 1). This covers an area of about 80-90 sq km exposing highly fossiliferous horizons composed of gritty nodular limestones, marls, shelly limestone and cream coloured limestone. The sequence seems to have been deposited in a shallow marine environment during an independent post-Maastrichtian transgression (Nagaraj & Mallikarjuna, 1993; Mallikarjuna & Nagaraj, 1996). The beds are generally flat lying, but occasionally show low dips (5°-10°). The area limits within latitudes 11° 08' to 11° 22' North and longitudes 79° 10' to 79° 17' East. The thickness of the succession is estimated to be of the order of 66 meters (Sundaram & Rao, 1984).

Based on the megascopic remains such as gastropods, lamellibranchs and well-known *Hercoglossa danica,* a lower Palaeocene age has been assigned for the Niniyur Formation. The formation is considered to represent a single palaeontological unit having Tethyan and Indo-Pacific zoogeographic affinity.

Practically no detailed work has been done on the foraminifera of Niniyur Formation. However, some of the earlier reports have dealt with the occurrence of algal remains (Rama Rao & Pia, 1936; Rama Rao & Prasanna Kumar, 1934; Rama Rao & Sambe Gowda, 1953, 1954; Sambe Gowda 1953, 1956; Verma 1954; Rama Rao 1956; Rao, *et al.*, 1963). Sastry *et al.* (1965) reported the occurrence of *Globorotalia (Truncorotalia) mossae* Hofker from the Niniyur Formation. Subsequently, some species of agglutinated foraminifera were recorded by Malur



Text-figure 1—Geological map of the Niniyur area, Tiruchirapalli District, Tamil Nadu.

(1969). Recent studies have reported the occurrence of abundant ostracode fauna from the limestone beds of the Niniyur Formation (Mallikarjuna, 1992; Nagaraj & Mallikarjuna, 1993; Mallikarjuna & Nagaraj, 1996).

Table 1 gives the scheme of stratigraphic succession of the Niniyur area (Mallikarjuna, 1992). The samples from different litho-units, viz., Adanakurchchi limestone, Subcrystalline shelly limestone and Argillaceous gritty nodular limestone, have yielded rich and interesting foraminiferal assemblage. The present record documents the foraminiferal taxa reported for the first time from the Niniyur Formation (Plates 1, 2 & 3). This includes 19 benthic and five planktic species. This occurrence of characteristic foraminiferal species seems to be an evidence in support of the boundary limit between Cretaceous and Tertiary sequence in the area.

Table 1—Lithologic succession of the Niniyur, Ariyalur area

FORMATION	LITHOTYPES	LITHOLOGICAL COMPOSITION	THICKNESS (APPROX.)
CUDDALORE SANDSTONE			
	Argillaceous gritty nodular limestone	Limestone with corals, gastropods and lamellibranchs; variegated marls and clays	
Niniyur Formation	Subcrystalline Shelly Limestone	Subcrystalline shelly limestone	66 m
	Adanakurchchi Limestone	Limestone with milioline tests	
ARIYALUR GROUP			

MATERIAL AND METHOD

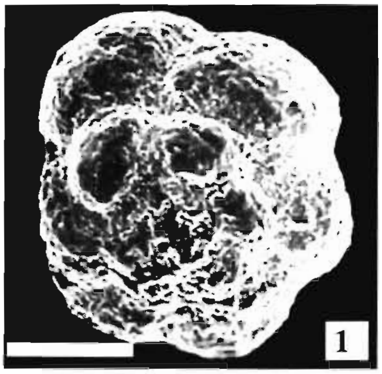
The exposures of Niniyur Formation are very scanty and mainly samples were collected from the unlined dugwells, quarry sections and nala cuttings.

PLATE 1

→

(All figures are of dorsal view; the scale bar on each photograph indicates 100 μm)

1. *Acarinina spiralis* (Bolli)
2. *Acarinina mckannai* (White)
3. *Morozovella praecursoria* (Morozova)
4. *Rosalina elagans* (Hansen)
5. *Planorotalites chapmani* (Parr)
6. *Planorotalites* cf. *pseudomenardii* (Bolli)
7. *Paralabamina lunata* (Brotzen)
8. *Cibicides aknerianus* (d'Orbigny)
9. *Gavelinella danica* (Brotzen)
10. *Asterigerina bartoniana* (Ten Dam)
11. *Protelphidium brotzeni* (Hofker)
12. *Fissoelphidium* sp.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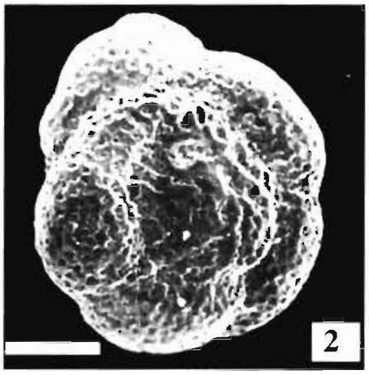
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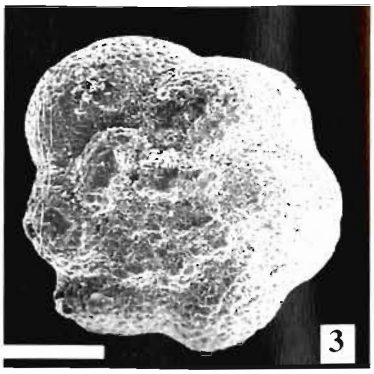
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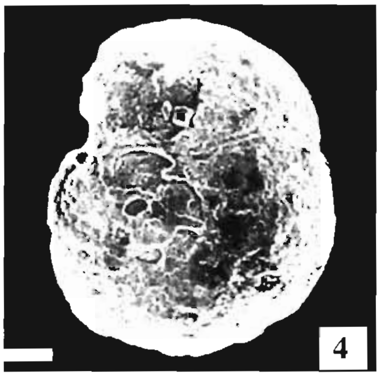
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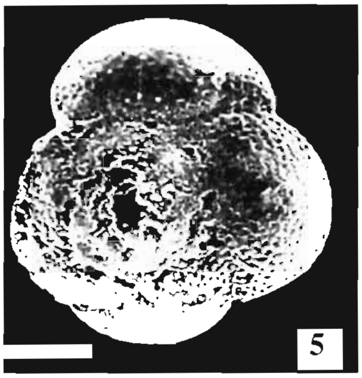
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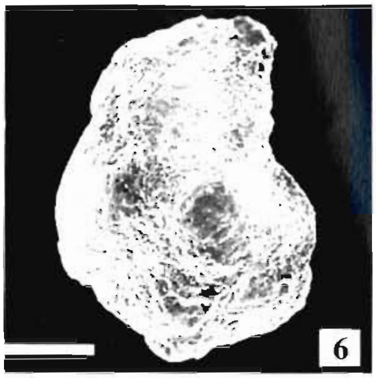
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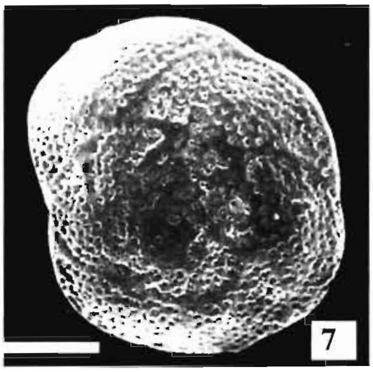
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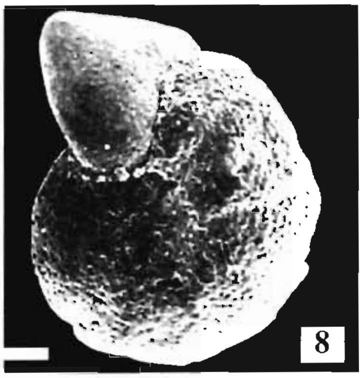
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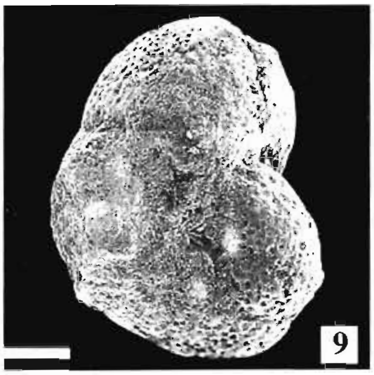
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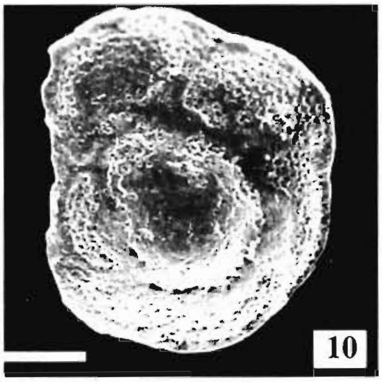
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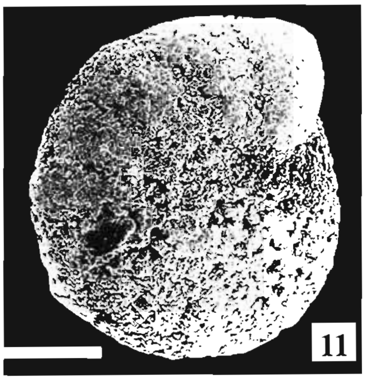
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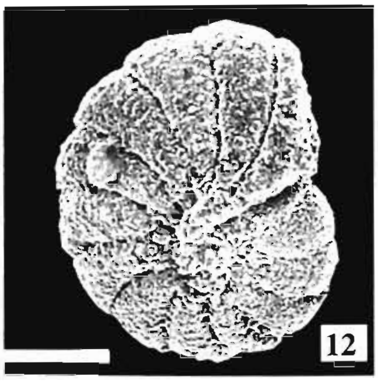
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PLATE 1

Table 2—Distribution of foraminifera in the Niniyur Formation

NINIYUR FORMATION															
Adanakurchchi limestone member		Subcrystalline shelly limestone member								Argillaceous gritty Nodular limestone Member					MEMBER
44	51	2	5	6	10	13	14	24	42	1	4	12	19	46	Sample No. / Species
			+					+							*Acarinina mckannai* (White) (P3-P5)
	+														*Acarinina spiralis* Bolli (P2)
	+														*Asterigerina bartoniana* (Ten Dam)
					+										*Bulumina schwager* (Yokoyama)
	+														*Cibicides aknerianus* (d'Orbigny)
					+			+							*Dentalina angusticostata* Cushman
	0														*Discorbis midwayensis* Soldadoensis
	+														*Paralabamina lunata* (Brotzen)
					+										*Fissoelphidium* sp.
								+							*Gavelinella danica* (Brotzen) (P2-P3)
+					@			+							*Globulina gibba* d'Orbigny
0					@			+							*Guttulina problema* d'Orbigny
	+														*Lagena laevis* (montagu)
	-														*Morozovella praecursoria* (Morozova) (P2-P3)
			+												*Nodosaria* sp.
	+														*Oolina apiculata* Reuss
	+														*Planorotalites chapmani* (Parr) (P3-P6)
			+												*Planorotalites* cf. *pseudomenardii* (Bolli) (P4)
	@	+		+	+							+	+	+	*Protelphidium brotzeni* (Hofker)
				+											*Polymorphina paleocenica* (Brotzen)
	@				0				+		+			@	*Quinqueloculina impressa* Reuss
											+		+		*Rosalina elegans* Hansen
											+				*Textularia conica* d'Orbigny
	@					0			0		@	0	0	@	*Triloculina trigonula* (Lamark)

(Abundance : +=<5; 0=5-10; @=>10)

Each sample weighing 200 gm was subjected to disaggregation for the separation of foraminifera and the method followed is the one detailed in Jones (1956). The forty samples examined have yielded rich foraminifera.

STRATIGRAPHIC DISTRIBUTION OF THE FAUNA

An interesting feature of fossil composition of the Niniyur Formation is the abundant occurrence of fossil algae, rich ostracode fauna and some species of agglutinated foraminifera. Foraminifera constitute moderate part of the microfossil assemblage when compared to Ostracoda and algae. The frequency and distribution of foraminifera are not uniform; they are rich locally, and while absent in other beds. The samples from different litho-units show the presence of characteristic calcareous smaller foraminiferal species (Table 2).

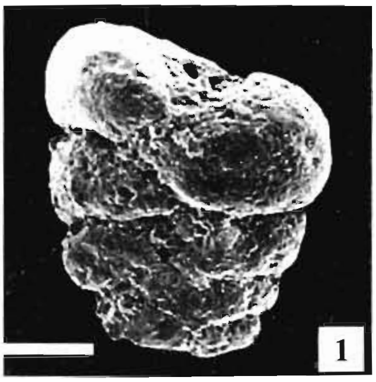
A brief account of lithological and microfossil composition of different lithounits of the Niniyur Formation is given below :

PLATE 2

⟶

(All figures are of side view, fig. 3 is a dorsal view; the scale bar on each photograph indicates 100 μm)

1. *Textularia conica* (d'Orbigny)
2. *Oolina apiculata* Reuss
3. *Discorbis midwayensis* Soldadoensis
4. *Quinqueloculina impressa* Reuss
5. *Dentalina angusticostata* Cushman
6. *Bulumina schwageri* (Yokoyama)
7. *Triloculina trigonula* (Lamark)
8. *Nodosaria.*
9. *Lagena laevis* (Montagu)
10. *Guttulina problema* d'Orbigny
11. *Globulina gibba* d'Orbigny
12. *Pseudopolymorphina paleocenica* (Brotzen)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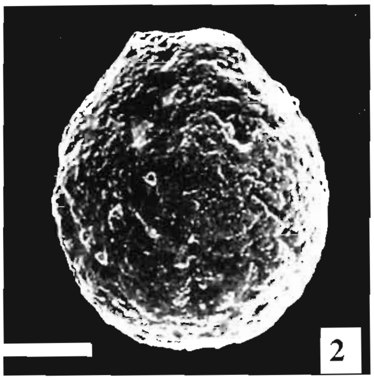
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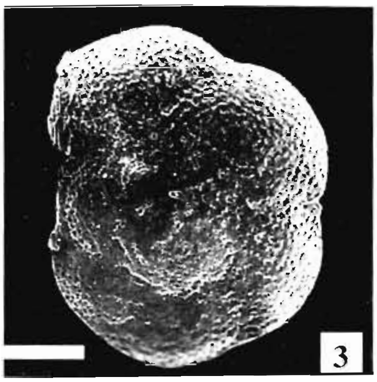
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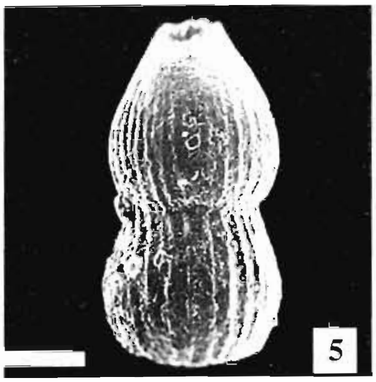
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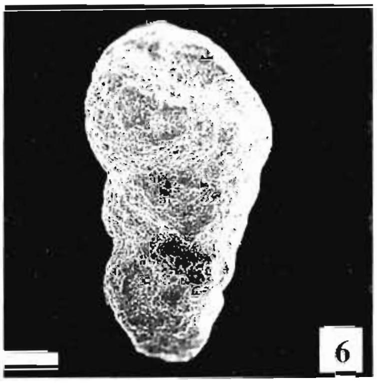
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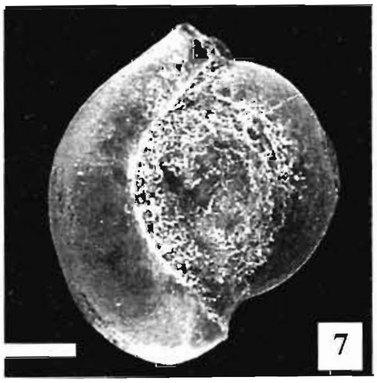
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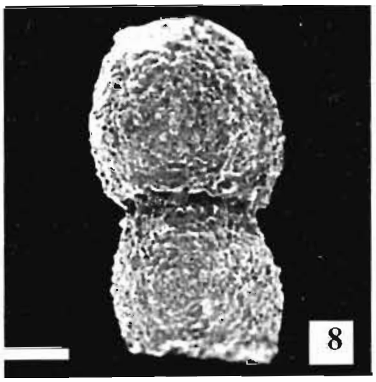
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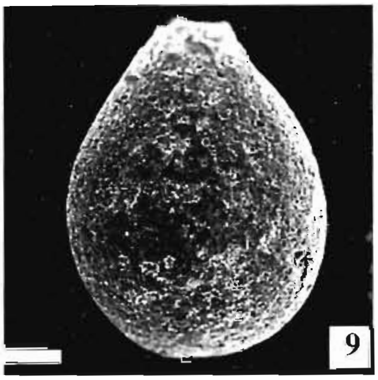
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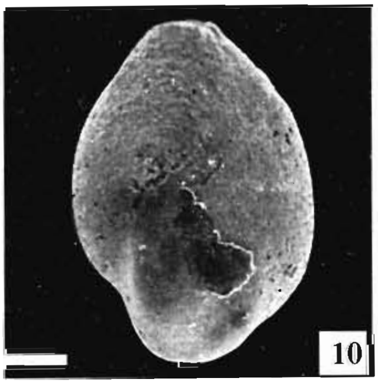
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PLATE 2

1. Adanakurchchi limestone

This is the lower fossiliferous unit and is widely exposed in and around Adanakurchchi, Tattar and Soundaricholapuram. It is mainly composed of argillaceous limestone and shows the presence of numerous milioline tests dominated by the genus *Quinqueloculina*. Fourteen species of foraminifera were recorded. The planktic species restricted to this unit are *Acarinina spiralis* (Bolli), *Morozovella praecursoria* (Morozova), and *Planorotalites chapmani* (Parr). The foraminifera are found associated with a rich ostracod fauna and both the groups indicate a shallow water condition of deposition.

2. Subcrystalline shelly limestone

This unit is exposed in and around Illaikadambur, Nattaguli, Chinna and Periya Elangachcheri. It is characterised by large shells of lamellibranchs and gastropods besides foraminifera. The significant megafossil species are *Lucina percrassa* and *Nautilus danicus*. The foraminiferal species recorded from this unit are *Protelphidium brotzeni* Hofker, *Planorotalites pseudomenardii* (Bolli), *Acarinina mckannai* (White), *Bulumina schwageri* (Yokoyama), *Dentalina angusticostata* Cushman, *Guttulina problema* d'Orbigny, *Globulina gibba* d'Orbigny and *Nodosaria* sp.

3. Argillaceous gritty, nodular limestone

This unit exposed near Sendurai, Niniyur, Illaikadambur and Anandavadi villages contains abundant megafossil remains such as corals, lamellibranchs and gastropods. Of these, *Cardita jaquinoti* (= *Cardita beaumonti*) is the most important. Among the microfossils, ostracodes dominate over foraminifera. Of the six species of foraminifera distributed through different rock-types, three are restricted to this member, viz., *Gavelinella danica* (Brotzen), *Textularia conica* (d'Orbigny) and *Rosalina elegans* Hansen.

The planktic assemblages from different litho-units of the Niniyur Formation are very characteristic and show a strong Lower Tertiary (Palaeocene) affinity.

AGE OF THE NINIYUR FORMATION

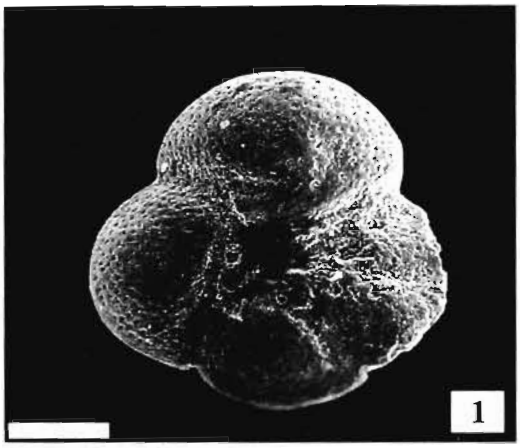
The Niniyur Formation has been traditionally considered Early Palaeocene (Danian) in age on the basis of the occurrence of *Hercoglossa danica*, which is characteristic of the Danian Stage (Blanford, 1862; Rama Rao, 1956). In recent years, emphasis has been shifted to planktic foraminifera. The reported occurrence of *Globorotalia (Trunçorotalia) mossae* Hofker from the Niniyur Formation is suggestive of Early Palaeocene age (Sastry *et al.*, 1965). Subsequent record of rich ostracode species from the Niniyur Formation and their affinity with other forms from different parts of the globe confirms the Palaeocene age (Mallikarjuna, 1992). The present study corroborates the previous age assignment and dates precisely the Niniyur Formation on the basis of the following planktic foraminiferal species, *Morozovella praecursoria* (Morozova), *Acarinina spiralis* Bolli and *A. mckannai* (White). They indicate correlation with the planktic foraminiferal zones and suggest that the Niniyur Formation is Early to Late Palaeocene in age.

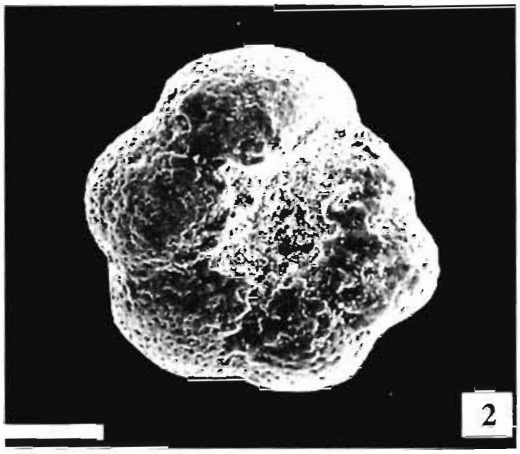
TAXONOMIC AND BIOSTRATIGRAPHIC DATA

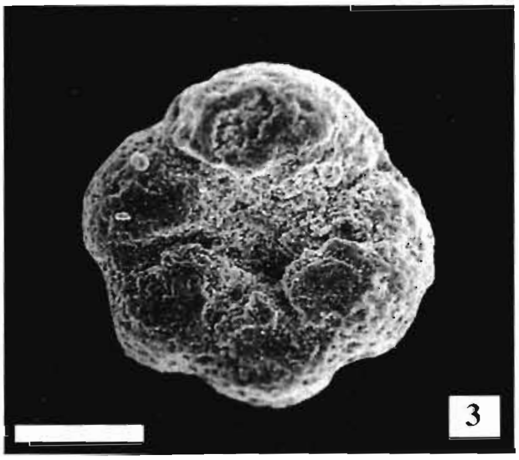
The important Palaeocene species of the present work are *Planorotalites* cf. *pseudomenardii* (Bolli), *P. chapmani* (Parr), *Morozovella praecursoria* (Morozova), *Acarinina spiralis* (Bolli) and *A. mckannai* (White).

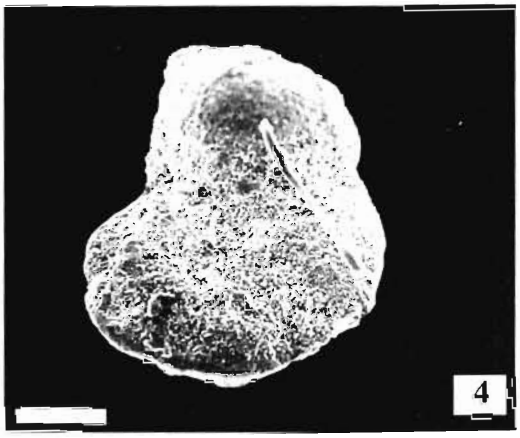
Planorotalites cf. *pseudomenardii* (Bolli) has biconvex and lenticular test with imperforate keel. Since it is poorly preserved, the wall structure is very difficult to identify. This species coincides with the *Planorotalites pseudomenardii* Zone (P4) of Blow (1969) and assigned a Late Palaeocene age. The species is known from the Mathew Landing Marl Member and Salt Mountain Limestone of Alabama, Hornerstown and Vincentown Formations of New Jersey, and Velasco Formations of Mexico (Loeblich & Tappan, 1957).

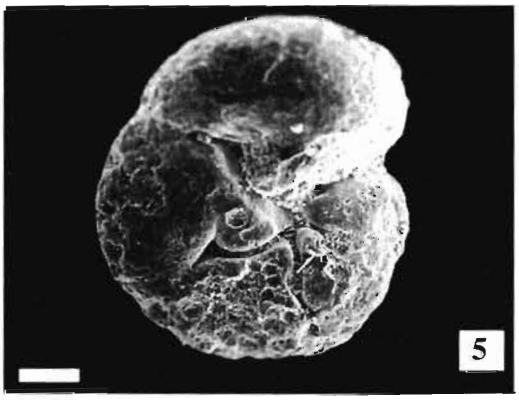
Morozovella praecursoria (Morozova) has high trochospiral test with subangular chambers increasing rapidly in size. Two and a half whorls are visible on the umbilical side. Sutures are distinct and depressed. Wall is calcareous and perforated. The species differs from *M. uncinata* by large number of chambers in the last whorl and from *A. spiralis* by having globular chambers. The species has been reported from the Early Palaeocene of N. Caucasus, Russia (Subbotina, 1953) and Montian of Tunisia (Salaj, 1980). *M. praecursoria* (Morozova) coincides with











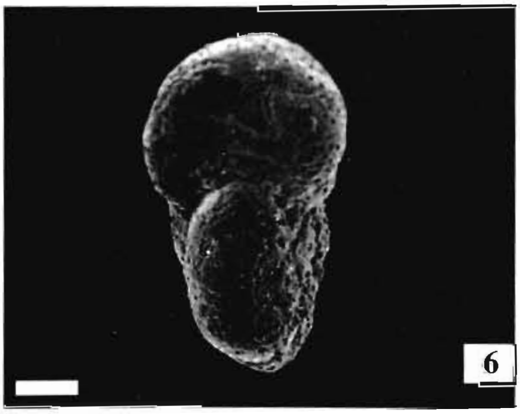


PLATE 3

(All figures are of ventral view, fig. 6 is a side view; the scale bar on each photograph indicates 100 μm)

1. *Planorotalites chapmani* (Parr)
2. *Morozovella praecursoria* (Morozova)
3. *Acarinina spiralis* (Bolli)
4. *Planorotalites* cf. *pseudomenardii* (Bolli)
5. *Rosalina elagans* (Hansen)
6. *Gavelinella danica* (Brotzen)

M. uncinata Zones (P2-P3) of Blow (1969), and Berggren and Van Couvering (1974), and assigned Lower Palaeocene to Middle Palaeocene age.

Acarinina mckannai (White) has five chambers in the final whorl. These chambers are considerably larger than those of the initial whorls and encroach on narrow and deep umbilicus. The outline of the test is almost subglobular with deep umbilicus. It is known from the Palaeocene of the Lizard Spring Formation, Trinidad (Bolli, 1957a), N. Caucasus, Russia (Subbotina, 1953) and Velasco Formation, Mexico (Shutskaya, 1958).

Acarinina spiralis (Bolli) shows high trochospirally coiled test resulting in a nearly globular shape; chamber globular and increasing rapidly in size; two or three whorls are visible on the spiral side and six chambers in the final whorl, sutures distinct and depressed; wall calcareous perforate and a broad umbilical aperture and interiomarginal arch in the final chamber. The species has been assigned a Lower Palaeocene (Upper Danian) age. It is reported from the Vincentown and Hornerstown Formations of New Jersey and Salt Mountain Limestone of Alabama (Loeblich & Tappan, 1957).

The planktic assemblage of the Niniyur Formation also contains a few long ranging species such as *Planorotalites chapmani* (Parr). The species ranges from Middle Palaeocene to Lower Eocene (P3-P6) and is characterised by the imperforate marginal band which gives the appearance of a keel. The forms have an equally biconvex arrowhead shape in profile, which has been recorded from the Palaeocene of King's Park Shale, Western Australia (McGowran, 1964), and Upper Eocene of southern Australia (Crespin, 1954).

Gavelinella danica (Brotzen) ranges from Lower Palaeocene to Upper Palaeocene (P2-P3) and has trochospiral test having slightly larger pores; spiral side evolute, umbilical side involute with deep and open umbilicus; periphery angular. In general, the periphery of the last chamber is more rounded than that of the earlier part. Aperture is interiomarginal. The species is more common in Palaeocene benthonic foraminiferal middle shelf depths (100 m) and rare in the midway of the Gulf Coast and its equivalents on the Atlantic Coastal Plain, as well as in Libya, where as it is rather common in the somewhat deeper-water sediments of Tunisia and the Aquitaine Basin.

These species of foraminifera are also known from the Palaeocene rocks of Sweden, Poland, Holand, Egypt, Texas, Alabama, Maryland, New Jersey, Mexico, Denmark and Australia. This distribution suggests their cosmopolitan character and also indicates wide geographic distribution of similar palaeoclimatic conditions facilitating extensive migration over long distances (Loeblich & Tappan, 1957; Berggren, 1974; Kureshey, 1984).

CONCLUSIONS

The post-Cretaceous transgression during Early Tertiary resulted in the deposition of the Niniyur Formation which is not only lithologically different from the underlying Kallamedu Formation (Upper Maastrichtian) but is also palaeontologically distinguishable. The Cretaceous-Tertiary boundary occurs over the continental sandstone beds of the Kallamedu Formation and below the marine limestones of the Niniyur Formation. This is marked by the complete disappearance of Upper Cretaceous (Maastrichtian) planktic foraminifera such as *Globotruncana* and some of the associated mega-invertebrate fauna, and the emergence of Lower Tertiary (Palaeocene) planktic species in the Niniyur Formation. The Lower Tertiary rocks of the Ariyalur area contain a relatively highly diversified and rich assemblage of foraminifera which indicate deposition of the Niniyur Formation in a shallow marine to brackish water environment with restricted influence of open marine conditions. The associated benthic species are geographically widely distributed and a few of them are common between Tethyan and Indo-Pacific biogeographic provinces. They are cosmopolitan in character and indicate prevalence of broadly similar palaeoclimatic conditions over distant areas.

The recorded planktic foraminifera corroborate the assigned Palaeocene age for the Niniyur Formation.

CHECK LIST OF FORAMINIFERA FROM THE NINIYUR FORMATION

Textularia conica (d'Orbigny)
Quinqueloculina impressa Reuss
Triloculina trigonula (Lamark)
Dentalina angusticostata Cushman
Nodosaria sp.
Lagena laevis (Montagu)
Globulina gibba d'Orbigny

Guttulina problema d'Orbigny
Pseudopolymorphina paleocenica (Brotzen)
Oolina apiculata Reuss
Planorotalites cf. *pseudomenardii* (Bolli)
Planorotalites chapmani (Parr)
Acarinina spiralis (Bolli)
Acarinina mckannai (White)
Morozovella praecursoria (Morozova)
Bulumina schwageri (Yokoyama)
Paralabamina lunata (Brotzen)
Cibicides aknerianus (d'Orbigny)
Gavelinella danica (Brotzen)
Protelphidium brotzeni (Hofker)
Discorbis midwayensis Soldadoensis
Rosalina elegans (Hansen)
Asterigerina bartoniana (Ten Dam)
Fissoelphidium sp. A

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REFERENCES

Berggren WA 1974. Palaeocene benthic foraminiferal biostratigraphy, paleobiogeography and paleoecology of Libya and Mali. *Micropaleontology* **20** (4): 449-465.

Berggren WA & Aubert J 1975. Palaeocene benthonic foraminiferal biostratigraphy, palaeobiogeography and palaeoecology of Atlantic Tethyan regions: Midway-type fauna. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **18**: 73-192.

Berggren WA & Van Couvering JA 1974. The late Neogene biostratigraphy, geochronology and palaeoclimatology of the last 15 million years in marine and continental sequences. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **16** (1-2) : 1-216.

Blanford HF 1862. On the Cretaceous and other rocks of South Arcot and Trichinopoly districts, Madras. *Mem. geol. Surv. India* **4**: 1-217.

Blow WH 1969. Late Middle Eocene to Recent planktonic foraminiferal biostratigraphy. *Proc I Int. Conf. Planktonic microfossils, Geneva, 1967.* **1**; 199-422.

Boersma A & Premoli Silva I 1983. Palaeocene planktonic foraminiferal biogeography and paleo-oceanography of the Atlantic Ocean. *Micropaleontology* **29** (4): 355-381.

Bolli HM 1957a. The genera *Globigerina* and *Globorotalia* in the Palaeocene-Lower Eocene Lizard Spring Formation of Trinidad. *B.W.I. U.S. Natl. Mus. Bull.* **215**: 61-82.

Bolli HM 1957. The genera *Praeglobotruncana, Rotalipora, Globotruncana* and *Abathomphalus* in the Upper Cretaceous of Trinidada. *B.W.I. Bull. U.S. Natn. Mus.* **215**: 51-60.

Bolli, HM 1957b. Planktonic foraminifera from the Eocene Navet and San Fernando formations of Trinidad. *B.W.I. Bull U.S. Natn. Mus.* **215**: 155-172

Crespin I 1954. Stratigraphy and micropaleontology of the marine Tertiary rocks between Adelaide and Aldinga, South Australia. *Rep. Bur. Miner. Resour. Australia* **12**: 1-65.

Jones JD 1956. *Introduction to microfossils, Harper's Geoscience Series.* Carey Croneis, Ed., : 7-18. New York.

Kureshy Ashfag A 1984. Palaeocene foraminifera of Pab, Pakistan, *II. Int. Symp. benth. foraminifera, El Aquitaine:* 349-351.

Leoblich A & Tappan H 1957. Studies in Foraminifera. *U.S. Natn. Mus. Bull.* **215** (9) : 173-198.

Mallikarjuna UB 1992. The study of ostracodes from the sedimentary sequences of Ariyalur and Niniyur groups of Tiruchirapalli District, Tamil Nadu, India. *Unpublished. Ph.D. Thesis.* Bangalore University, India.

Mallikarjuna UB & Nagaraj HM 1996. Ostracodes from the Ariyallur Group (Late Cretaceous), Cauvery Basin, southern India. *J. geol. Soc. India* **48**: 189-201.

Malur MN 1969. Agglutinated foraminifera from the unfossiliferous sandstone near Niniyur, Tiruchirapalli area, south India. *Curr. Sci.* **19**: 464.

McGowran B 1964. Foraminiferal evidence for the Palaeocene age of the Kings's Park Shale (Perth Basin, Western Australia). *Proc. R. Soc. W. Australia* **47** (3) : 81-86.

Nagaraj HM & Mallikarjuna UB 1993. Ostracodes from the Niniyur Group (Lower Tertiary) of Tiruchirapalli District, south India. *In:* Mckenzie, KG & Jones PJ (Editors)—*Ostracodes in life and Earth Science. Proc. 11th Int. Symp. ostracoda, Australia:* 207-212. A A Balkema.

Rama Rao L 1956. Recent contributions to our knowledge of the Cretaceous rocks of south India. *Proc. Indian Acad. Sci.* **B44**: 185-245.

Rama Rao L & Prasanna Kumar C 1934. On the flint and cherts from the upper most Cretaceous beds (Niniyur Stage) of the Trichinopoly District, south India. *Proc. Indian Acad. Sci.* **1** (10): 10-18.

Rama Rao L & Gowda SS 1953. Occurrence of *Clypeina* (Dasycladaceae) of the south Indian Cretaceous. *Curr. Sci.* **22**: 332-333.

Rama Rao L & Gowda SS 1954. Solonoporaceae from the Cretaceous rocks of south India. *Curr. Sci.* **23**: 177-179.

Rama Rao L & Pia J 1936. Fossil algae from the uppermost Cretaceous beds (Niniyur Group) of the Trichinopoly District, south India. *Mem. geol. Surv. India, Palaeont indica,* N.ser., **21** (4) : 1-49.

Rao BRJ, Mamgain VD & Sastry MVA 1963. A note on the Niniyur Stage of Cretaceous formations of Trichinopoly District, Madras. *Indian ninerals* **17** (2): 190-192.

Salaj J 1980. Microbiostratigraphie du cretace et du Palaeogene de la Tunisie septentrionale et orintale. *Institut Geologique dionyz stur, Bratislava:* 9-241.

Sambe Gowda SS 1953. Occurrence of *Holosporella* in the Niniyur Group (Danian) of the Trichinopoly Cretaceous, south India. *Curr. Sci.* **22**(6) : 169- 170.

Sambe Gowda SS 1956. *Piania niniyurensis*, a new dasycladaceous alga from the Niniyur Group (Danian) of the Trichinopoly Cretaceous, south India. *J. geol. Soc. India* **1**: 152-155.

Sastry MVA, Rao BRJ & Mamgain VD 1965. Note on the occurrence of Globorotalia in Niniyur Stage, south India. *Curr. Sci.* **34** (4): 199-120.

Shutskaya EK 1958. Foraminifery Verknikh sloev "Datsko-Montskikh" izvestnyakov yugo-zapadnogo kryma. *VNIGRI Trudy* **9**: 197-210.

Subbotina NN 1953. Fossil foraminifers of the USSR: *Globigerinidae, Hantkeninidae* and *Globorotaliidae. Trudy VNIGRI,* new series **79**: 296 (in Russian). Translated into English by E. Lees. Fossil foraminifera of the USSR, *Globigerinidae, Hantkeninidae and Globorotaliidae, Collect's Ltd., London* and *Wellingborough,* 321.

Sundaram R & Rao PD 1984. Lithostratigraphy of Cretaceous and Palaeocene rocks of Tiruchirapalli District, Tamil Nadu, south India. *Rec. geol. Surv. India* **115** (5): 9-19.

Verma CP 1954. On the algal genera *Neomeris* and *Acicularia* from the Niniyur (Danian) beds of the Trichinopoly area. (S. India). *Proc. natn. Inst. Sci. India* **20** (3).

Is it possible to demarcate floristically Pleistocene/ Holocene transition in India?

A. Bhattacharyya & Vandana Chaudhary

Bhattacharyya A & Chaudhary V 1997. Is it possible to demarcate floristically Pleistocene/Holocene transition in India? *Palaeobotanist* **46** (1, 2) : 186-190.

The data on the floristic change during transitional phase of Pleistocene and Holocene are scanty. Although shifting of glacial to nonglacial climate is considered elsewhere for the demarcation of Pleistocene/Holocene, it could not be observed in India except at the glaciated sites in higher Himalayas. A major change can be traced in the nonglacial region due to strengthening of monsoon associated with higher insolation largely around this transition. Replacement of steppe by savanna in Rajasthan, increase in mangrove taxa in Arabian Sea sediments, decline of grassland with Shola constituents in Nilgiris, all happened under climatic change from arid to warm moist around 11,000-9,000 B.P. In the Himalayan region, at the higher elevations replacement of alpine taxa by subalpine birch has been noted in Kashmir and Himachal Pradesh during this transition, which is similar to Europe and North America where arctic elements are replaced by subarctic elements. However in Ladakh, the trans-Himalayan region, this transition is characterised by dominance of steppe taxa represented by Chenopodiaceae and *Artemisia* indicating aridity .

Key-words—Floristic changes, Palynology, Pleistocene/Holocene Boundary, India.

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सारौंश

क्या वनस्पतिजात के आधार पर भारत में प्लिस्टोसीन/होलोसीन परिवर्तन सुनिश्चित करना संभव है?

आमलव भट्टाचार्य एवं वन्दना चौधरी

प्लिस्टोसीन एवं होलोसीन कालीन परिवर्तन सम्बन्धी वनस्पतिजातीय आँकड़े बहुत कम हैं। यद्यपि प्लिस्टोसीन/होलोसीन सीमा सुनिश्चित करने लिए हिमानी से अहिमानी जलवायु को काफी महत्व दिया गया है, भारत में हिमालय के ऊंचाई पर स्थित स्थानों के अलावा अभी तक प्रेक्षित नहीं किये जा सके हैं। इस परिवर्तन के आस-पास अहिमानी क्षेत्र में एक मुख्य परिवर्तन सुनिश्चित करने का प्रयास किया जा सकता है। राजस्थान में स्टेप वनस्पति के स्थान पर सवाना, अरब सागर के अवसादों में मैंग्रोव वर्गकों की वृद्धि, नीलगिरि क्षेत्र में घासभूमि के स्थान पर शोला अवयव आदि सभी परिवर्तन लगभग 11000-9000 वर्ष पूर्व के आस-पास हुए जलवायवी परिवर्तन के समय हुए हैं। हिमालयी क्षेत्र में अधिक ऊँचाई पर काश्मीर एवं हिमाचल प्रदेश में इसी परिवर्तन के समय अल्पीय वर्गकों के स्थान पर उप-अल्पीय बर्च वर्गकों का समावेश हुआ जो कि यूरोप और उत्तरी अमेरिका के समान है। तथापि, लद्दाख में हिमालय के पार वाला क्षेत्र स्टेप वर्गकों की बाहुल्यता व्यक्त करता है जिससे शुष्क परिस्थितियों का होना इंगित होता है।

IN reconstruction of floristic changes during the Quaternary, palynological data provide significant information. Macrofossils (fruits, seeds, leaves, cones and other plant fragments) can also be used to reconstruct floristic changes but such data are not available for the Late Quaternary. On the other hand, substantial palynological data have been generated which show floristic changes in time and space. The available data to demarcate any drastic floristic changes that may have occurred during the Pleistocene/Holocene (P/H) transition in India have been reviewed.

GANGA PLAIN

There are many reports on geomorphological evidences demarcating Pleistocene and Holocene sequences (Singh & Mawar, 1992; Kumar *et al.*, 1996). Generally P/H transition could be recognised by changes from low sinuosity Late Pleistocene aggradational bed load stream to Holocene high sinuosity suspended load. This change has also been recorded in stratigraphic column by the fairly abrupt changes from coarse to fine sediments (William & Royce, 1982). Activation and formation of river channels and lakes were more active during 12,000 to 8,000 BP due to low sea level and increased water budget resulted from melting of glacier as well as high rainfall (Singh,1996). Available pollen data are not sufficient to depict floristic scenario during this transition. Except few, most of the pollen data are derived from shallow cores or the sections having high sedimentation rate and thus having much younger dates, restricted within 7,000 BP (Gupta,1981; Sen & Banerjee, 1990; Barui & Chanda, 1992). Palynological studies from a longer record indicate mangrove swamp conditions during last glaciation phase in lower Bengal Basin, but no data are available regarding floristic change around P/H transition (Chanda & Hait, 1996). A 2 m core was analysed from Bastua, Madhya Pradesh, which shows clear demarcation of sandy clay and organic mud at 1.7 metre (Chauhan, 1995). This zone may be dated around 10,000 BP since sediments at both upper and lower depths have been dated 8,710 BP and 11,550 BP respectively. During this period the area seems to be occupied by grassland under cool arid climate (Chauhan, 1995). However, drastic change in sediments from clay to organic mud may suggest depositional environment might be warm moist.

RAJASTHAN

Palynological studies from the lakes of Rajasthan (Singh *et al.*, 1990) reveal that steppe, characterised by Chenopodiaceae/Amaranthaceae, grasses, *Artemisia*, *Aerva* and *Ephedra*, flourished during 20,000 to 13,000 BP. It indicates hyperarid climate when lake level was much lower due to weaker southwest monsoon; winter monsoon is believed to have been stronger than today. From 13,000 BP onwards, with intermittent increase in precipitation due to stronger summer and winter precipitation, steppe was replaced by shrub savanna grassland and, lake fluctuated from saline to fresh water. From 9,000 to 6,000 BP this savanna, in which *Prosopis* was a prominent tree element, flourished with the continuing amelioration of climate and higher lake level (Singh *et al.*, 1990). This increased lake level, evidenced by the rise of sedges, *Typha* and corresponding decrease of halophytic taxa, is also supported by the stratigraphic and geochemical evidences (Wasson *et al.*, 1984). However, Meher-Homji (1996) does not agree and opines that true indicators of wet phases are not seen in pollen diagrams; if these were there it should also reflect analogous deciduous forest of the Aravallis.

SOUTH INDIA

Review of the palynological record starting from about 40,000 BP to recent from Nilgiri Hills (Gupta, 1990) and from 20,000 to recent from Palni Hills (Bera *et al.*, 1996) indicates that around 15,000 to 7,000 BP the climate was most favourable when close evergreen Shola forest dominated in this region. The Shola declined subsequently mainly due to human activities. Thus here P/H transition, marked by the close evergreen forest, comes under the bracket year of climatic optimum noted around 15,000 to 7,000 BP. The development of peak forest here does not coincide with the period of increased northeast monsoon during LGM (Sarkar *et al.*, 1990). This might be due to continued low temperature. However, its coincidence with the two phases of increased SW monsoon intensity during 13,000-12,000 BP and 10,000 to 9,000 BP (Overpeck *et al.*, 1996) might be due to associated higher insolation which reached maximum around 9,000 BP (Kutzbach, 1981). Analysis of $\delta^{13}C$ values covering time span of last 20,000 BP from peats in Nilgiri Hills (Sukumar *et al.*, 1993) also provides additional support regarding existence of trees around this P/H transition. Generally $\delta^{13}C$ values range from -24 per mil to - 34 per mil in C3 plants in which mostly are trees and shrubs, and -6 per mil to - 19 per mil in C4 plants which are mostly xerophytes. Thus any change in climate would reflect the values of $\delta^{13}C$ in peat (Friedman, 1983). In the Nilgiri Hills during 20,000 - 16,000 BP there were mostly C4 plants indicating arid phase. From about 16,000 BP more negative signatures of $\delta^{13}C$ indicating dominance of C3 vegetation have been noted and it reached optimum at around 10,600 BP (Sukumar *et al.*, 1993). However, in a latter observation this peak has been noted at around 9,000 BP (Rajagopalan *et al.*, 1997) which coincides with the peak of enhanced monsoon at 10,000-9,500 BP (Overpeck *et al.*, 1996).

HIMALAYAN REGION

Except for a few, most of the palynological studies in this region have been made either from Late Holocene (Sharma & Chauhan, 1988; Chauhan & Sharma, 1996 a,b; Mazari *et al.*, 1996; Bhattacharyya & Chauhan, 1997) or covering only Pleistocene (Agrawal *et al.*, 1989) .

Lower Himalaya

Most of pollen diagrams are made from cores (4,000 BP to recent) from the western Himalaya from lake margin. Even from the available longer palaeoclimatic records from 52 m deep lacustrine sediment section from Naukuchia Tal, floristic scenario after 21,500 BP could not be reconstructed since corresponding sediments are found barren of pollen contents (Kotlia *et al.*, 1997). Thus, floristic signature during P/H transition remains unrepresented from the western Himalayas.

In the eastern Himalaya the P/H transition has been characterised by the formation of oak forest under amelioration of climate replacing arid phase characterised by Oak Savanna around 10,000 BP (see Chauhan & Sharma, 1996b).

Higher Himalaya

There are several reports from this region which indicate drastic changes in lithology from fine clay to peaty or organic rich clay around 9,000 BP (Derbyshire & Owen, 1996; Sharma & Owen, 1996) which might be due to changes from glacial to nonglacial climate. The transition of fine grey clay to organic rich dark brown clay at Marhi (Bhattacharyya, 1988) seems to be contemporaneous development since it has a date of 8,000 BP, a few cm above this transition. Generally, peat or organic deposit has begun to form only after the last glacial period around 10,000 yr BP. Palynological data recorded from several sub- alpine sites, like Lake Rara National Park, west Nepal (Tabata *et al.*, 1988; Yasuda, 1988), and Kashmir Valley (Dodia *et al.*, 1985) also suggest that there were marked changes during P/H transition which are indicated, in general, by increase in broad leaved taxa at the expense of conifer taxa. Even in the simplified vegetational sequences made (Vishnu-Mittre, 1979) from the published pollen diagram of Toshmaidan, above tree limit, in Kashmir (Singh & Agrawal, 1976) show drastic decrease in conifer taxa especially around 11,360 to 10,000 BP. In the sub-alpine region, the replacement of alpine taxa by sub alpine birch noted in pollen diagram made from Marhi, Himachal Pradesh (Bhattacharyya, 1989) seems to be analogous to Europe and North America where arctic elements are replaced by sub-arctic elements during this P/H transition.

TRANS HIMALAYAN REGION

P/H transition is characterised by arid climate, as at present, in this region and is indicated by the dominance of Chenopodiaceae, *Artemisia*, *Ephedra* and other steppe taxa in the pollen diagram from Tsokar Lake, Ladakh (Bhattacharyya, 1989). Stable isotope studies for carbon and oxygen from calcium carbonate from lacustrine sediments from the same site also confirm it. Adjacent Tibetan Plateau was also arid during P/H boundary as evidenced by drastic increase of $\delta^{18}O$ ratios around 10,000 yr BP (Thompson *et al.*, 1989).

MARINE SEDIMENTS

Palynological studies from marine sediments from Arabian Sea have shown an increase in taxa which indicate enhanced monsoon during 13,000-12,500 BP and 10,000-9,500 BP. Enhanced monsoon during these periods is also corroborated by other proxy data (Overpeck *et al.*, 1996). The pattern of changes of monsoon as derived from pollen data in Rajasthan seems to be synchronous with these marine records. Moreover, these observations have been found to have close relationship with terrestrial records from Africa and other region of Asia (Anderson & Prell, 1993).

DISCUSSION AND CONCLUSION

During the INQUA subcommission meeting 1961, major opinion favoured on fixing the P/ H boundary in between the Younger Dryas and Preboreal, i.e., around 10,000 B.P. (Fairbridge, 1983). However, criteria considered elsewhere may not be applicable in India because of its diversified flora in response to varied climate ranging from tropical to alpine. At the lower elevation the impact of climate may not reach to threshold point for changing vegetation since only the Himalayan region were ice covered during the Quaternary. Due to interlinked climatic phenomena (Kutzbach *et al.*, 1993; Ruddiman & Kutzbach, 1989; Broccoli & Manabe, 1992), especially teleconnection in between monsoon and to extant of snow cover (Prell & Kutzbach, 1992; Kutzbach *et al.*, 1993), there is a great variability in monsoon. Thus, changes in floristics mainly due to limiting effect of precipitation from one site to other could also be visualised .

Floristic signatures around P/H transition in India may be unique in terms of influence and feed back action of climate, especially changes in temperature, monsoon and western disturbances, along with other physiographic and biotic factors during shifting of glacial to nonglacial environment. With the available pollen data, major changes across this transition can only be assumed in the Himalayan region where influences of glacial to nonglacial climate are obvious. In this region, migration of taxa of lower elevation to higher elevation could be expected with the change of climate. However, the interpretation of pollen diagrams from the montane region needs more attention because the presence of a large amount of pollen taxa from the lower elevation vitiates the pollen spectrum at high altitude. In such cases not only modern pollen/ vegetation relationship which help to understand present day behaviour of flora in sediments, but quantification of pollen in sediment also needs to be determined through calculating pollen influx and absolute pollen frequency. No studies have been made from this point of view. In the lower Himalaya and other regions floristic changes noticed might be due to variable intensity of monsoon in relation to impact of changing of Himalayan snow cover. However, it has been observed that during last glaciation the development of forest under ameliorating climate has started much earlier around 16,000 BP and reached optimum around 11,000-9,000 BP in Rajasthan and in tropical montane. But in the Himalayan region it might have started much later and development of interglacial vegetation probably had started around 11,000 to 9,000 BP. It is apparent that the impact of deglaciation was earlier at the lower altitude sites than at higher elevation. In some analyses, although there were some indications of vegetational changes during this transition, proper emphasis was not placed on sampling for both palynological and C-14 datings. In such cases wide sampling and paucity of C-14 dates hampered the reconstruction of fine resolution pollen diagrams. For a detailed floristic scenario, macrofossil analysis side by side to pollen analysis should also be considered, but data in this regard is almost lacking. The basis for classifying Quaternary strata is primarily biological, however, radio isotope datings provided the time-frame to unravel the exact response of the floristic changes to climatic changes.

REFERENCES

Agarwal DP, Dodia R, Kotlia BS, Razdan H & Sahni A 1989. The Plio-Pleistocene geologic and climatic record of the Kashmir Valley, India : a review and new data. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **73** : 267-286.

Anderson DM & Prell WL 1993. A 300 Kyr record of upwelling off Oman during the late Quaternary : evidence of the Asian southwest monsoon. *Palaeoceanography* **8** : 193-208.

Barui NC & Chanda S 1992. Late Quaternary pollen analysis in relation to palaeoecology, biostratigraphy and dating of Calcutta peat. *Proc. Indian natn. Sci. Acad.* **B58**(4) : 191-200.

Bera SK, Gupta HP & Farooqui A 1996. Berijam lake: 20,000 years sequence of palaeofloristics and palaeoenvironment in Palni Hills, south India. *Geophytology* **26**(1) : 99-104.

Bhattacharyya A 1988. Vegetation and climate during post glacial period in the vicinity of Rohtang Pass, Great Himalayan Range. *Pollen Spores* **30** : 417-427.

Bhattacharyya A 1989. Vegetation and climate during the last 30,000 years in Ladakh. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **73** : 25-38.

Bhattacharyya A & Chauhan MS 1997. Vegetational and climatic changes during recent past around Tipra bank glacier, Garhwal Himalaya. *Curr. Sci.* **72**(6) : 408-412.

Broccoli AJ & Manabe S 1992. The effects of orography on middle latitude northern hemisphere dry climates. *J. Climate* **5** : 1181-1201.

Chauhan MS 1995. Origin and history of tropical deciduous Sal (*Shorea robusta* Gaertn) forests in Madhya Pradesh, India. *Palaeobotanist* **43**(1) : 89-101.

Chauhan MS & Sharma C 1996a. Pollen analysis of mid Holocene sediments from Kumaon Himalaya. *Geol. Surv. India Spec. Publ.* **21**(1) : 257-269.

Chauhan MS & Sharma C 1996b. Late Holocene vegetation of Darjeeling (Jore-Pokhari), eastern Himalaya. *Palaeobotanist* **45** : 125-129.

Chanda S & Hait AK 1996. Aspects and appraisal of Late Quaternary vegetation of lower Bengal Basin. *Palaeobotanist* **45** : 117-124.

Derbyshire E & Owen LA 1996. Quaternary glacial history of the Karakoram Mountains and northwest Himalayas: a review. *J. Quat. Int.* **199** : 1-17.

Dodia R, Agarwal DP & Vora AB 1985. New pollen data from the Kashmir bogs : a summary. *In* : Agarwal DP *et al.*, (Editors)—*Climate and geology of Kashmir and central Asia* : 101-108. T.T. Printers & Publishers, New Delhi.

Fairbridge RW 1983. The Pleistocene-Holocene boundary. *Quaternary Sci. Rev.* **1** : 215-244.

Friedman I 1983. Palaeoclimate evidence from stable isotopes. *In* : Porter SC (Editor)—*Late Quaternary environments of the United States* **1** : 385-389. Univ. Minnesota Press, Minneapolis.

Gupta HP 1981. Palaeoenvironment during Holocene time in Bengal Basin, India, as reflected by palynostratigraphy. *Palaeobotanist* **27**(2) : 138-160.

Gupta HP 1990. Sholas in south Indian montane : past, present and future. *Palaeobotanist* **38** : 394-403.

Kotlia BS, Bhalla MS, Sharma C, Rajagopalan G, Ramesh R, Chauhan MS, Mathur PD, Bhandari S & Chacko ST 1997. Palaeoclimatic conditions in the Upper Pleistocene and Holocene Bhimtal-Naukuchia Tal lake basin in south-central Kumaun, North India. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **130** : 307-322.

Kumar G, Khanna PC & Prasad S 1996. Quaternary stratigraphy of the Indo-Gangetic Plain and sub Himalaya, Uttar Pradesh. *In* : Pandey J. *et al.* (Editors)—*Contrs. XV Indian Colloq. Micropaleont. Stratigr., Debradun* : 811-826.

Kutzbach JE 1981. Monsoon climate of the Early Holocene, climate experiment with the earths orbital parameter for 9000 years ago. *Science* **214** : 59-61.

Kutzbach JE, Prell WL & Ruddiman WF 1993. Sensitivity of Eurasian climate to surface uplift of the Tibetan plateau. *J. Geol.* **101** : 177-190.

Mazari RK, Bagati TN, Chauhan MS & Rajagopalan G 1996. Palaeoclimatic record of last 2000 years in Trans-Himalayan Lahaul- Spiti Region. *In* : Mikami T *et al.*, (Editors)—*Palaeoclimate and environmental variability in Austral-Asian transect during the past 2000 years*. Proc. 1995 Nagoya IGBP- PAGES/ PEP II Symp. : 262-269.

Meher-Homji VM 1996. Monsoon: a bioclimatologist's point of view. *Curr. Sci.* **71**(5) : 352-357.

Overpeck J, Anderson D, Trumbore S & Prell W 1996. The southwest Indian monsoon over the last 18000 years. *Climate Dynamics* **12** : 213- 225.

Prell WL & Kutzbach JE 1992. Sensitivity of the Indian monsoon to forcing parameters and implications for its evolution. *Nature* **360** : 647-652.

Rajagopalan G, Sukumar R, Ramesh R, Pant RK & Rajagopalan G 1997. Late Quaternary vegetational and climatic changes from tropical peats in southern India—an extended report up to 40,000 years BP. *Curr. Sci.* **73** : 60-63.

Ruddiman WF & Kutzbach JE 1989. Forcing of Late Cenozoic Northern Hemisphere climate by plateau uplift in southern Asia and the American west. *J. geophys. Res.* **94** : 18,409-18,427.

Sarkar A, Ramesh R, Bhattacharyya SK & Rajagopalan G 1990. Oxygen isotope evidence for a stronger winter monsoon current during the last glaciation. *Nature* **343** : 549-551.

Sen PK & Banerjee M 1990. Palyno-plankton stratigraphy and environmental change during the Holocene in the Bengal Basin, India. *Rev. Palaeobot. Palynol.* **65** : 25-35.

Sharma C & Chauhan MS 1988. Studies in the late Quaternary vegetational history in Himachal Pradesh-4. Rewalsar Lake II. *Pollen Spores* **30** : 395-408.

Sharma M & Owen LA 1996. The Quaternary glacial history of NW Garhwal Himalaya. *Quat. Sci. Rev.* **15** : 335-365.

Singh G & Agarwal DP 1976. Radiocarbon evidence for deglaciation in northwestern Himalayas, India. *Nature* **260** : 232.

Singh G, Wasson RJ & Agarwal DP 1990. Vegetational and seasonal climatic changes since the last full glacial in the Thar desert. *Rev. Palaeobot. Palynol.* **64** : 351- 358.

Singh H & Mawar P 1992. Quaternary geology and geomorphology of northern part of the Ganga-Ramganga interfluve area, Ganga Basin, Bijnor and Garhwal districts, Uttar Pradesh. *Rec. geol. Surv. India* **125**(8) : 56-57.

Singh IB 1996. Geological evolution of Ganga Plain—an overview. *J. palaeontol. Soc. India* **41** : 99-137.

Sukumar R, Ramesh R, Pant RK & Rajagopalan G 1993. A δ^{13}C record of Late Quaternary climate change from tropical peats in southern India. *Nature* **364** : 703-706.

Tabata H, Tsuchiya K, Shimizu Y, Fujita N, Matsui K, Koike F & Yumoto T 1988. Vegetation and climatic changes in Nepal Himalayas. I. Vegetation and climate in Nepal Himalayas as the basis of palaeoecological studies. *Proc. Indian natn. Sci. Acad.* **A 54**(4) : 530-537.

Thompson LG, Mosley-Thompson E, Davis ME, Bolzan JF, Dai J Yao, T Gundestrup, N Wu, X Klein L & Xie Z 1989. Holocene-late Pleistocene climatic ice core records from Qinghai-Tibetan Plateau. *Science* **246** : 474-477.

Vishnu-Mittre 1979. Palaeobotanical evidences of the environment of early man in northwestern and western India. *Grana* **18** : 167-181.

Wasson RJ, Smith GI & Agarwal DP 1984. Late Quaternary sediments, minerals and inferred geochemical history of Didwana Lake, Thar Desert, India. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **46** : 345-372.

Williams MAJ & Royce K 1982. Quaternary geology of the middle Son valley, north central India: implications for prehistoric archaeology. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **38** : 139-162.

Yasuda Y 1988. Vegetation and climatic changes in Nepal Himalayas. II. A preliminary study of the Holocene vegetational history in the Lake Rara National Park area, West Nepal. *Proc. Indian natn. Sci. Acad.* **A 54**(4) : 538-549.

Late Pleistocene/Holocene vegetation and environment in and around Marian shola, Palni Hills, Tamil Nadu

S.K. Bera, Anjum Farooqui & H.P. Gupta

Bera SK, Farooqui A & Gupta HP 1997. Late Pleistocene/Holocene vegetation and environment in and around Marian shola, Palni Hills, Tamil Nadu. *Palaeobotanist* **46** (1,2) : 191-195.

This paper highlights the results obtained from fine resolution palynostratigraphy and chronostratigraphy of 1.7 m deep sediment profile from Marian shola in Palni Hills. Palynological reports have unravelled a two-fold vegetation development, viz., shrub savanna-grassland-shrub savanna reflecting two-fold climatic oscillations such as warm and moist-cold and dry-warm and moist under tropical surroundings. Radiocarbon dates have revealed 30,000 years age for the total deposits. The sediments are mostly lacustrine and laid down under reducing environment indicating slow rate of deposition, i.e., top 1 m deposits were accumulated at the rate of 1 cm per 107.50 years while bottom 70 cm deposits were laid down at the rate of 1 cm per 275.70 years.

Key-words — Palaeoenvironment, Marian Shola, Pleistocene/Holocene, India.

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साराँश

तमिलनाडु मे पलनी पहाड़ियो मे मारियन शोला और इसके आस-पास अनंतिम प्लिस्टोसीन/होलोसीन कालीन वनस्पति एवं पर्यावरण

समीर कुमार बेरा, अन्जुम फारुकी एवं हरीपाल गुप्ता

प्रस्तुत शोध-पत्र में पलनी पहाड़ियों में मारियन शोला से 1.7 मीटर गहरी परिच्छेदिका के परागाणुस्तरिकीय एवं कालानुस्तरिकीय अध्ययन से प्राप्त परिणाम प्रस्तुत किये गये हैं। उपलब्ध परिणामों से झाड़ी-सवाना-घासभूमि से झाड़ी-सवाना प्रकार की वनस्पति होने के संकेत मिले हैं जिसके आधार पर उष्णकटिबन्धीय जलवायु में उतार-चढ़ाव प्रदर्शित होते हैं। इन निक्षेपों की 30,000 वर्ष रेडियोकार्बन आयु आँकी गई है। ये अवसाद सरोवरी हैं तथा कम निक्षेपण दर से इनका निक्षेपण हुआ है। ऊपरी एक मीटर निक्षेप एक सेन्टीमीटर प्रति 107.50 वर्ष की दर से निक्षेपित हुआ है जबकि नीचे तली के अवसाद एक सेन्टीमीटर प्रति 275.70 वर्ष की दर से निक्षेपित हुए हैं।

MARIAN shola forest is situated in Palni Hill ranges, Tamil Nadu at an elevation of 2360 m asl between Lat. 10° 12' to 10° 18' north and Long. 77° 26' to 77° 34' east. The present study has been undertaken as an effort to build up the local picture of palaeovegetation and palaeoenvironment enabling to reconstruct the history of shola forest and causes of its degradation. The object of undertaking this area for palynological study is to tune with the data obtained from Nilgiris, Palni Hills and Anamalai Hills concerning the status of grassland vs. shola forest to ascertain climatic cycles involving various controlling factors (Bera & Gupta, in press; Blasco & Thanikaimoni, 1974; Gupta, 1973; Gupta & Prasad, 1985; Gupta & Bera, in press; Menon, 1968; Vasanthy, 1988; Vishnu-Mittre & Gupta, 1970).

The geological formation is largely metamorphic, rocks being granitic gneiss. The soil is often poor in areas subjected to erosion and outwash but in moist swampy depressions peat and clay are also found. Laterite is another significant feature which denotes a wet environment. The soil profile largely comprises fibrous organic mud and silty clay.

Upland savanna above 2000 m cover more than two third of the plateau in Palni. It is often found that the hilly regions are occupied by evergreen shola forests which are characterised by short-boled trees. Premier tree components, such as, *Eurya japonica*, *Gordonia obtusa*, *Sideroxylon tomentosum*, *Elaeocarpus ferrugineus*, *Euonymus crenulatus* and *Symplocos foliosa* occur in the mid forest while *Rhododendron nilagiricum* occupies periphery of the forest. The ephimerals, e.g., *Andropogon foulkrii*, *Cymbopogon polyneuros*, *Fimbristylis* sp., *Anaphalis lawii*, *Cyanotis* sp., *Leucas subfruticosa*, *Heracleum tingens*, *Cassia mimisoides*, *Cnicus wallichii*, *Viola* *patrinii*, *Impatiens floribunda*, etc. occupy the areas in near vicinity of the forest.

MATERIAL AND METHOD

Five surface samples were collected in a transect from within the forest thicket across the open land in and around Marian shola, Palni Hills. Three samples (1-3) were collected from the forested area and two samples (4-5) from open land at an interval of 100 m each. One sediment profile was sampled up to 1.7 meter at 10 cm interval employing Hiller's manual peat-auger. Samples were packed separately in polythene bags adding a few drops of phenol to prevent fungal growth. Samples for radiometric dating were collected from 50 cm, 100 cm and 130 cm depths.

The sediments are blackish-brown to black in colour from the surface down to 150 cm depth and look doughy when moist but crack when dried. The sediments are mostly lacustrine and were laid under reducing environment. Radiocarbon dates have revealed an age of 30,000 years for the total deposits. Pollen analysis was done following conventional maceration technique (Erdtman, 1943).

MODERN POLLEN/VEGETATION RELATIONSHIP

Modern surface samples (moss cushions) from Marian shola have been pollen analysed to find the modern vegetation relationship and interplay of pollen in order to precisely interpret the pollen records from the sediment profile. The pollen records are given below.

Sample 1 — The pollen assemblage of this sample has 35 per cent representation of arboreals. Alien taxa, such as, *Pinus* are 4 per cent of the total pollen assemblage. Among the core-shola arboreals, *Symplocos*, *Ilex*, *Osbeckia* and Myrtaceae are dominant whereas, *Eurya*, *Glochidion*, *Euonymus*, *Palaquium*, *Dodonaea*, Oleaceae, *Rhododendron* and *Ligustrum* are either poor or sporadic in distribution. Among nonarboreals, *Ranunculus*, *Senecio* and Lamiaceae are represented in low curve whereas *Artemisia*, *Peperomia*, etc. are sporadically present. Poaceae represents the ground vegetation at the value of 22 per cent. Both monolete and trilete spores attain 15 per cent each.

Sample 2 — This sample was collected from margin of the forest. The pollen spectrum of this sample has revealed relatively higher values for arboreals (45%). Alien taxa, such as, *Acacia* and *Pinus* are 10 per cent each. The prominent shola taxa represented are *Ilex*, Myrtaceae, *Symplocos*, *Eurya*, Meliaceae, *Pavetta* and Oleaceae; *Elaeocarpus*, *Celastrus*, *Glochidion*, *Palaquium*, *Mallotus* are recorded sporadically. Among nonarboreals, Poaceae is 20 per cent, followed by other ephimerals like *Ranunculus*, *Peperomia*, *Senecio*, Lamiaceae and Chenopodiaceae either in low or sporadic values. Monolete fern spores are 15 per cent and trilete spores are 8 per cent.

Sample 3 — This sample is from the outskirt of the forest. The pollen spectrum has revealed predominance of nonarboreals over arboreals. The significant feature of this sample is sudden disappearance of most of the prominent shola taxa recorded in previous two samples. The arboreals represented by *Eurya*, *Ilex*, *Symplocos*, *Pavetta* and Oleaceae are 27 per cent. *Pinus*, the only alien taxon recorded, has low values. Among nonarboreals Poaceae show significant increase to 39 per cent. Other ephimerals, such as, *Ranunculus*, *Senecio*, Lamiaceae and Rubiaceae also show increased frequency. Trilete fern spores are 10 per cent and monoletes 5 per cent.

Sample 4 — This sample was collected at a distance of 100 m from the periphery of the forest. The pollen spectrum depicts preponderance of nonarboreals over arboreals. The dominant taxa such as *Euonymus*, *Symplocos*, *Ilex*, *Rhododendron*, *Osbeckia* and *Viburnum*, etc. collectively add up to 27 per cent. *Celastrus*, *Valeriana* and Anacardiaceae are sporadically recorded. Frequency of *Pinus* is comparatively less. The ground vegetation is dominated by Poaceae (42%) followed by *Ranunculus*, *Senecio* and Lamiaceae in improved values as compared to the preceding sample. *Cnicus*, *Peperomia*, Lamiaceae and Chenopodiaceae are recorded either in low values or only sporadically. The fern spores are represented in low values.

Sample 5 — This sample was procured from a distance of 200 m from the periphery of the forest. The pollen spectrum shows a drastic fall in the frequency of arboreals (5%). Only stray occurrence of *Ilex*, *Rhododendron* and Oleaceae is observed.

Poaceae attained highest value (78%) followed by other ephimerals like *Impatiens*, *Senecio*, *Ranunculus*, *Heracleum*, *Artemisia*, etc. Rubiaceae and Chenopodiaceae are recorded either sporadically or in low values. Fern spores are also recorded in low values.

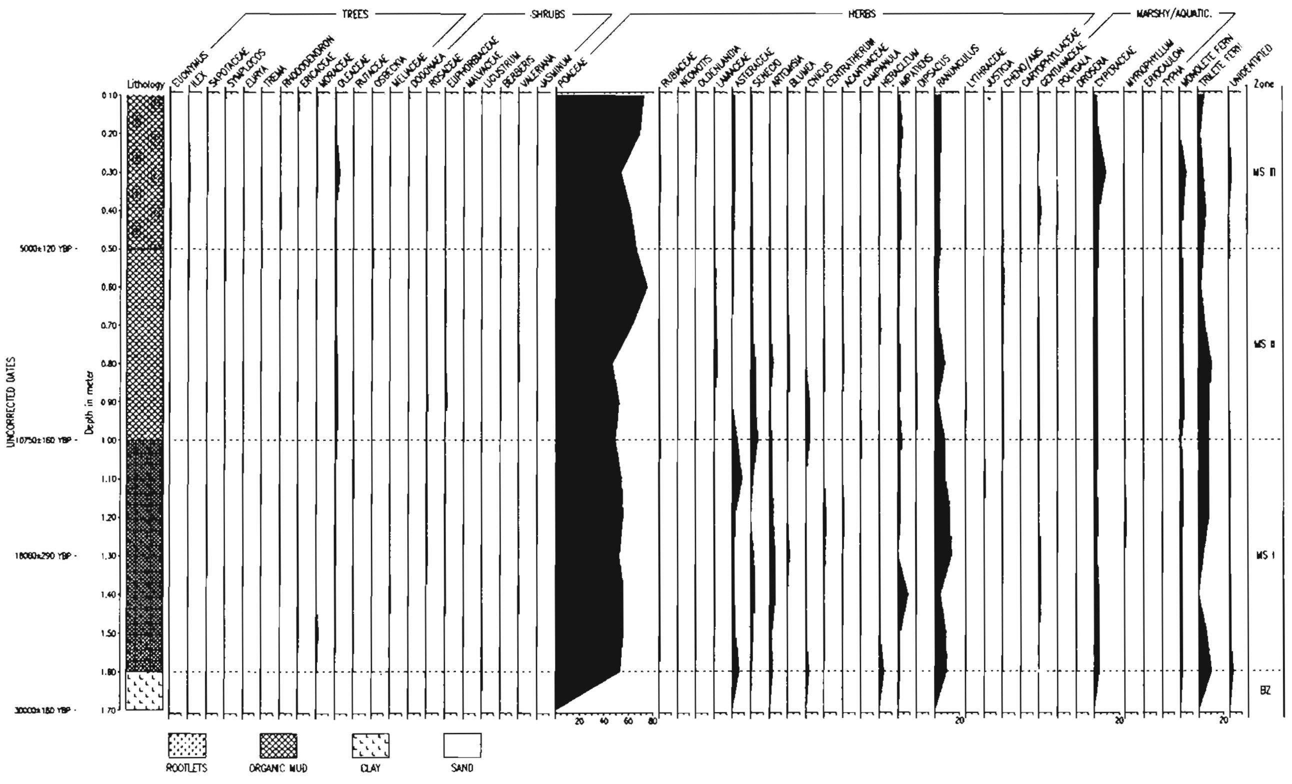
After making a careful analysis of the pollen spectra, it is visualised that the shola constituents (27-45%) are quite faithfully represented in the samples collected from within the forested areas. Nonetheless, their occurrence in the samples from open area is either negligible or scanty. Thus the interplay of the pollen of shola components is restricted to the forested area only and therefore, this observation has been taken into consideration while reconstructing the palaeovegetation.

POLLEN DIAGRAM AND ITS COMPOSITION

One pollen diagram from 1.7 meter deep sediment profile has been constructed and three pollen zones were recognised. The lowermost part of the profile between 30,000-25,000 BP has not yielded any palynodebris and thereby it has been designated as BZ (barren zone). This span indicates the prevalence of oxidising depositional environments. The remaining profile is classified into three pollen zones prefixed with site initials MS I, II and III (Text-figure 1).

Pollen zone MS I (25,000-10,000 BP)

This zone is marked by the presence of low to stray occurrence of typical shola constituents followed by predominance of graminoid pollen attaining up to 52 per cent of the total pollen content. Sapotaceae, Oleaceae and Moraceae are recorded in low values. *Osbeckia*, *Ligustrum*, Ericaceae and Rosaceae are represented sporadically. The shola forest associated ephimerals, such as, *Senecio*, *Artemisia*, Acanthaceae, *Impatiens* and *Ranunculus* are also recorded. Lamiaceae, *Cnicus*, Gentianaceae and Chenopodiaceae are present in relatively low values. Marshy and aquatic taxa, e.g., Cyperaceae, *Myriophyllum* and *Eriocaulon* are meagrely represented. Among ferns, trilete spores attain high value as compared to monolete spores. The climatic condition in which the vegetation of this zone developed could be interpreted as increasing warm-humid and decreasing cold-dry, reflecting an open shrub savanna.



Text-figure 1—Pollen diagram from Marian Shola, Palni Hills, south India.

Pollen zone MS II (10,000-5000 BP)

This zone is marked by the rise in the value of Poaceae forming two summits of about 50 per cent and 80 per cent in the lower and upper parts of the zone. Most of the shola constituents, except Oleaceae, Euphorbiaceae and *Berberis*, disappeared from the scene. Rosaceae and Moraceae have reduced. Among nonarboreals, *Ranunculus, Impatiens, Senecio, Artemisia, Blumea* and Lamiaceae are the dominant taxa recorded in this zone. *Centratherum, Heracleum*, Rubiaceae, Lythraceae and Cheno/Ams are represented either sporadically or in low values. *Campanula, Neonotis* and *Polygala* appear for the first time in the scenario. Among marshy and aquatic taxa, Cyperaceae remained same as before whereas, *Myriophyllum, Eriocaulon* and *Typha* are sporadic. Trilete fern spores are recorded in consistently high values as compared to monolete spores. Thus, this vegetation complex suggests the existence of vast stretches of grasslands, and onset of cold and dry climate.

Pollen zone MS III (5000 BP to Present)

This zone is marked by significant invasion of shola woods into the grassland. *Ilex, Euonymus, Symplocos, Eurya, Rhododendron* and *Trema*, etc. emerged right in the beginning and continued throughout the zone. Simultaneously some close associate of shola forest, such as, *Ranunculus, Impatiens, Heracleum* and Asteraceae, also improved than before but *Senecio, Artemisia, Blumea*, Lamiaceae, etc. relatively reduced. The grasses show consistent improvement. Among marshy and aquatic taxa Cyperaceae gained slight improvement whereas, *Eriocaulon* occurred only sporadically. Trilete fern spores are recorded comparatively in low values. whereas, monolete spores show slight improvement in the middle zone. Thus, the vegetation scenario could be interpreted as showing the co-existence of shola forest and grassland which may be due to warm and humid climate.

HISTORY OF VEGETATION AND CLIMATE

Quaternary vegetational history has been reconstructed for various areas in south Indian montanes, namely, Nilgiris, Palnis, and Anamalai Hills. The pollen assemblage from Pykara region, characterised by paucity of arboreal species, is indicative of two phases of drier climate separated by a moist interval (Menon, 1968). Blasco and Thanikaimoni (1974) recorded dominance of pollen of savanna species over that of shola trees in the Pykara and Parson' Valley swamps. Vishnu-Mittre and Gupta (1970) and Gupta (1973) proposed that at Kakathope, grass cover was formed following the destruction of shola forest. Gupta and Prasad (1985) recorded three phases of vegetational development during 30,000 BP at Colgrain, Ootacamund, Nilgiris. Vasanthy (1988) observed that montane grasslands persisted in Sandynallah of Nilgiri Hills since ca. 30,000 BP. Gupta and Bera (in Press) have recovered a pollen assemblage dating back to >40,000 BP from Bombay shola forest in Palni Hills indicating three phases of vegetation development, i.e., degeneration of shola forest, grassland, re-establishment of shola forest, reflecting on three fold climatic oscillations such as increasing cold and decreasing moist, cold and dry, and warm and moist climatic regimes. The pollen assemblage from Anamalai Hills indicates that the area during 1500 BP was without trees on the landscape and that some of the nonarboreal taxa, e.g., *Senecio, Heracleum, Impatiens, Peperomia*, etc., are closely associated with the forest in south India and are the positive indicators of the existence of shola woods (Bera & Gupta, in Press).

The findings of the present study in and around Marian shola have an important bearing upon the theories regarding the origin and ecological status of upland savanna of Nilgiris, Palnis and Anamalai. The existence of montane grassland and evergreen shola forest have posed an enigmatic problem as to which plant community be considered as climatic climax plant community.

The face value picture of pollen spectra obtained from surface samples does not portray factual composition of modern vegetation; the study has rather revealed that the nonarboreal taxa are preponderant and the trees are either absent or under-represented. Three successional phases of vegetation development have been recovered out of the palynological study of 1.7 m deep profile from Marian shola. The first phase covering a time span between 25,000-10,000 BP is marked by the occurrence of open shrub savanna denoting warm-humid and decreasing cold-dry climatic regime. The second phase covering time span between 10,000-5000 BP has witnessed a shift in vegetation suggesting the existence of far and wide grassland under cold and dry climatic condition. Thereafter, the third phase of vegetation development, ranging from 5000 years to present has registered overall improved values of shola forest constituents showing the co-existence of forest and grassland under warm and humid climatic regime.

Furthermore, pollen evidence suggests that the savanna represent the climatic climax of the forest zone during 30,000 BP and was not formed by degradation of forest on one hand and the sholas represent a second climatic climax, i.e., the forest zone on the other hand. Further, it is to mention that today the study area is totally devoid of natural forest and not subjected to grazing and periodic burning. This clue has definitely supported the view that the persistence of the present savanna especially around swampy areas in Marian shola should have been governed largely by abiotic factor such as frost and other soil condition (clayish, rich in organic content and poor drainage).

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REFERENCES

Bera SK & Gupta HP (in Press). Late Holocene vegetation development in Anamalai Hills, Tamil Nadu, south India. *Palaeobotanist.*

Blasco F & Thanikaimoni G 1974. Late Quaternary vegetational history of southern region. *In*: Surange KR, Lakhanpal RN & Bharadwaj DC (Editors)—*Aspects and appraisal of Indian palaeobotany*: 632-643. Birbal Sahni Institute of Palaeobotany, Lucknow.

Erdtman G 1943. *An introduction to pollen analysis.* Waltham Mass., U.S.A.

Gupta HP 1973. Quaternary vegetational history of Ootacamund, Nilgiris, south India-1. Kakathope and Rees Corner. *Palaeobotanist* **20**(1) : 74-90.

Gupta HP & Bera SK (in Press). Vegetation and environment of Palni Hills, south India since 50,000 years B.P. *C.G.K. Ramanujam Commem. Vol.* Kakatiya University.

Gupta HP & Prasad K 1985. The vegetational development during 30,000 years B.P. at Colgrain, Ootacamund, Nilgiris, south India. *J. Palynol.* **21** : 174-187.

Menon VK 1968. Pollen analysis of late glacial deposits from Pykara, Ootacamund, India. *J. Palynol.* **2-3** : 1-10.

Vasanthy G 1988. Pollen analysis of Late Quaternary sediments : evolution of upland savanna in Sandynallah (Nilgiris, south India). *Rev. Palaeobot. Palynol.* **55**(1-3) : 175-192.

Vishnu-Mittre & Gupta HP 1970. The origin of Shola forest in the Nilgiris, south India. *Palaeobotanist* **19** : 110-114.

Quaternary sediments of Indo-Gangetic, Brahmaputra and adjoining inland basins and the problem of demarcation of Pleistocene-Holocene Boundary

S.K. Kar, Surendra Prasad & Gopendra Kumar

Kar SK, Prasad S & Kumar G 1997. Quaternary sediments of Indo-Gangetic, Brahmaputra and adjoining inland basins and the problem of demarcation of Pleistocene-Holocene Boundary. *Palaeobotanist* **46** (1,2): 196-210.

The Quaternary sediments deposited in the Indo-Gangetic, Brahmaputra and adjoining smaller inland basins and *Duns* formed after the Middle Pleistocene Himalayan Orogenic Movement (HOM-4), are fluvial-fluviolacustrine and or lacustrine in nature. A synthesis of the available data in the Brahmaputra Basin and its comparison with that of the Indo-Gangetic Basin and *Duns* suggests two cycles of sedimentation, separated by a period of erosion and non-deposition and continuous in inland basins, such as Bhimtal-Naukuchia Tal, Hawalbagh in Kumaun region in Uttar Pradesh and Loktak Lake in Manipur. The sediments of the first cycle which terminated in late Upper Pleistocene are, in general, oxidised and referred as the Older Alluvium, while that of the second assigned to Holocene, are unoxidised grey in colour and constitute the Newer Alluvium.

Key-words — Palaeoenvironment, Indo-Gangetic Basin, Brahmaputra Basin, Himalayan Orogenic Movement, Quaternary (India).

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सारांश

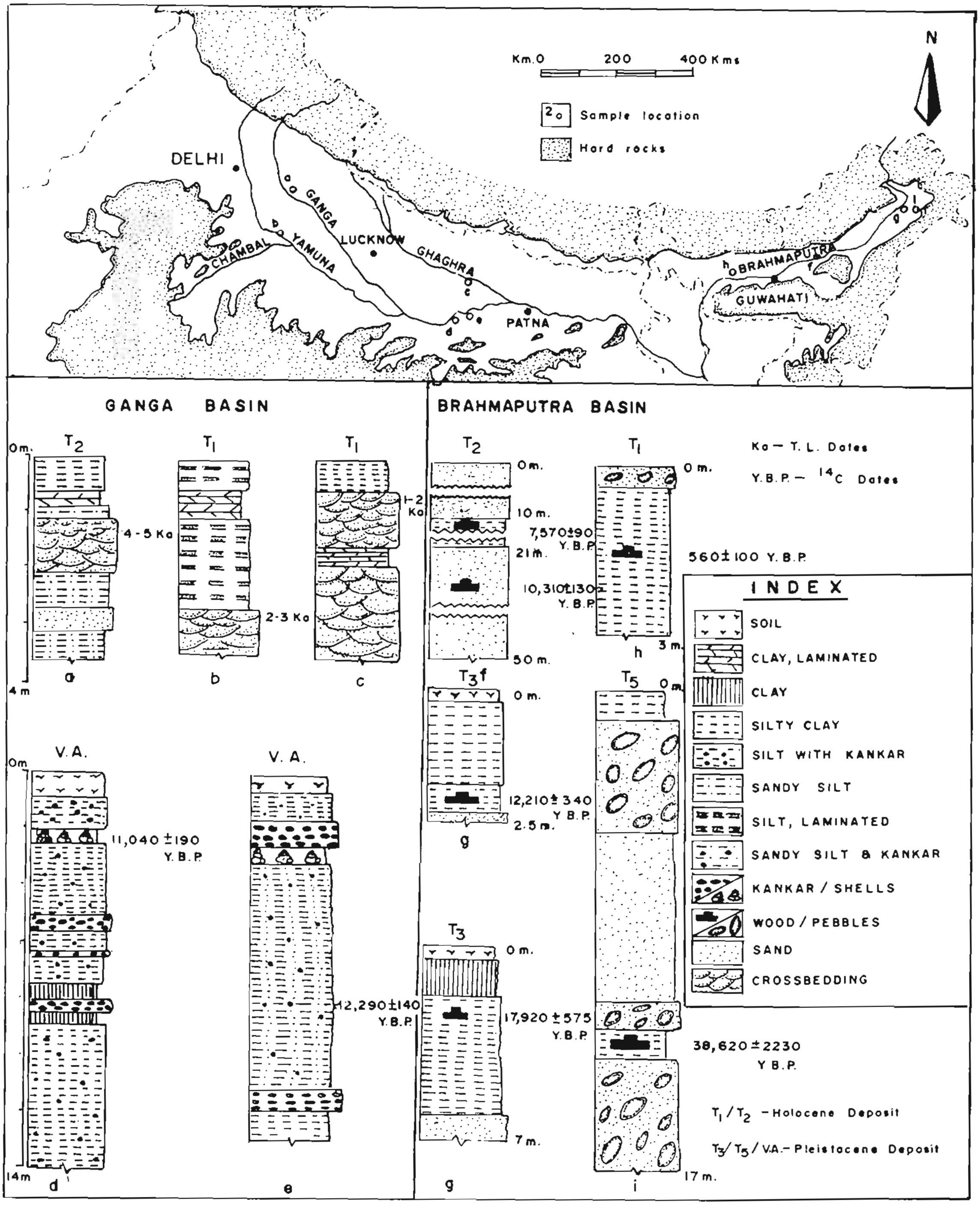
इंडो-गंगा, ब्रह्मपुत्र एवं आस-पास की अंतःस्थली द्रोणीयों के क्वाटरनरी युगीन अवसाद तथा प्लिस्टोसीन-होलोसीन सीमा के सीमांकन की समस्या

एस. के. कर, सुरेन्द्र प्रसाद एवं गोपेन्द्र कुमार

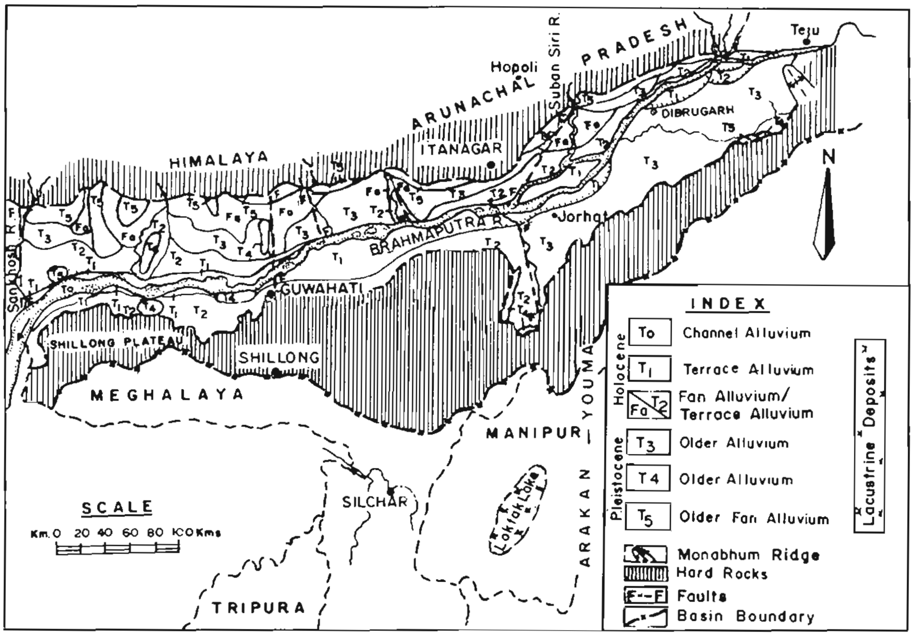
इंडो-गंगा, ब्रह्मपुत्र एवं आस-पास की छोटी अंतःस्थली द्रोणीयों तथा दून में निक्षेपित क्वाटरनरी अवसाद जो मध्य प्लिस्टोसीन हिमालय पर्वतन प्रक्रिया के पश्चात् बने हैं, नदीय, नदीय-सरोवरी अथवा सरोवरी परिस्थितियों की देन हैं। ब्रह्मपुत्र द्रोणी पर उपलब्ध आँकड़ों के विश्लेषण तथा दून एवं इंडो-गंगा द्रोणी से इसकी तुलना से पता चला है कि ये अवसाद दो चक्रों में निक्षेपित हुए हैं। ये अवसाद एक दूसरे से अपरदन, अनिक्षेपण तथा अविच्छिन्न अंतःस्थली द्रोणीयों जैसे उत्तर-प्रदेश में कुमायुं क्षेत्र में भीमताल - नौकुचियाताल तथा मणिपुर में लोकताक झील, के कारण अलग है। अनंतिम उपरि प्लिस्टोसीन कालीन पहले चक्र के अवसाद सामान्यतः ऑक्सीकृत हैं तथा इन्हें प्राचीनतर जलोढ़ के नाम से जाना जाता है जबकि होलोसीन कालीन दूसरे चक्र के अवसाद भूरे रंग के अनाक्सीकृत हैं तथा नवीनतर जलोढ़ कहलाते हैं।

IN the Indian subcontinent, the Quaternary fluvial, fluvio-lacustrine and lacustrine sedimentation has broadly been related to three cycles of sedimentation (Kumar *et al.*, 1996a). These three cycles correspond to supersequences XIII (upper part), XIV and XV of Shanker *et al.* (1996). The first cycle of sedimentation formed part of the ongoing Late Neogene sedimentation in the Siwalik Basin or the Foredeep that continued into Lower Pleistocene. It terminated with last phase of Himalayan Orogeny (HOM-4) during early Middle Pleistocene. The second cycle initiated in Middle Pleistocene in basins formed after HOM-4, viz., the Indo-Gangetic, Brahmaputra, *Duns* (valleys) in sub-Himalaya and inland basins in Lesser Himalaya and Arakan Youma mountains and terminated in late Upper Pleistocene. It continued in some smaller inland basins/lakes. The third cycle of sedimentation commenced on the advent of Holocene and is still continuing. The sediments of the first cycle formed part of the Kimin Formation or the Upper Siwalik Group. In the northern part of the basin these sediments were involved in HOM-4 and gave rise to folded were and uplifted sub-Himalayan ranges. In the southern part these constitute the Banda Group in the Bundelkhand Plain (Kumar *et al.*, 1996 a,1996 b) and the Dihing Formation forming the Mana Bhum Ridge and Arakan-Youma mountains (Krishnan, 1968) in the Brahmaputra Plain.

The sediments related to second and third cycles, generally described as the Quaternary deposits, formed extensive Indo-Gangetic and Brahmaputra Plains, between the Himalaya in the north, the Vindhyan ranges, Shillong Plateau and Arakan Youma mountains in the south (Text-figure 1). These Quaternary sediments were classified as the Older Alluvium and Newer Alluvium by Medlicott (1865) and as Pleistocene river terraces and alluvium in Brahmaputra Plain by Maclaren (1904). Wadia (1939)



Text-figure 1— Map showing location of Indo-Gangetic and Brahmaputra plains.



Text-figure 2—Map showing distribution of Late Pleistocene-Holocene sediments in Brahamputra Basin, Assam and Loktak Lake, Manipur.

classified these sediments as the Older Alluvium (the *Bhangar*) and Newer Alluvium (the *Khadar*) in the Indo-Gangetic Plain. This classification was accepted by Pascoe (1964) and most of the other workers.

The data generated during the last three decades in the Indo-Gangetic Plain, Uttar Pradesh and Bihar were synthesised by Kumar *et al.* (1996a, 1996b) and Sinha *et al.* (1995), respectively. The present paper synthesises the published data on the Brahmaputra Basin and adjoining inland basins (Anon, 1974 in Balasundaram, 1977; Goswami *et al.*, 1984; Kar, 1981 a, 1981b, 1990, 1991; Kar & Ramesh, 1984; Goswami & Kar, 1978, 1979; Khan, 1977; Goswami & Ramesh, 1979; Bhatnagar *et al.*, 1990; Satyanarayana & Kar, 1987; Sinha & Sinha, 1984; Buragohain *et al.*, 1995; Sinha *et al.*, 1995; Sinha, 1996) and traverses taken by one of us (SKK). The information is compared with that on the Indo-Gangetic Basin to establish lithostratigraphy for regional correlations with special reference to the Pleistocene-Holocene Boundary. The radiometric carbon dating and TL dating of samples were carried out at the Birbal Sahni Institute of Palaeobotany, Lucknow and Physical Research Laboratory, Ahmedabad, respectively.

PLATE 1

1, 2. Red silt-clay and light brown sand (T_5 Unit) unconformably overlying Tertiary Sandstone (Tipam Sandstone), Silchar, Assam.

3,4. Closeup view of the bouldery member (T_5 Unit) Jayrampur, Tirap District, Arunachal Pradesh.

5. Brown Silty-clay and sand sequence of T_4 Unit, Mirza, Kamrup District, Assam.

6&7. Occurrence of sand dykes in silty clay member of T_2 Unit indicating neotectonic activity in the area, Soalkuchi, Kamrup District, Assam.

8. Grey-sand, clay and pebbly sand sequence of T_2 Unit Chhayagaon, Kamrup District, Assam.

9. Orange brown clay (T_4 Unit) exposed on the bank of river Brahmaputra; Mirza, Kamrup District, Assam.

10. Exposed bank section of sandy clay and sand sequences of T_1 Unit, Saikhowaghat, district Tinsukia, Assam.

11. Grey sand and silt-clay sequence of T_2 Unit, Kamrup District, Assam.

12. Yellowish orange silty clay of T_3 Unit being mined for brick kiln purposes, Dibrugarh, Assam.

13. Contact of grey sandy silt (T_1 Unit) overlying the grey silty clay of T_2 Unit Soalkuchi, Kamrup District, Assam.

14. Contact relation between grey, silty clay of T_2 Unit and orange brown silty clay of T_4 Unit, Palasbari, Kamrup District Assam.

15. Contact relationship between grey silty clay of T_2 Unit and yellowish orange silty clay of T_3 Unit, Tinsukia, Assam.

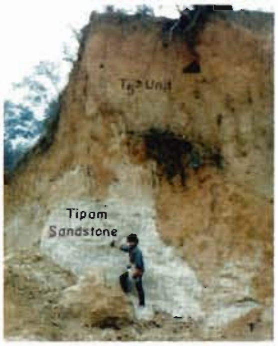
16. Disconformable relationship between grey, calcareous silt of Newer Alluvium (Bhat Alluvium) and reddish brown silty clay of Varanasi Alluvium (Older Alluvium), East of Kasia, Uttar Pradesh.

17. Reddish brown silty clay with calcretes of Varanasi Alluvium (Older Alluvium), Auraiya, Uttar Pradesh.

18. Spatial distribution of T_1 and T_2 Unit Soalkuchi, Kamrup District, Assam.

19. Photo showing disposition of T_1 and T_2 Terraces of Rapti River, Gorakhpur, Uttar Pradesh.

20. Stabilised channel bar (T_0 Unit) of Brahmaputra River north of Palasbari, Palasbari District, Assam showing collection of sand samples.



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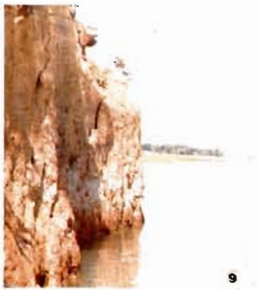
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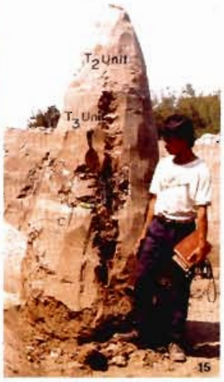

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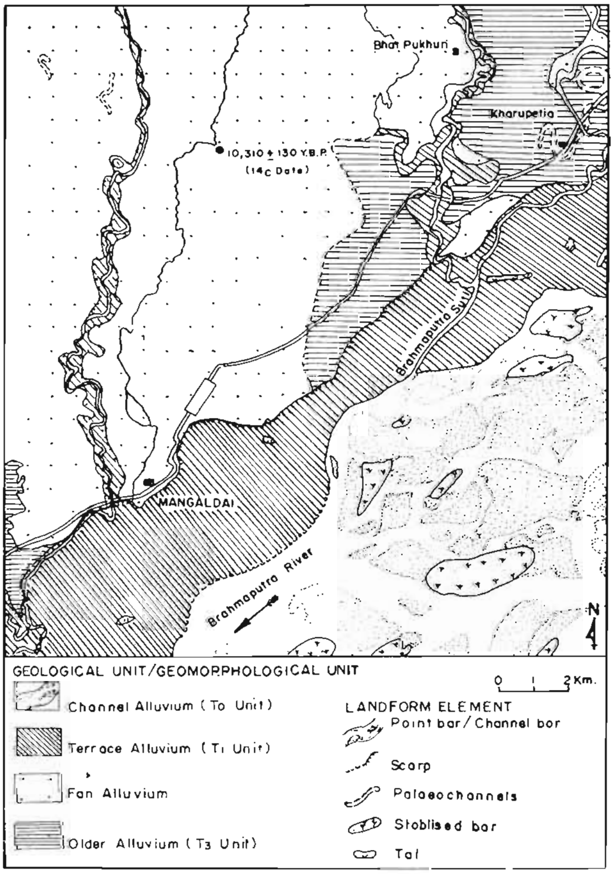
PLATE 1

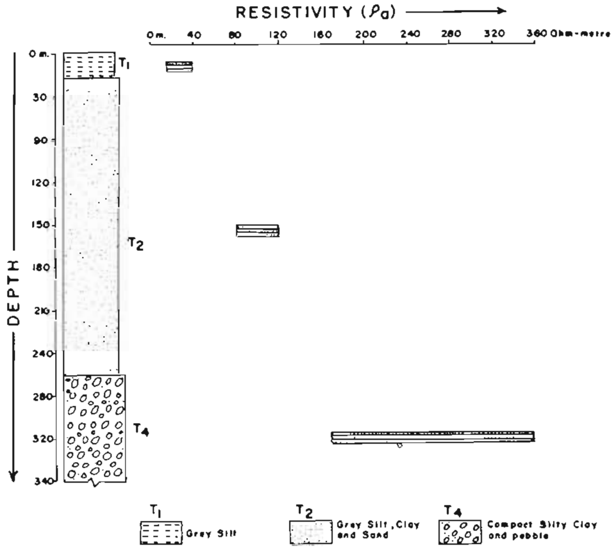
BRAHMAPUTRA BASIN

The Brahmaputra Plain in Assam, covering an area of about 56,000 sq km evolved during Middle Pleistocene period by alluviation of the depression formed between the sub-Himalaya and the Precambrian massif of the Shillong Plateau and the uplifted Arakan Youma Mountains due to post-Siwalik Himalayan Orogenic Movement. Its development is linked with phases of uplift, glaciation (?) and erosion of the Himalaya, and basement tectonics affecting the Shillong massif and the basin of deposition (Balasundaram, 1977).

The Quaternary sediments have been classified into Older Alluvium and Newer Alluvium (Table 1), the former forming high level terraces of either side of the valley and the latter superimposed over the Older Alluvium close to hill-fronts as fans and within narrow flood plain of the present rivers defined by their palaeobanks as low level terraces (Text-figures 2, 3). The Older Alluvium sediments show varying degree of oxidation and have higher resistivity due to their being semi-consolidated as compared to Newer Alluvium which is unoxidised (Text-figure 4).



Text-figure 3—Geological and geomorphological map of Mangaldai area, Darrang District, Assam (after Satyanarayan & Kar 1987).



Text-figure 4—Correlation diagram of resistivity vis-a-vis Quaternary sediments (data source- Rao, 1989)

Table 1—Generalised lithostratigraphy of the Quaternary deposits of Brahmaputra Basin

AGE	LITHOSTRATIGRAPHY	
		Channel Alluvium (T_0)
Holocene	Newer Alluvium	Terrace Alluvium (T_1)
		Terrace Alluvium (T_2)
		Alluvial Fan (Fa)
	Disconformity	
? Middle to		Older Terrace Alluvium (T_3)
Upper Pleistocene	Older Alluvium	Older Terrace Alluvium (T_4)
		Older Terrace Alluvium (T_5)
	Unconformity	
Upper Pliocene to Lower Pleistocene	Kimin (Upper Siwalik) and Dihing Formation	

Older Alluvium

It is a valley-fill deposit comprising three cycles of alluviation each separated by a period of non-deposition and erosion giving rise to three high level terraces (T_5-T_3) about 6-40 metres above the present level of the river. The sediments of the first cycle has widest and highest distribution on either sides of the Brahmaputra Valley and the subsequent cycles successively occupy narrower and lower levels (Text-figure 5). The sediments rest unconformably over the folded Siwalik Supergroup or over the Dihing

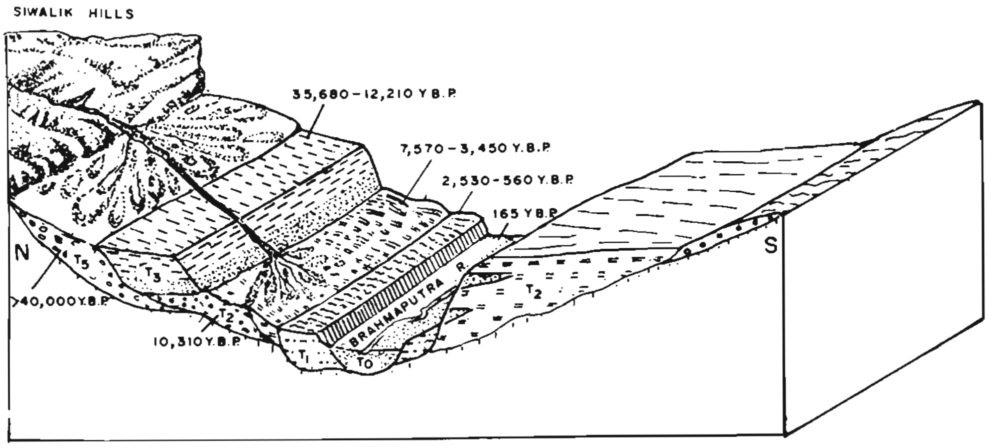
Table 2 — **Radiometric (^{14}C) ages of Quaternary sediments from the Brahmaputra Valley and adjoining inland basins/lakes (samples dated by the Birbal Sahni Institute of Palaeobotany, Lucknow. BS refers to their Lab. Reg. No.)**

GEOLOGICAL FORMATION		DATING MATERIAL	DEPTH OF SAMPLE (bgl) IN m	AGE (^{14} C HALF LIFE 5568 YR) IN YR BP	REMARKS
A. Newer Alluvium					
T_0	i.	Wood	1.0	100 ± 95	BS 627
	ii.	Wood	1.0	160 ± 90	BS 570
	iii.	Wood	1.2	165 ± 80	—
T_1	i.	Wood	1.6	560 ± 100	BS 572
	ii.	Wood	2.0	1,060 ± 120	BS 5626
	iii.	Wood	3.0	1,570 ± 90	BS 748
	iv.	Wood	2.0	1,780 ± 90	BS 750
	v.	Wood	4.5	2,530 ± 130	BS 747
T_2	i.	Wood	2.0	3,450 ± 110	BS 313
	ii.	Wood	2.5	7,570 ± 120	
Fan (Fa)	i. Mangaldai	Wood	25.0	10,310 ± 130	
B. Older Alluvium					
T_3	i.	Peat	1.5	17,920 ± 575	
Backswamp		Peat	1.4	12,210 ± 340	
T_4		Wood	2.5	34,680 ± 2960	
T_5	i.	Wood	1.75	35,680 ± 1810	BS 571
	ii.	Wood	12.5	38,020 ± 2230	BS 573
	iii.	Wood	2.2	40,000	BS 712
	iv.	Carbonised wood	34.3	> 40,000	BS 783
C. Fluvio-lacustrine, Loktak Lake, Manipur					
	i. 760 RL	Wood	2.0	1,780 ± 100	BS 147
	ii. 800 RL	Peat	5.3	11,470 ± 190	BS 145
	iii. 800 RL	Peat	10.0	25,465 ± 660	
	iv. 820 RL	Peat	2.5	32,560 ± 1170	
D. Hapoli Formation					
	Ziro Valley	Peat		40,000	
	Tale Valley	Carbonised wood		25,400 ± 750	BS 248

Formation, older Tertiaries (Pl. 1, figs 1, 2) and Precambrian basement rocks.

There is no data to construe the lower age limit for the sediments. The sedimentation in the basin probably initiated sometime during Middle Pleistocene and continued till late Upper Pleistocene, as indicated by the presence of peat in T_3 dating around 18,000 BP.

Older Terrace Alluvium (T_5) — This forms the highest terrace of the Quaternary landscape and abuts against the dissected mountain front of the Sub-Himalaya and is exposed almost continuously



Text-figure 5—Disposition of Late Quaternary sediments-across Brahmaputra River, Assam (model after clark & Williams 1986).

along the northern boundary of the Brahmaputra Plain (Maclaren, 1904), about 20-40 m above the river level. It also occurs in discontinuous linear zones on southern part of the basin. Deposited as superimposing mega-fans (the Chapar/Kuklong Formation—Poddar *et al.* in Balasundaram, 1977), it has a proximal end comprising semi-consolidated, poorly sorted melange of boulder, pebble, gravel, sand and silt with well developed soil profile. The pervasive pedogenic transformation imparts it blood red, brick red to ochre yellow colouration due to ubiquitous oxidation. Its distal end has characteristic laterised top. The reddish brown silty clay (2-4 m thick) is underlain by thick boulder bed (Pl. 1, figs 3, 4). Together with T_4 and T_3 units, it has been referred as Older Alluvium by Medlicott (1865). In Upper Assam, a carbonised wood associated with this unit indicates an age 38,020±2230 BP (Text- figure 1, i; Table 2).

Older Terrace Alluvium (T_4) — This unit has very limited distribution in the entire Brahmaputra Plain and occurs in detached and isolated outcrops (about one km wide) 15 m above the river level but 15-20 m below terrace T_5. It also occurs as a hummock in T3 terrace. A typical section at Parbatipur in Upper Assam exposes about 3 m of orange brown silty clay at top followed below by pebble-boulder sequence more than 20 m thick (Pl. 1, figs 9, 5, 14). It is well exposed around Palasbari, Kamrup District, and referred as "RED BANK" (Coulson, 1942). Its equivalent unit in Bangladesh Plain is referred as Barind (Horgan & McIntire, 1954). It corresponds to Sorbhog Formation in Manas Basin, Lower Brahmaputra Valley (Poddar *et al.* in Balasundaram, 1977). The radiometric ^{14}C date of 34,680 ± 2960 BP of entrapped wood comes from Khowai Valley, Tripura (Anon, 1968).

Older Terrace Alluvium (T_3) — This is the most extensively developed unit of the Older Alluvium. On the north bank of the Brahmaputra River it is exposed almost continuously in narrow belt from near Pasighat (Khan, 1977) to Sankosh River in the west, while on the south bank it is extensively developed forming wide plain between Namsai and Ledo and continues up to west of Jorhat. Its surficial extensions further in west have not been recorded/ mapped possibly due to subsidence of the area along NNW-SSE trending cross-fault along Dhansiri River, a south bank tributary of the Brahmaputra River (Text-figure 2). In a section at Tinsukia, the top 1.5 m, is composed of silty clay followed below by fine to medium sand more than 3 m thick (Text figure 1g). The soil development is reached up to ultisolic level. The typical colour is yellowish orange (Pl. 1, figs 12,15). At places, a black plastic clay or silty clay horizon, about 3.6 m thick, is encountered about 1-2 m below top, which in the basal part contains peat, carbonised wood and leaf-impressions. From near Tinsukia, a carbonised wood has been dated to 17,920 ± 575 BP. The T_3 surface hosts a number of back swamps which enclose peat beds dating 12,210 ± 340 BP (Table 2).

Newer Alluvium

This is the third and the youngest cycle of ongoing Quaternary sedimentation which initiated on the advent of Holocene. It is subdivided into three subcycles which, in ascending order, are represented by the Alluvial fan deposits, Terrace Alluvium (T_2-T_1) and Channel Alluvium (T_0). The alluvial fan deposits are superimposed over the Older Terrace Alluvium (T_3), while the latter two representing the flood plain deposits, are confined to present day channel courses and deposited over cut and eroded Terrace Alluvium (T_3) (Pl. 1, fig.15; Text-figure 2).

Alluvial fans — These mark the initiation of the Newer Alluvial cycle and are developed mainly along the northern hill front forming piedmont zone. In this zone the rivers draining the Himalaya and the Mishmi Hills debouch in the plain dumping their load in the form of alluvial fans of varying dimensions. Such fans are extensively seen upstream of the trijunction of the Brahmaputra, Dibong and Lohit rivers, and at other places, such as, Mangaldai (Text-

Table 3—Generalised Quaternary, lithostratigraphy of the Indo-Gangetic Basin and foredeep

AGE	LITHOSTRATIGRAPHY
Holocene	Channel alluvium and colovial fan deposits Terrace Alluvium Alluvial Fan deposits
	---------- Disconformity ----------
	Palaeo-aeolian deposits
	---------- Disconformity ----------
Middle to Upper Pleistocene	Varanasi Alluvium
	---------- Unconformity ----------
Upper Pliocene to Lower Pleistocene	Upper Siwalik and Banda Groups

figure 3). These fans are essentially made up of unoxidised sediments containing angular to subangular boulders in apical part and gradually grading to coarse sand at the distal end. The entrapped wood is dated 10,310 ± 130 BP. Similar fans of smaller dimensions are also developed along the northern margins of the Tertiary Hills in the southern part of the plain.

Terrace Alluvium — It is essentially a deposit of the present Brahmaputra drainage system which has been deposited as low-level terraces within the flood-plains of the rivers defined by palaeobanks. The sedimentation and development of the Terrace Alluvium is not uniform and continuous throughout the course of the Brahmaputra River. It appears to have been controlled by neotectonic block movements along N-S or NNW-SSE trending cross-faults such as Dhubri Fault (Gee, 1934), Manas, Dhansiri-Kopili faults, etc. The flood-plain is narrow with no or insignificant sediments if Terrace Alluvium (T_1) in uplifted blocks, such as between Guwahati and west of Goalpara. The development of about 60 km wide flood-plain with Terrace Alluvium (T_2) west of Dhansiri (south bank) River, may be due to down faulting of area to its west.

The sedimentation of the Terrace Alluvium has taken place in two phases, one forming the Terrace-T_2, about 3-4 m below T_3-surface. While the other, Terrace-T_1 is 1-3 m below it (T_2). The T_2 terrace comprises grey silty-clay and pebbly sandstone (Pl. 1, figs 8,11). Peat and wood associated with it at Hazo give ^{14}C age of 7,570 ± 120 BP. In the wide terrace, north of Palasbari in Soalkuchi (Hazo) area numerous sand dykes are seen (Pl. 1, figs 6, 7) which may be related to pre-historic earthquake in the area (Kar, 1990).

The Terrace T_1 (Pl. 1, figs 13, 18) is extensively developed downstream of Jorhat. It is continuously seen along the right bank of the Brahmaputra River up to Sankosh River. Its development along the left bank is restricted up to a few km. upstream of Guwahati and again downstream of Goalpara. The surface is replete with abundant channel features such as cut-off meanders, levees, backswamps in the form of numerous open water/marshy lands. It is composed dominantly of grey sand overlain by silt (Pl. 1, figs 10, 13). The ^{14}C dates of the wood fragments associated with some of the silty clay deposits in backswamp area and with sand in the terrace range between 2,530 ± 130 and 560 ± 100 BP (Table 2).

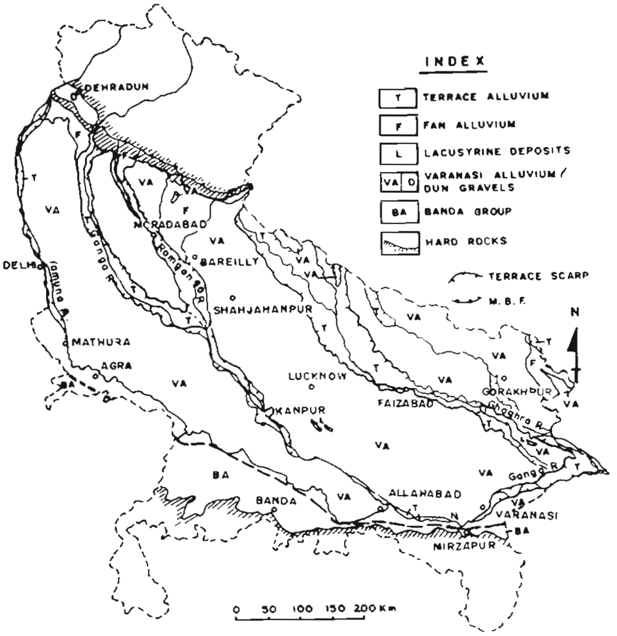
Channel Alluvium (T_0) — The present day active channel, defined by banks of the rivers, and its associated depositional elements like point-bar, channel-bar, meander-scrolls, etc. are grouped under T_0. These are dominantly sandy in nature. In one such established channel bar (Pl. 1, fig. 20) the decomposed vegetal matter gives ^{14}C dates 160 ± 90 and 100 ± 95 BP.

INDO-GANGETIC BASIN

It is one of the largest basins in the world of Quaternary fluviatile deposits. It extends from Indus Basin in the west to Ganga Basin in the east merging with Brahmaputra Basin in the Bengal Plain. Of these basins, the area covered by the Ganga drainage system lies between the sub-Himalayan ranges in north and the Vindhyan and the Chotanagpur plateau in south while that covered by the Indus lies between sub-Himalaya and the Aravalli ranges. The Delhi-Haridwar ridge forms the dividing line.

Lithostratigraphically, the sediments have broadly been classified as Older Alluvium and Newer Alluvium (Wadia, 1939), the former has been named variously in different section (Kumar *et al.*, 1996a, 1996b; Thussu, 1995; Saini & Anand, 1996; Saini & Mujtaba, 1996; Das Gupta, 1996; Roy *et al.*, 1987; Garg & Singh, 1991, 1992, 1993; Sinha *et al.*, 1995, 1996). The classification given by Kumar *et al.*, (1996a) is followed here with some modifications (Table 3).

In the modified classification, the Older Alluvium (Wadia, 1939) has been subdivided into Banda Group and Varanasi Alluvium. The former, coeval with the Upper Siwalik Group, was deposited in the Siwalik Basin or foredeep, and hence, does not form part of the sedimentation in the Indo-Gangetic Basin (Kumar, 1996b). The Varanasi Alluvium is most extensively developed and studied in the Gangetic Plain of Uttar Pradesh (Text-figures 6, 7). It rests unconformably over the Banda Group with development of a *kankar* conglomerate containing vertebrate fossils at base and continues eastwards to Bihar and plains of Bengal where it merges with the Older Alluvium of the Brahmaputra Basin. In the west, it continues into plains of Haryana and Punjab and further west in Pakistan.

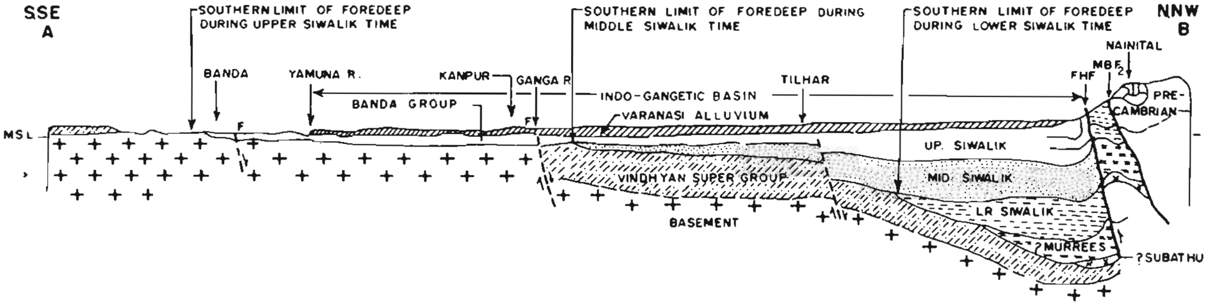


Text-figure 6—Quaternary geological map of Ganga Basin, Uttar Pradesh.

The Varanasi Alluvium comprises large coalescing mega-gans of material brought down from Himalaya and show considerable facies variation from rudaceous in apical part close to sub-Himalaya in north to an alternation of fine sand and lacustrine loamy silty clay at distal end in south. In Bihar plain, different facies have been named differently as distinct formations such as Ganauli, Hazipur, Maguraha, Volcanic Ash Bed, Thakurganj, Khutauna, Sonpur Formations, etc. by Sinha *et al.* (1995), which is untenable in the light of studies in Uttar Pradesh. It is significant that the Varanasi Alluvium also unconformably overlies the horizon yielding Lower Pleistocene vertebrate fossils equivalent to Upper Siwalik (Verma, 1997). An ash bed has also been recorded at the base of the rudaceous facies at Garjia in the Kosi Valley in Nainital District, Uttar Pradesh (Shukla & Kar, 1997). In Bengal plain, the Older Alluvium is represented by the Lalgarh Formation of which the Lower Lalgarh may correspond to the Banda/Upper Siwalik Group and the Upper Lalgarh, containing reworked laterite, vertebrate fossils and Palaeolithic tools of Middle to Upper Pleistocene age (Vaidyanathan & Ghosh, 1993), may be equivalent of the Varanasi Alluvium The sediments, in general, show varying degree of oxidation from dark reddish to yellowish-brown (Pl.1, fig. 17) with development of *kanker* (caliche) beds at 4-5 levels, each representing short break in sedimentation due to fluctuations in climate from warm humid to semi-arid or arid at different intervals. The other evidence for such breaks is the presence of a *kanker* conglomerate, about 30 cm thick, noticed in river bluff section at Kanar near Malihabad, Uttar Pradesh (Nigam, 1994).

The sedimentation of the Varanasi Alluvium terminated in Late Upper Pleistocene due to onset of cool climate related to last glaciation. The glaciation brought about withdrawal of drainage and development of residual lakes over the Varanasi Alluvial plain. These lakes were the sites for the deposition of grey lacustrine clays enclosing rich fauna comprising fresh water molluscs, ostracods, and charophytes which give ^{14}C date of 11,040 ± 190 BP, about 2 m below ground level (Joshi & Bhartiya, 1991). The palaeo-aeolian deposits were also formed in eastern Uttar Pradesh which have been referred as *Bhur* deposits (Dwivedi *et al.,* 1991, 1997; Khan *et al.,* 1991, 1992) and which give TL date of 10 Ka in western Uttar Pradesh (Table 4).

The Newer Alluvium of Wadia (1939) has been divided into three formations — the Alluvial Fan, Terrace Alluvium and the Channel Alluvium in ascending order. In addition, there are lacustrine deposits exposed in dried up or active lakes over the Varanasi Alluvial plain. The Newer Alluvium, as a



Text-figure 7—Generalised geological section showing configuration of foredeep and Indo-Gangetic Basin.

rule, is unoxidised. The Alluvial Fan deposits formed as a result of rejuvenation of the drainage system on return of warm humid climate on the advent of Holocene. These are superimposed over the Older Alluvium (Pl.1, fig. 16) along debouching points of the rivers close to sub-Himalaya. The evolution and development of the present drainage system is controlled by basement configuration and cross faults (Khan *et al.*, 1996; Prasad *et al.*, 1996).

The flow direction of the rivers of the Indo-Gangetic Plain is controlled by the Delhi-Haridwar Ridge resulting in easterly flow of rivers of the Ganga System and westerly of the Indus System. The development of terraces, T_2 and T_1 (Pl.1, fig. 19) is discontinuous and controlled by neotectonic adjustments along cross-faults (Khan *et al.*, 1996) in area lying to the west of Monghyr Ridge (Sastri *et al.*, 1971) and not by fluctuations in the sea level. The effect of sea level changes may have controlled the development of the terraces in area to the east of the ridge. The TL ages of 4000-5000 BP and 3000-1000 BP are obtained from terrace T_2 and T_1, respectively (Table 4). In the Bengal delta, the corresponding ^{14}C date is 4,810±120 BP (Vaidyanathan & Ghosh, 1992).

The Channel Alluvium (T_0) is confined within the active flood plain of the rivers defined by banks. It occurs as point-bar, lateral bar, channel bar, etc.

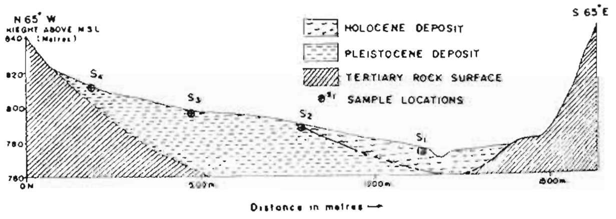
The lacustrine deposits which correspond to the Newer Alluvium are seen in many palaeodrainage lines represented by cut-off meander-loops (ox-bow lakes) on the Varanasi Alluvial plain. It comprises grey clays with marl beds which have given ^{14}C age of 8,300 BP (Rajagopalan, 1992).

Table 4—**Radiometric (^{14}c) and TL ages of Quaternary sediments from the Indo-Gangetic Plain, Uttar Pradesh (samples dated at PRL, Ahmedabad)**

GEOLOGICAL FORMATION	LOCATION	MATERIAL	DEPTH OF SAMPLE bgl IN m	AGE ^{14}C IN BP; TL IN Ka
A. Newer Alluvium				
T1	Ghaghra River near Dohrighat	Sand	1.0	1-2 Ka
T1	Yamuna River near Etawah	Sand	3.0	2-3 Ka
T2	Ganga River near Sareli (Badaun)	Sand	1.4	4-5 Ka
B. Palaeo-aeolian deposit				
	Mound near Shekhupur (Badaun)	Light brown sand	8.0	10 Ka
C. Older Alluvium				
Varanasi Alluvium	i. Sukhdevghat (Muzaffar Nagar)	Calcrete	15.0	12,740 ± 850 770 BP
	ii. Zamania (Varanasi)	Calcrete	10.0	12,290 ± 140 BP

INLAND AND DUN (VALLEY) BASINS

A large number of small isolated inland and *Duns* basins developed contemporaneously with the formation of the Indo-Gangetic and Brahmaputra Basins during Himalayan Orogeny-4 both in the Arakan Youma and the Himalaya. Here sedimentation coeval with the Varanasi Alluvium/Older Alluvium and Newer Alluvium took place. Some of these basins (lakes) are active where fluviolacustrine sedimentation is still continuing.



Text-figure 8—Diagrammatic cross-section across Loktak Lake, Manipur.

Basins in the Arakan Youma Mountain

One of the inland basins located in the Imphal Valley is the Loktak Lake (Pl. 2, figs 1, 2) that has been studied in detail (Kar, 1981; Ray & Sar, 1969; Sarkar & Chandra, 1980; Shukla & Mahapatra, 1986; Shukla, 1987). Earlier, Oldham (1883) had considered the entire Imphal Valley to have been formed due to erosion of the crest of an anticline in the Disang Formation. Of the Quaternary sediments, only 206.60 m have been studied (54.20 m of surface exposures and 152.40 m from a core of a drill-hole in the periphery of the present level of the lake; Text-figure 8). The drilling did not touch the basement rock (Ray & Sar, 1969). However, in an exposed section along the peripheral margin, Tureloo Valley, a lignite bed containing Pliocene-Pleistocene flora has been recorded (Bhattacharya, 1973).

The Loktak Lake sediments comprise unconsolidated boulder beds interbedded with grey to black clay with peat as seen exposed along the margin of lake. The boulder bed contains rounded to surrounded boulders and pebbles of siltstone and shale set in sandy matrix derived from the Disang Formation. The matrix in the boulder bed exhibits variable degree of oxidation from brown to yellow at the highest exposed level at 820 m, gradually reducing to greyish yellow mottled at 800 m to unoxidised at 760 m (lake level). The clay sediments increase in thickness towards the centre, and on exposure, forms hard and lumpy blocks (Pl. 2, fig. 3, 4). The C^{14} ages obtained from the peat are 32,560 ± 1170 BP at highest level of 820 m, 25,465± 660 BP at 810 m, 11,470 ± 190 BP at 800 m and 1,780± 100 BP at 760 m lake level. Palynological analysis of these samples at depth 15 to 20 m indicated a heterogeneous assemblage of ferns (Pteridaceae and Polypodiaceae), conifers (Pinaceae), monocotyledons and dicotyledons. The monocotyledons are represented largely by wild grass-pollen along with those of cultivated type. The dicotyledons are dominated by pollen belonging to the member of Anacardiaceae, Asteraceae, Euphorbiaceae and Rubiaceae. This assemblage indicates a Late Quaternary age (Sarkar & Chanda, 1980).

Basins in the Himalayan domain

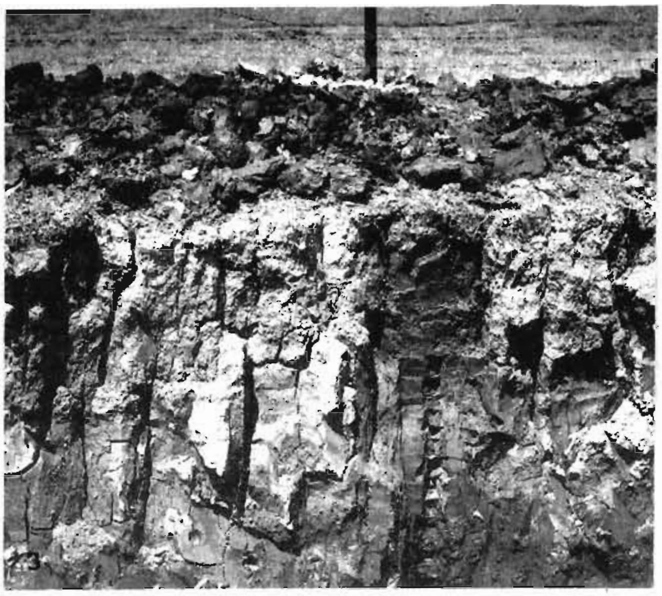
A large number of intermontane basins, *Duns* (Valley) in the sub-Himalaya and inland basins in Lesser Himalaya are recorded. The *Duns* were formed after the folding and uplift of the Siwalik Supergroup during HOM-4 where sedimentation commenced in the Middle Pleistocene and is still continuing. One such *Dun*, is the Dehradun Valley in northwest Himalaya, Uttar Pradesh where the Quaternary valley fill— the Dun Gravels, have been classified as the Shyampur Formation and the Newer Alluvium, the former is considered coeval with the Varanasi Alluvium and the latter corresponds to Alluvial Fan deposits (Nambiar & Rai, 1994). Similar valley fills have also been recorded from western Nepal (Corvinus, 1995).

In the Lesser Himalayan domain, a large number of basins or lakes have been recorded. In eastern Himalaya, these are located in Ziro and Tale Valleys. In Ziro Valley, the fill constituting the Hapoli Formation (Shanker *et al.*, 1989), is exposed in three levels. The peat associated with the middle level gives ^{14}C age of 40,000 BP (Anon, 1978) while in Tale Valley the carbonised wood dates 25,400 ± 750 BP (personal communication by G.C. Vaz, GSI to SKK).

In Uttar Pradesh, a large number of desiccated and active lakes occur in Kumaun Lesser Himalaya. These include Nainital, Naukuchia Tal, Bhimtal, Sat Tal, Hawalbagh, etc. The Lake sediments exposed between Bhimtal and Naukuchia Tal have been studied by Kotlia (1995). In an exposed 52 m thick sequence, the fluvio-lacustrine deposits comprise 'conglomerate-mudstone-claystone with unconsolidated sandstone.' The conglomerate consists of angular clasts of mafic Bhowali Volcanic embedded in silt to gravel size matrix. It occurs at several levels each indicating, possibly, palaeo-landslides. The mudstones, silty in nature, show well defined laminations and are greyish to bluish in colour. Silty claystones are dark brown to reddish coloured and enclose several pieces of charcoal. The 'sandstone' layers are greyish to light brown and the one occurring about 10.5 m above the base has yielded Upper Pleistocene micromammalian assemblage of Soricidae and Muridae families. The radiocarbon dates of mudstone from 19.6 and 33 m above the base give ages 40,000 and 32,320± 2270 BP (Kotlia, 1995). Similar data is also available from Hawalbagh area in Kosi Valley, where the lake formed around 44,000 BP and lasted till 2,000 BP (Valdiya *et al.*, 1996).

DISCUSSIONS

A comparative study of the data available from the Brahmaputra Basin, Indo-Gangetic Basin and *Duns* indicates that sedimentation post-dates Siwalik/Dihing Group in basins formed due to early Middle Pleistocene HOM-4, and appears to be more or less simultaneous. The sediments have been classified into Older Alluvium and Newer Alluvium, the former showing varying degree of oxidation, while the latter, are unoxidised. The only difference being the absence of *Kanker* (caliche) in the Older Alluvium of the Brahmaputra Basin which in the Indo-Gangetic Basin is found at 4-5 levels each representing a break of short duration in sedimentation related to changes in climate from warm humid to arid or semi-arid. Though, there is no development of the *Kanker* in the Brahmaputra Basin, these short breaks in



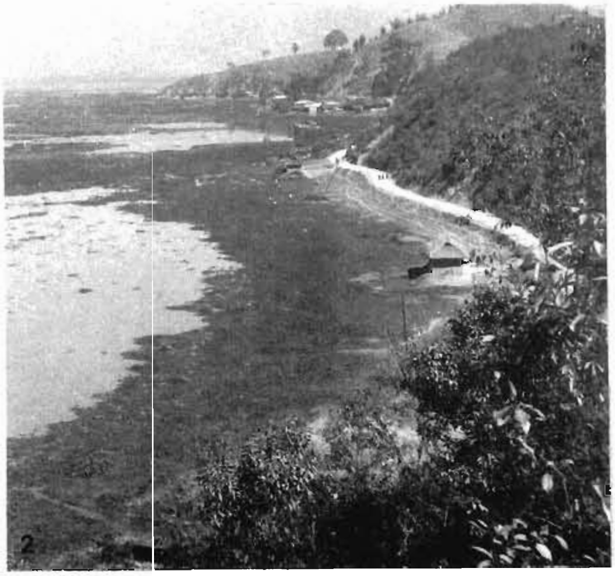


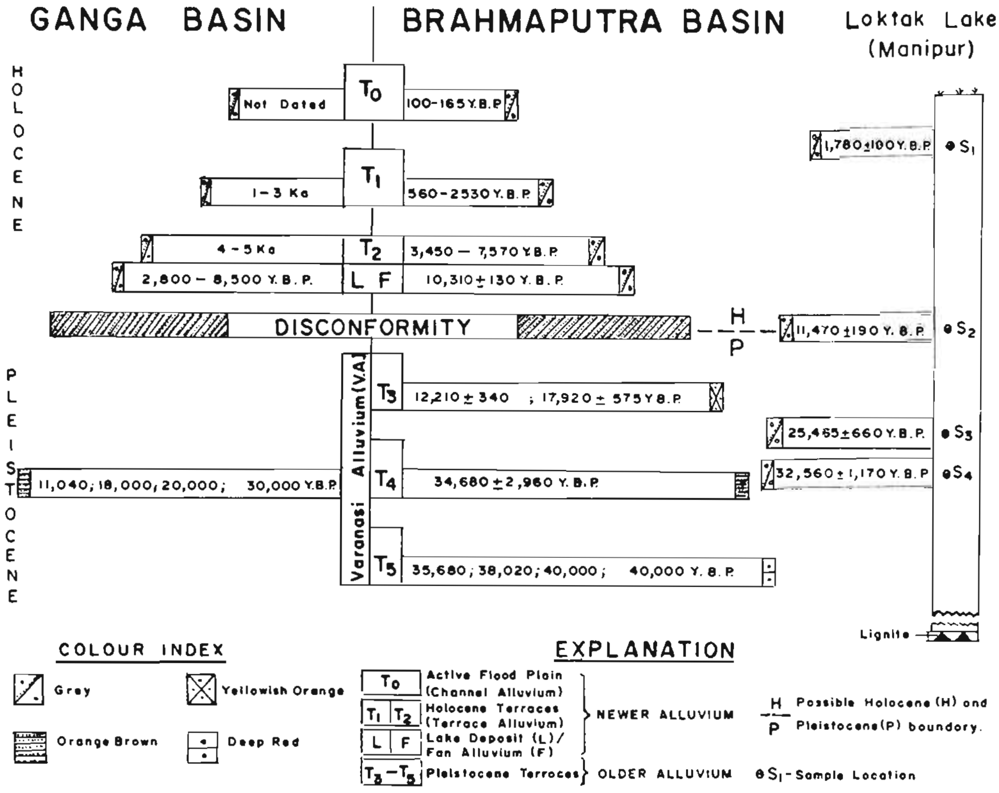
PLATE 2

1. View of Loktak Lake, Manipur.
2. Bog and peat accumulation around the Loktak Lake, Manipur.
3. Section exposing sticky black clay/peat deposit of Loktak Lake, Manipur.
4. Loktak Lake deposit showing possible Pleistocene-Holocene (H/P) interface.

sedimentation resulted in deposition of Older Alluvium in three sub-cycles, each separated by a period of erosion leaving wide benches (terraces) on either side of the Brahmaputra Valley. There is no data to indicate the lower age limit for initiation of sedimentation in the Brahmaputra Basin which in the Indo-Gangetic Basin commenced during Middle Pleistocene.

There appears to be an appreciable break in between sedimentation of the Older Alluvium and the Newer Alluvium in all the basins as the sediments of the latter are unoxidised. This break in sedimentation may be related to global cooling due to last glaciation towards the end of Upper Pleistocene resulting in cessation of fluvial sedimentation. The effects of this change in climate are also reflected in lowering of the sea level and impounding of water over T_3 terrace and Varanasi Alluvial plain.

With the return of warm humid climate on advent of the Holocene, the drainage rejuvenated



Text-figure 9 —^{14}C/T.L. records and possible Pleistocene-Holocene Boundary.

leading to deposition of younger alluvial fans of varying dimensions over the Older Alluvium and subsequently defining of courses of the present drainage system and their flood plains confined to palaeo-banks on either sides and deposition of Terrace Alluvium. The radiometric ages of 10,310± 130 BP from Alluvial fan and 7,570 to 3,450 BP (Text-figure 9) from terraces of the Mangaldai area, Assam are indicative of time of initiation of sedimentation of the Newer Alluvium and deposition of the Terrace Alluvium. This warming of climate is also reflected in a marine transgression around 14,500 BP along the West Coast of India (Nigam *et al.*, 1992). It is interesting that the data from eastern coastal region of China also suggest a transgression around 10,000 BP as it overlies a peat deposit dated 11,520±690, 11,510±570 and 10,800±140 BP, occurring at different depths (Song-Ling & Yun-Shan, 1985). The palaeomagnetic studies in this area also indicated an age of 12,350 BP (Morner, 1977). The palynological studies on sediments of the Tsokar Lake, Laddakh have indicated amelioration of climate 10,000 BP wherein a decline in steppe vegetation and increase of junipers has been recorded (Bhattacharya, 1989).

In inland Loktak Lake/Basin and other basins in Lesser Himalaya, there appears to be continuous sedimentation beginning sometime in Late Pleistocene (earlier than 40,000 BP) and continued into Holocene. The field observations in the Loktak Lake deposits show a gradual change in degree of oxidation from yellowish brown in Older sediments, dating around 32,560 BP, to unoxidised sediments giving an age around 1,780 BP. The sediments giving an age around 11,470 BP (Pl. 2, fig. 4) show mottled appearance of grey and yellow, hue and lie in between. This possibly indicates an interface between Pleistocene and Holocene.

PLEISTOCENE-HOLOCENE BOUNDARY

The demarcation of an epoch boundary requires a record of continuous sedimentation. The separation of the Pleistocene sediments (Older Alluvium) from the Holocene (Newer Alluvium) is primarily based on degree of oxidation. The oxidised sediments, in general, are assigned to Pleistocene while the unoxidised to Holocene. However, sediments of Older Alluvium, which were not exposed to atmosphere, do not show oxidation. Since the studies in the fluvial Indo-Gangetic and Brahmaputra Basins show an unconformable or disconformable relationship between the two, these areas are not suitable for demarcation of the boundary.

The studies from inland basins show almost continuous fluvio-lacustrine sedimentation from Late Pleistocene (around 40,000 BP) to Holocene (around 2,000 BP), and are therefore, ideally suited for demarcation of the boundary. The marked climatic changes at the Pleistocene/Holocene Boundary, from warm-humid to cooler related to last glaciation in Late Pleistocene and reversed to present warm-humid climate, may have their reflections not only in characters of sediments and rate of sedimentation but also in flora and fauna. The detailed studies on these aspects are lacking. In addition, studies on chemostratigraphy and magnetostratigraphy may also help in regional and global correlations for demarcation of the boundary.

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REFERENCES

Anon 1974. Geology and mineral resources of States of India : Assam, Manipur, Meghalaya, Mizoram, Nagaland and Tripura. Part IV. *Geol. Surv. India Misc. Publ.* **30** : 1-24.

Anon 1978. New find of peat from Assam and Tripura. *Geol. Surv. India News* **9**(4).

Balasundaram MS (Editor) 1977. Contributions to geomorphology and geohydrology of the Brahmaputra Valley. *Geol. Surv. India Misc. Publ.* **32**: 1-291.

Balasundaram MS & Murthy MVN 1977. Brahmaputra Basin studies— an appraisal. *Geol. Surv. India Misc. Publ.* **32** : 271-284.

Bhatnagar PS, Satyanarayana G & Kar SK 1990. Report on Quaternary geological mapping in the lower reaches of the Brahmaputra Valley (north bank). *Geol. Surv. India Unpubl. Progr. Report F.S.* 1985-86.

Bhattacharya A 1989. Vegetation and climate during the last 40,000 yrs in Ladak. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **73** : 25-38.

Bhattacharya AC 1973. A report on detailed investigation of lignite, Tureloo Valley, Manipur South District, Manipur. *Geol. Surv. India Unpubl. Progr. Reports F.S.* 1972-73.

Buragohain AK, Ganguly D, Surendranath M & Burman G 1995. Quaternary geological and geomorphological mapping of the Brahmaputra Valley, Karbi Anglong, Golaghat and Jorhat districts, Assam. *Rec. geol. Surv. India* **127**(4) : 20-22.

Clark J & Williams MAJ 1986. Palaeoenvironments and prehistory in north central India : a preliminary report. *In* : Jacobson J (Editor)— *Studies in the archaeology of India and Pakistan* : 19-41. New Delhi.

Coulson AL 1942. Water supply of the Darrang District, Assam. *Mem. geol. Surv. India* **76** : 1-152.

Dasgupta G 1996. Comment (2) on the paper, "Quaternary stratigraphy and sedimentation of the Indo-Gangetic Plains, Haryana" by J.L. Thussu. *J. geol. Soc. India* **48**(2) : 233-235.

Dwivedi GN, Sharma SK & Khanna PC 1991. Quaternary geology and geomorphology of a part of lower reaches of Ghaghra Basin, Azamgarh, Basti, Deoria, Faizabad, Gorakhpur and Mau districts, U.P. *Rec. geol. Surv. India* **124**(8) : 53-67.

Dwivedi GN, Sharma SK, Prasad S & Rai RP 1997. Quaternary geology and geomorphology of a part of Ghaghra-Rapti-Gandak sub-basins of Indogangetic plain, Uttar Pradesh. *J. geol. Soc. India* **49**(2): 193-202.

Garg RL & Singh J 1991. Systematic Quaternary geological and geomorphological mapping in Sangrur and adjacent parts of Patiala and Faridkot districts, Punjab. *Rec. geol. Surv. India* **124**(8): 25-26.

Garg RL & Singh J 1992. Systematic Quaternary geology and geomorphological mapping in parts of Bhatinda, Faridkot, Ferozepur and Sangrur districts, Punjab. *Rec. geol. Surv. India* **125**(8) : 21-23.

Garg RL & Singh J 1993. Quaternary geology and geomorphology of parts of Faridkot and Ferozepur districts, Punjab. *Rec. geol. Surv. India* **126**(8) : 35-37.

Gee ER 1934. Dhubri Earthquake of 1930. *Mem. geol. Surv. India* **65**.

Goswami AB & Kar SK 1978. Neotectonic activity in Upper Assam. *Abstract Symp. Harnessing the river Brahmaputra, Guwahati.*

Goswami AB & Kar SK 1979. The evidence of neotectonic movements in the Quaternary sediments of upper Assam. *Abstract 66th Indian Science Congress, Hyderabad.*

Goswami AB & Kar SK 1979. Geomorphology of the Dibrugarh, Assam. *Abstract 66th Indian Science Congress, Hyderabad.*

Goswami AB, Sinha RK, Ramesh NR, Bandopadhyay SK & Kar SK 1984. Quaternary geology and geomorphology of a part of the Dibrugarh District, Assam. *Geol. Surv. India Unpubl. Progr. Report F.S.* 1977-79.

Joshi DD & Bhartiya SP 1991. Geomorphic history and lithostratigraphy of eastern Gangetic plain, Uttar Pradesh. *J. geol. Soc. India* **37** : 569-576.

Kar SK 1981a. Landuse in Manipur Valley : Scope of development. *Proc. Indian Sci. Congr. Abstract* **4**.

Kar SK 1981b. Geomorphological and geological mapping of Manipur Valley around Loktak Lake, Manipur. *Rec. geol. Surv. India Unpubl. Progr. Reports F.S.* 1978-79.

Kar SK 1990. Geoenvironmental appraisal of Palasbari area, Kamrup District, Assam. *Rec. geol. Surv. India* **123**(4) : 86-88.

Kar SK 1991. Geoenvironmental appraisal of Palasbari area, Kamrup District, Assam. *Rec. geol. Surv. India* **124**(4) : 107-108.

Kar SK & Ramesh NR 1984. Quaternary geology and geomorphology of parts of the Noa Dihing and Burhi Dihing Basins, Lohit and Tirap districts, Arunachal Pradesh, Dibrugarh District, Assam. *Rec. geol. Surv. India Unpubl. Progr. Report F.S.* 1983-84.

Khan AU 1987. Report on geomorphological mapping and study of related fluvial processess in parts of Dibang Valley, Lohitt District of Arunachal Pradesh and Dibrugarh District, Assam. *Rec. geol. Surv. India Unpubl. Progr. Reports F.S.* 1976-77.

Khan AU, Bhartiya SP & Kumar G 1996. Cross faults in Ganga Basin and their surface manifestations. *Geol. Surv. India Spec. Publ.* **21**(2) : 215-220.

Khan NA, Gupta GK, Prasad S & Rai RP 1991. Quaternary geological and geomorphological studies in parts of Rapti sub-basin, Gorakhpur, Maharajganj, Basti and Deoria districts, Uttar Pradesh. *Rec. geol. Surv. India* **124**(8) : 57-59.

Khan NA, Gupta GK, Prasad S & Rai RP 1992. Quaternary geological and geomorphological studies in parts of Rapti sub-basin, Maharajganj and Deoria districts, Uttar Pradesh. *Rec. geol. Surv. India* **125**(8) : 44-46.

Kotlia BS 1995. Upper Pleistocene Soricidae and Mundal from Bhimtal-Bilaspur deposits, Kumaun Himalaya, India. *J. geol. Soc. India* **46**(2) : 177-190.

Krishnan MS 1968. *Geology of India and Burma.* Higgin Bothams, Madras.

Kumar G, Khanna PC & Prasad S 1996a. Quaternary stratigraphy of the Indo-Gangetic plain and sub-Himalaya, Uttar Pradesh. *IX Indian Colloq. Micropal. Stratigr. Dehradun* : 811-825.

Kumar G, Khanna PC & Prasad S 1996b. Sequence stratigraphy of the foredeep and evolution of the Indo-Gangetic Plain, Uttar Pradesh. *Geol. Surv. India Spec. Publ.* **21**(2) : 173-207.

Maclaren JM 1904. The geology of Upper Assam. *Rec. geol. Surv. India* **31**(4) : 179-209.

Medlicot HB 1865. Geological notes on Assam and the hills to the south of it. *Mem. geol. Surv. India* **4** : 416-442.

Möörner NA 1977. The Gothenberg magnetic excursion. *Quaternary Res.* **7** : 413-427.

Morgan JP & McIntire WG 1954. Quaternary geology of the Bengal Basin, East Pakistan and India. *Bull. geol. Soc. America* **70** : 319-342.

Nambiar KV & Rai RP 1994. Quaternary geology and geomorphology of Ganga Basin in Hardwar, Dehradun, Pauri and Tehri districts, U.P. *Rec. geol. Surv. India* **127** : 185-189.

Nigam AC 1994. Quaternary geology and geomorphology of part of Ganga Basin in Allahabad, Hardoi, Lucknow, Pratapgarh, Rae Bareli and Unnao districts, Uttar Pradesh. *Geol. Surv. India Unpubl. Reports F.S.* 1991-92.

Nigam R, Hashmi NH, Menejes ET & Wagn AB 1992. Fluctuating sea levels of Bombay (India) between 14,500 and 10,000 yrs before present. *Curr. Sci.* **62**(3) : 309-311.

Oldham RD 1883. Report on the geology of Manipur State and Naga Hills. *Mem. geol. Surv. India* **(I-XIX)** : 237.

Pascoe EH 1964. *Manual of geology of India and Burma* **3**: 1980-2016. Government of India, Delhi.

Prasad S, Singh G & Kar SK 1996. Effect of basement configuration on Quaternary sedimentation between Chandauli and Ballia, eastern Uttar Pradesh. *National Symp. on Recent Researches in sedimentary basins : Implications for Exploration of natural resources XIII conventions of IAS* : 18-19. Banaras Hindu University, Varanasi.

Rajagopalan G 1992. Radiocarbon ages of carbonate materials from Gangetic Alluvium, Gangetic plain. *In* : Singh IB (Editor)—*Terra Incognita* : 45-48. Geology Department, Lucknow University.

Rao VM 1989. Geophysical investigation for study of overburden and bed rock topography in Greater Guwahati area, Kamrup District, Assam. *Geol. Surv. India Unpubl. Progr. Report F.S.* 1989.

Ray AK & Sar SN 1969. A report on the groundwater exploration in the Manipur Valley, Manipur State. *Geol. Surv. India Unpubl. Progr. Report F.S.* 1968-69.

Roy RK, Chattopadhyay GS & Bisaria BK 1987. Geoscientific appraisal of Munger District, Bihar for rural development. *Bull. geol. Surv. India* ser. B **49** : 1-154.

Saini HS & Anand VK 1996. Lithostratigraphic frame work and sedimentological evolution of the Quaternary deposits of north western Haryana. *Geol. Surv. India, Spl. Publ.* **21** (2) : 227-231.

Saini HS & Mujtaba SAI 1996. Comment (1) on the paper, "Quaternary stratigraphy and sedimentation of the Indo-Gangetic Plains, Haryana" by J.L. Thussu. *J. geol. Soc. India* **48** : 230-233.

Sarkar S & Chandra S 1980. A preliminary palynological investigation of some Quaternary deposits of Manipur. *Abstract 67th Indian Science Congress, Calcutta.*

Sastri VV, Bhandari LL, Raju ATR & Dutta AK 1971. Tectonic frame work and sub-surface stratigraphy of the Ganga Basin. *J. geol. Soc. India* **12** : 222-233.

Satyanarayana G & Kar SK 1987. Quaternary geology and geomorphology of a part of the Dhansiri sub-basin, Darrang District, Assam. *Geol. Surv. India Unpubl. Progr. Report F.S.* 1986-87.

Shanker R, Kumar G & Saxena SP 1989. Stratigraphy and sedimentation in Himalaya: a reappraisal in geology and tectonics of Himalaya. *Geol. Surv. India Spl. Publ.* **26** : 1-60.

Shanker R, Kumar G & Singh G 1996. Sequence stratigraphy and major geological events of Himalaya. *Geol. Surv. India Spl. Publ.* **26** (1): 1-12.

Shukla R & Kar SK 1997. Record of bentonitic clay near Garjia, Ramnagar, district Nainital, Uttar Pradesh. *J. geol. Soc. India* **50** : 107-109.

Shukla RC 1987. Geoenvironmental appraisal of Imphal Urban area, Manipur. *Geol. Surv. India Unpubl. Progr. Report F.S.* 1986-87.

Shukla RC & Mahapatra NR 1986. Geoenvironmental evaluation of Imphal Valley, Loktak Lake and its catchment areas, Manipur. *Geol. Surv. India Unpubl. Progr. Report F.S.* 1985-86.

Sinha AP, Verma SK, Sinha RK & Reddy BS 1995. Identification and documentation of Quaternary stratotypes for intra and inter basinal correlation in parts of north Bihar plains with special reference to neotectonic/seismogenic features. *Rec. geol. Surv. India* **128**(3) : 192-193.

Sinha KK & Sinha RK 1984. Quaternary geology and geomorphology of a part of the lower Subansiri Basin, Lower Subansiri District (Arunachal Pradesh), and Darrang and North Lakhimpur districts (Assam). *Geol. Surv. India Unpubl. Progr. Report F.S.* 1982-83.

Sinha M, Sinha AP & Reddy BSS 1996. Identification and documentation of Quaternary stratotypes for intra and inter-basinal correlation in parts of north Bihar plains with special reference to neotectonic/seismogenic features. *Rec. geol. Surv. India* **129** (3) : 165-168.

Song-Ling Z & Yun-Shan C 1985. Transgression and sea level changes in the eastern coastal region of China in the last 300,000 years. *In* (Editor)—*Quaternary geology and environment of China* : 200-209. China Ocean Press, Beijing.

Thussu JL 1995. Quaternary stratigraphy and sedimentation of the Indogangetic plains, Haryana. *J. geol. Soc. India* **46**(5) : 533-544.

Vaidyanathan R & Ghosh RN 1993. Quaternary of the East Coast of India. *Curr. Sci.* **64**(11-12) : 804-816.

Valdiya KS, Kotlia BS, Pant PD, Shah M, Mungali N, Tewari S, Shah N & Upreti M 1996. Quaternary palaeo-lakes in Kumaon Lesser Himalaya. Finds of neotectonic and palaeoclimatic significance. *Curr. Sci.* **70**(25) : 157-161.

Verma BS 1997. Time stratigraphic reappraisal of vertebrate fauna of the older alluvium of Uttar Pradesh. *Rec. geol. Surv. India* **129**(8) : 182-186.

Wadia DN 1939. *Geology of India.* 2nd Ed. MacMillan and Co. Ltd., London.

Vegetation and climate during Late Holocene in Garhwal Himalaya

M.S. Chauhan, Chhaya Sharma & G. Rajagopalan

Chauhan MS, Sharma C & Rajagopalan G 1997. Vegetation and climate during Late Holocene in Garhwal Himalaya. *Palaeobotanist* **46** (1,2) : 211-216.

Pollen analysis of a 5 metre deep profile from Chharaka Tal (Sat Tal) in Garhwal Himalaya has brought out that during 2800-1900 BP mixed conifer-broad leaved temperate forests comprising chiefly *Pinus, Cedrus, Betula, Quercus* associated with *Abies, Alnus, Salix* and *Carpinus* grew in the region under cool and moist conditions. Later on, during 1900-1200 BP the temperate forests continued but with reduced frequencies of *Pinus, Betula, Quercus, Carpinus, Alnus*; sedges, however, improved. This change in vegetation composition reflects deterioration of the climate. The increase in frequencies of sedges indicates transformation of the lake into a swamp. Subsequent to this period, the expansion of *Pinus, Cedrus* and *Abies* together with non-arboreal elements, viz., sedges, grasses, *Artemisia*, Ranunculaceae, etc. indicates further deterioration of climate.

Key-words—Vegetation, Palaeoenvironment, Garhwal Himalaya, Late Holocene, India.

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सारांश

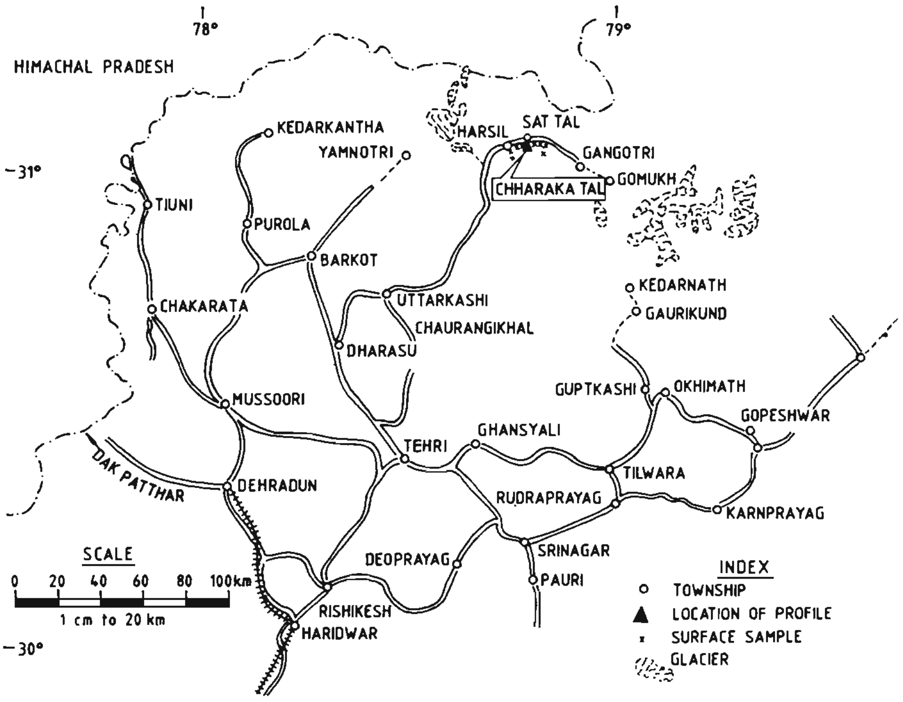
गढ़वाल हिमालय में अनंतिम होलोसीन के समय वनस्पति और जलवायु

मोहन सिंह चौहान, छाया शर्मा एवं गोविन्दराजा राजगोपालन

गढ़वाल हिमालय में छरका ताल (सत ताल) की एक पाँच मीटर गहरी परिच्छेदिका के परागकण विश्लेषण से यह पाया गया है कि 2800-1900 वर्ष पूर्व इस क्षेत्र में ठंडी एवं नम परिस्थितियों में मुख्यतया *पाइनस, सिड्रस, बिटुला, क्वरकस, एबीज, एल्नस, सेलिक्स* एवं *कार्पाइनस* से युक्त मिश्रित कोनिफर-चौड़ी पत्तियों वाले शीतोष्ण वन विद्यमान थे। बाद में 1900 से 1200 वर्ष पूर्व हालाँकि शीतोष्ण वन विद्यमान थे परन्तु *पाइनस, बिटुला, क्वरकस, कार्पाइनस* एवं *एल्नस* की संख्या कम हो गई थी परन्तु इसके विपरीत सेजों का आधिक्य हो गया था। वनस्पति में इस प्रकार का परिवर्तन जलवायु में होने वाले परिवर्तन का द्योतक है। सेजों की वृद्धि से झीलों का दलदली परिस्थितियों मे बदलना इंगित होता है। इसके बाद *पाइनस, सिड्रस* एवं *एबीज* तथा अवृक्षीय अवयवों आदि की वद्धि से पुनः जलवायु में परिवर्तन इंगित होता है।

COMPREHENSIVE data on the vegetation of Quaternary period is available through investigation of a large number of lacustrine deposits from western Himalaya, viz., Kashmir (Gupta *et al.*, 1984; Sharma & Gupta, 1985; Sharma *et al.*, 1985), Himachal Pradesh (Sharma & Singh, 1974a, 1974b; Sharma, 1985; Sharma & Chauhan, 1988; Bhattacharyya, 1988, 1989) and Kumaon (Vishnu-Mittre *et al.*, 1967; Gupta, 1977; Gupta & Khandelwal, 1982; Chauhan & Sharma, 1996). However, similar proxy data for Garhwal Himalaya, the sector between Himachal Pradesh and Kumaon, remain yet to be generated. Recently, Sharma and Gupta (1995) have studied a Late Holocene profile from Nachiketa Tal, Uttarkashi. The present paper is an effort in this direction to deduce climatic sequence in the subalpine belt of Garhwal Himalaya covering the Late Holocene period. The present study deals with a 5 metre deep profile from Chharaka Tal of Sat Tal group of seven lakes in Uttarkashi. Seven lakes which constitute Sat Tal are Chharaka Tal, Mardung Tal, Dabur Tal, Ghunt Tal, Rikh Tal, Baman Tal and Lotia Tal.

Sat Tal, as the name indicates, is a group of seven mini lakes situated at an altitude of 3500-4500 m a.s.l., 78 km north-east of Uttarkashi and 7 km east of Harsil near Dharali Village (78° E long.; 31°10′N lat.). Sat Tal area is characterised by lofty mountain ranges with valleys and gorges having mostly the moraine deposits formed as a consequence of intense glaciofluvial activities in the region. The region



Text-figure 1—Sketch map of Garhwal Himalaya showing the area of study.

remains under thick snow cover for major part of the year. Chharaka Tal, a major constituent lake of Sat Tal group, at present is transformed into a big swamp. This lake, about 400 sq metres in area, has almost circular outline (Text-figure 1).

VEGETATION

Pure *Pinus wallichiana* (blue pine) dense forests occur at the lower altitudes with occasional thickets of *Berberis* sp., *Rubus ellipticus, Zanthoxylum alatum, Crataegus* sp., *Indigofera* sp., etc. Herbaceous undergrowth marked by scanty patches of *Polygonum* sp., *Potentilla* sp., is seen in certain moist situations and shady depressions. The bluepine forests extend up to the subalpine zone. Pure stands of *Cedrus* and *Abies* also grow in the region.

Besides the overall dominance of bluepine forests, temperate broad-leaved forests comprising chiefly *Betula utilis, Alnus nepalensis, Quercus dilatata, Rhododendron campanulatum, R. barbatum, Salix elegans* and *Corylus colurna* occur in moist and shady depressions. Main shrubby associates of these forests are *Rosa macrophylla, Rubus niveus, R. biflorus, Viburnum* spp., *Berberis asiatica, Ilex dipyrena, Cotoneaster microphyllus*, etc. The luxuriant herbaceous vegetation comprises chiefly *Polygonum speciosum, Thalictrum chelidonii, Paeonia emodi, Geum elatum, Saussurea taraxifolia, Hypericum* sp., *Galium* sp., *Primula* sp., *Androsace* sp., *Jasminum humile, Viola serpens, Rumex nepalensis, Geranium wallichianum* and *Anemone rivularis*, etc.

MATERIAL AND METHOD

Material for the present study includes both surface samples and sedimentary profile. Eight surface samples (moss cushions) were collected in a transect at an interval of 50 m from the vicinity of Chharaka Tal to understand the modern pollen/vegetation relationship in the region. Sediments for pollen analysis were collected at 5 cm interval, from a 5 m deep profile from Chharaka Tal, using Hiller's peat auger. Samples for radiometric dating were also collected from this profile.

The sediments in the profile are mainly composed of fibrous peat and organic mud, intermixed with rootlets, silt and sand at different depths. The lithological details are as below:

Depth in metre	*Lithology*
0-1.00	Fibrous peat with rootlets
1.00-1.20	Fibrous peat with silt
1.20-2.00	Fibrous peat with rootlets
2.00-2.20	Water
2.20-2.50	Fibrous peat with rootlets
2.50-3.00	Fibrous peat with organic mud
3.00-3.50	Decomposed organic mud
3.50-4.00	Decomposed organic mud with charcoal pieces
4.00-4.30	Decomposed organic mud with sand
4.30-4.50	Decomposed organic mud
4.50-5.00	Decomposed organic mud with sand

The solitary radiocarbon date available for this profile at the depth of 3.65-3.75 m is BS-1287 2090±140 BP. Samples from other depths could not be dated owing to insufficient carbon content.

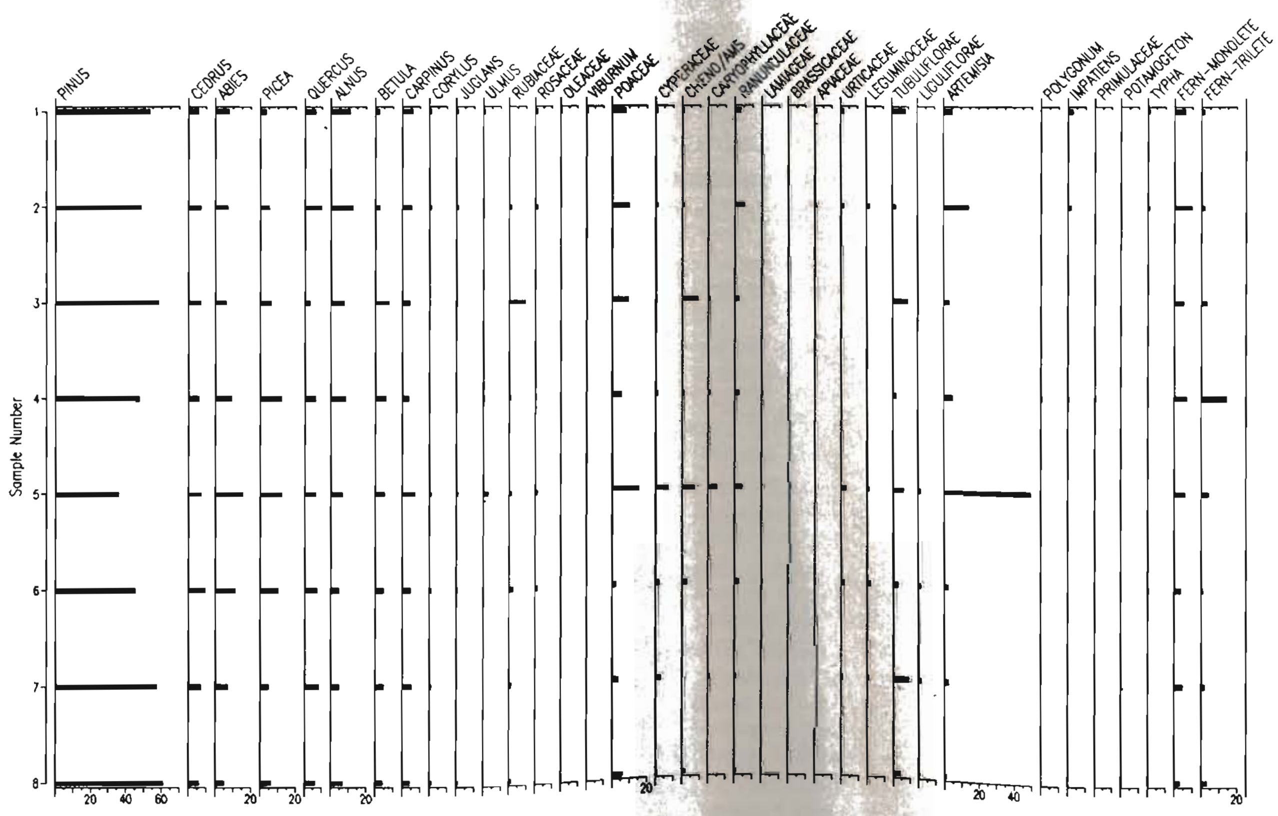
The conventional procedure of pollen analysis (Erdtman, 1943) was employed for extraction of pollen/spores from the surface and profile samples.

POLLEN ANALYSIS

The pollen counts vary from 200-400 for surface as well as profile samples analysed here. The percentage frequencies of the recovered pollen taxa have been calculated in terms of total terrestrial plant pollen. The plant taxa have been categorised as trees, shrubs, herbs and ferns and are arranged accordingly in pollen spectra and pollen diagram.

Modern pollen/vegetation relationship

The pollen assemblage obtained from the study of 8 surface samples from the vicinity of Chharaka Tal (Text-figure 2) has an overall dominance of arboreals over non-arboreals. The high values of *Pinus* (35-62%) correspond with its present dominance in the region, whereas the moderate frequencies of other growing conifers, such as, *Cedrus* (5-9%), *Abies* (5-15%) and *Picea* (5-12%) reflect their patchy occurrence. The representation of some of the broad-leaved taxa, viz., *Quercus* and *Betula* (2-8% each), *Alnus* (5-15%), *Carpinus* (3-7%) too portrays their restricted distribution in the region. However, *Rhododendron, Juglans, Corylus, Ulmus,*



Text-figure 2—Pollen spectra from Chharaka Tal (Sat Tal), Garhwal Himalaya.

and certain other taxa, though growing frequently in the region, are recorded either scantily or absent in the pollen spectra.

Among the non-arboreals, Poaceae (2-15%), Cyperaceae (1-8%), Cheno/Ams (1-6%) and Tubuliflorae (2-10%), despite their fluctuating frequencies, do exhibit a consistent representation. *Artemisia* is met with in good values, but its excessively high frequency in sample No. 5 is attributed to local abundance around the provinence. The frequent occurrence of monolete and trilete spores reveals profuse growth of ferns in the area.

Description of pollen diagram

The pollen diagram (Text-figure 3) constructed from Chharaka Tal has been divided into three distinct pollen zones (CH-I, CH-II and CH-III). The pollen zones are prefixed with "CH" after the name of the investigated site and are described below:

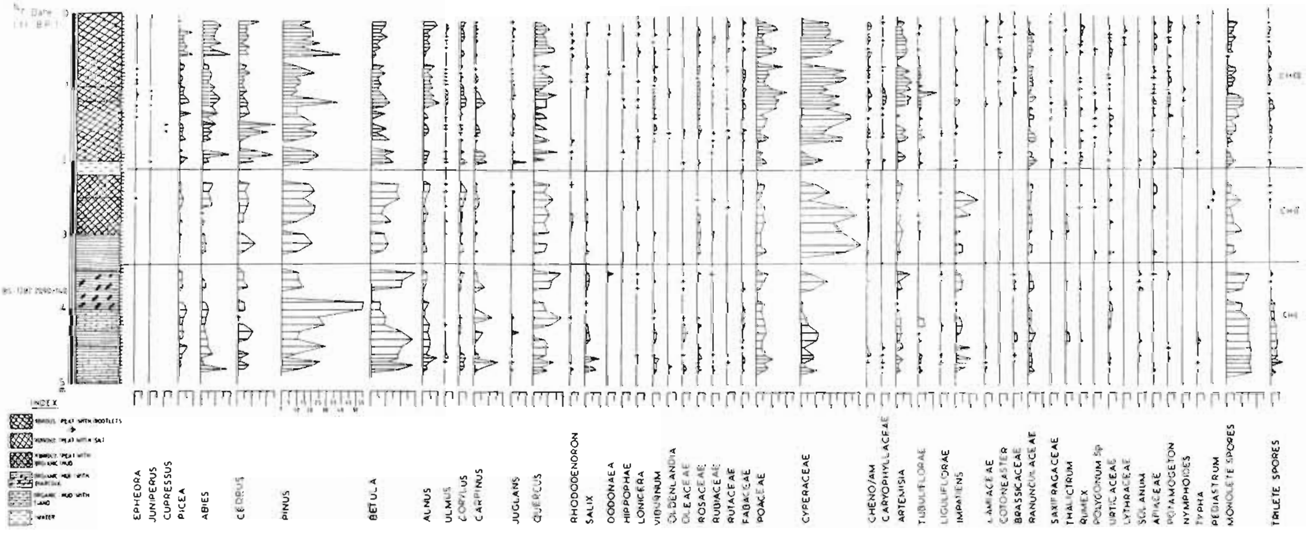
Pollen Zone CH-I (5.00-3.40 m): Pinus-Betula-Quercus-Carpinus-Abies-Cedrus-Cyperaceae-Poaceae Assemblage—This pollen zone, with solitary radiocarbon date of BS-1287 2090±140 BP in the upper part and encompassing the time span 2800-1900 BP, reveals the existence of mixed conifer-broad-leaved forests in the region. The major arboreals, *Pinus* (15-55%), *Betula* (8-20%), *Quercus* (8-30%), *Alnus* (2-10%), *Abies* (2-19%), *Cedrus* (4-10%) and *Picea* (2-5%) are represented consistently. Other components recorded in the zone are *Corylus* and *Salix* (0.5-5% each) together with shrubby elements—*Viburnum* and Rosaceae.

Among the non-arboreals, sedges (2-11%), Poaceae (3-12%), *Impatiens* (0.5-11%), *Artemisia* (0.5-8%) and Ranunculaceae (2-5%) are the chief constituents. Tubuliflorae (5%), Brassicaceae, *Thalictrum*, Cheno/Ams and Urticaceae (2% each) are also represented. Fern spores are present in fairly high frequencies.

Pollen Zone CH-II (3.40-2.10 m) : Pinus-Betula-Quercus-Cedrus-Abies - Alnus-Corylus-Cyperaceae-Poaceae Assemblage—This phase covering the time span 1900-1200 BP has an almost similar floristic composition as in Pollen Zone CH-I. However, right from the commencement of this pollen zone, an overall decline in most of the arboreals, such as, *Pinus* (7-25%), *Betula* (6-18%), *Quercus* (8-14%), *Abies* (1-7%), *Picea* (2-4%) and *Carpinus* (1-6%) is recorded. *Cedrus* (5-13%), on the other hand, shows an increasing trend.

The herbaceous taxa, such as, Cyperaceae (10-40%) and *Impatiens* (3-15%) also exhibit an increasing trend, whereas Poaceae (4-7%), Caryophyllaceae (2.5-7%) and Ranunculaceae (1-2%) show reduced frequencies than in the Pollen Zone CH-I. Fern spores too are recovered in comparatively lower values.

Pollen Zone CH-III (2.10-0 m) : Pinus-Cedrus-Betula-Quercus-Picea-Alnus-Cyperaceae-Poaceae-Artemisia Assemblage—This pollen zone covering



Text-figure 3—Pollen diagram from Chharaka Tal (Sat Tal), Garhwal Himalaya.

the time span 1200 BP to the present shows an overall improvement in the non-arboreals with a simultaneous decline in arboreals, particularly the broad-leaved elements—*Betula* (2-15%), *Quercus* (3-13%) and *Salix* (2%). *Alnus* (2-10%) and *Carpinus* (1-10%) too show increased frequencies. The non-arboreals become more frequent in this pollen zone. Cyperaceae (3-35%) maintains its dominance. Poaceae (2-28%), *Artemisia*, Tubuliflorae (2-10% each) and Ranunculaceae (1-7%) exhibit a rising trend. Fern spores are recorded frequently.

HISTORY OF VEGETATION AND CLIMATE

The lithology of the profile from Chharaka Tal shows no variation as it is mainly composed of fibrous peat and decomposed organic mud. Assuming modern age for top of the profile and more or less uniform rate of sedimentation which is approximately 1 cm/5.65 yrs, it could be possible to extrapolate dates at other depths from this profile. The bottom of the profile might be dated to around 2800 BP. Likewise, two more dates, i.e., 1900 BP at 3.40 m depth and 1200 BP at 2.10 m depth have also been extrapolated for the demarcation of the temporal changes in the floristic composition in the region.

The pollen sequence in the investigated profile has brought out vegetational succession and contemporary climatic fluctuations in the region, covering the last 2800 years. It has unravelled that between 2800 to 1900 BP luxuriant mixed temperate conifer-broad leaved forests comprising chiefly *Pinus, Betula, Quercus, Abies* and *Cedrus*, in order of their dominance, existed in the region. Thermophilous broad-leaved elements, such as, *Corylus, Alnus, Juglans, Rhododendron* together with bushes of *Viburnum*, Oleaceae and Fabaceae were other noteworthy associates of these forests. The overall vegetational composition demonstrates that the region during this period was under the influence of moist temperate climate. This is also corroborated by the marked preponderance of fern spores.

Between 1900 and 1200 BP these mixed temperate conifer-broad leaved forests continued to grow in the region without any major change in floristic composition. However, reduced frequencies of major forests ingredients namely *Pinus, Betula, Alnus, Quercus,* etc. denote that the forests became sparse during this period. The decline in forest density probably resulted as a consequence of deterioration of climate which turned cooler but less moist. This is further supported by sharp decline in ferns. As a consequence to this harsh climatic change, the lowering of lake level and simultaneous transformation of the lake into swampy land commenced. This is quite apparent from the marked expansion of sedges in the area.

For the past 1200 years, mixed temperate conifer-broad-leaved forests have existed in the region except that the conifers like *Abies, Picea, Cedrus* and *Pinus* have become more prominent. However, most of the broad-leaved taxa, such as, *Betula, Quercus,* etc. correspondingly declined except for *Alnus* which improved during this period. The evident expansion of conifers and simultaneous reduction in the broad-leaved taxa demonstrate futher deterioration in the climate. The prevailing climatic regime has also led to the transformation of the lake into a swamp, which at present supports copious growth of sedges.

Improvement of grasses together with other ruderal/culture plant taxa, such as, Caryophyllaceae, Chenopodiaceae/Amaranthaceae, *Artemisia*, Tubuliflorae is indicative of increased anthropogenic pressure on the natural vegetation during recent past.

REFERENCES

Bhattacharyya A 1988. Vegetation and climate during post glacial period in the vicinity of Rohtang Pass, Great Himalayan Range. *Pollen Spores* **30** (3-4) : 417-427.

Bhattacharyya A 1989. Vegetation and climate during the past 30,000 years in Ladakh. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **73** : 25-38.

Chauhan MS & Sharma C 1996. Pollen analysis of Mid-Holocene sediments from Kumaon Himalaya. *Geol. Surv. India Spec. Publ.* **2** (1) : 257-269.

Erdtman G 1943. *An introduction to pollen analysis.* Chronica Botanica, Waltham, Mass., U.S.A.

Gupta HP 1977. Pollen analytical reconnaissance of post glacial deposits from subtropical zone in Nainital, Kumaon Himalaya. *Palaeobotanist* **24**(3) : 215-244.

Gupta HP & Khandelwal A 1982. Late-Holocene palynology from the lake in Sat Tal Valley, district Nainital, Kumaon Himalaya. *Geophytology* **12**(2) : 313-321.

Gupta HP, Sharma C, Dodia R, Mandavia C & Vora AB 1984. A palynological interpretation of climatic changes in Kashmir (India) during the last three million years. *In* : Whyte RO (Editor)—*The evolution of the East Asian environment* **2** : 553-562. Centre of Asian Studies, Univ. Hong Kong.

Sharma C 1985. On the Late-Quaternary vegetational history in Himachal Pradesh-3. Parasram Tal. *Geophytology* **15**(2) : 206-218.

Sharma C & Chauhan MS 1988. Studies in the Late-Quaternary vegetational history in Himachal Pradesh-4. Rewalsar Lake-II. *Pollen Spores* **30**(3-4) : 395-408.

Sharma C & Gupta A 1995. Vegetational history of Nachiketa Tal, Garhwal Himalaya, India. *J. Nepal geol. Soc.* **10** : 29-34.

Sharma C & Gupta HP 1985. Palynostratigraphy and palaeoenvironments: Krachipathra, Lower Karewa, Kashmir. *In :* Agrawal DP *et al.* (Editors)—*Climate and geology of Kashmir: the last 4 million years. Current trends in geology* **6** : 91-95. Today & Tomorrow's, Printers & Publishers, New Delhi.

Sharma C, Gupta HP, Dodia R & Mandavia C 1985. Palynostratigraphy and palaeoenvironment: Dubjan, Lower Karewa, Kashmir. *In* : Agrawal DP *et al.* (Editors)—*Climate and geology of Kashmir: the last 4 million years. Current trend in geology* **6** : 69-73. Today & Tomorrow's Printers & Publishers, New Delhi.

Sharma C & Singh G 1974a. Studies in the Late-Quaternary vegetational history in Himachal Pradesh-1. Khajiar Lake. *Palaeobotanist* **21**(2): 144-162.

Sharma C & Singh G 1974b. Studies in the Late-Quaternary vegetational history in Himachal Pradesh-2. Rewalsar Lake. *Palaeobotanist* **21**(3) : 321-338.

Vishnu-Mittre, Gupta HP & Robert R 1967. Studies of the Late-Quaternary vegetational history of Kumaon Himalaya. *Curr. Sci.* **36**(2) : 539-540.

Palynological recognition of the Karharbari-Barakar Formations in the sub-surface sediments of Wardha Coalfield, Maharashtra, India

Ananta Prasad Bhattacharyya

Bhattacharyya AP 1997. Palynological recognition of the Karharbari-Barakar Formations in the sub-surface sediments of Wardha Coalfield, Maharashtra, India. *Palaeobotanist* **46** (1, 2) : 217-219.

Palynological investigation of coal and associated sediments in two bore-holes MWS-23 and MWS-33 from Wardha Valley Coalfield, Maharashtra has been done. Results indicate the presence of Upper Karharbari and Lower Barakar Formations in the coalfield. .

Key-words—Palynostratigraphy, Karharbari Formation, Barakar Formation, Lower Permian, Wardha Valley, India.

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सारांश

महाराष्ट्र (भारत) मे वर्धा कोयला-क्षेत्र के उपसतही अवसादों मे करहरबारी-बराकार शैल-समूहो की विद्यमानता के परागाणविक प्रमाण

अनन्त प्रसाद भट्टाचार्य

महाराष्ट्र में वर्धा घाटी कोयला-क्षेत्र के एम-डब्ल्यू-एस० 23 एवं 33 नामक दो वेध-छिद्रों के कोयले और सहयुक्त अवसादों का परागाणविक अन्वेषण किया गया। उपलब्ध परिणामों से इस कोयला-क्षेत्र में उपरि करहरबारी एवं अधरि बराकार शैल-समूहों की उपस्थिति व्यक्त होती है।

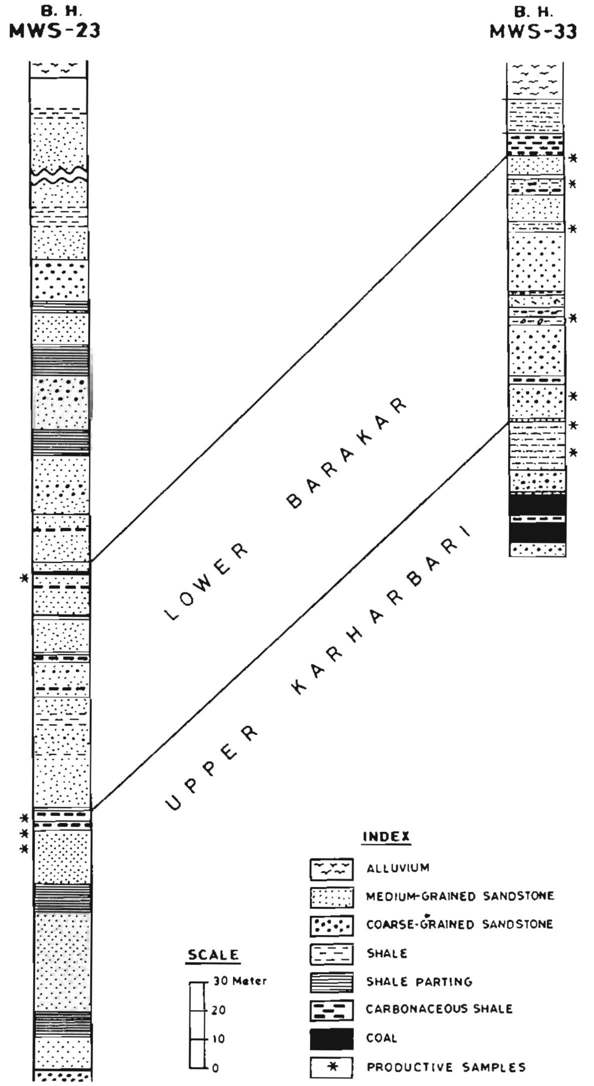
THE Wardha Valley Coalfield, north-western extension of the Godavari Valley coalfields, preserves a rock sequence from Early Permian to Early Cretaceous. The coal-bearing tracts under active mining are confined to a narrow peripheral part along the western fringes of the basin where coal occurs at shallower depths. The geology of the coal-bearing eastward tract on dip side is little known due to widespread overlap of Kamthi sediments. The succession of the Gondwana sequence in the Wardha Valley Coalfield is given below (after Raja Rao, 1982) :

Maleri Formation
----------Unconformity------------
Kamthi Formation
----------Unconformity------------
Barakar Formation
Talchir Formation
----------Unconformity------------
Sullavi Formation
Pakhal Formation

Palynofossils from the Permian of Chandrapur District have been described by Lele (1984), Agashe and Chitnis (1970), Agashe and Geetha (1979), Agashe and Suresh (1979) and Agashe *et al.* (1984). Anand-Prakash and Khare (1970) reported palynology and petrographic characters of the working coal seams.

The present palynological investigation has been carried out on the coal and associated sediments in the two bore holes MWS-23 and MWS-33 drilled by Mineral Exploration Corporation Limited. Both bore holes, according to MECL, pass through Kamthi, Maitur and Barakar Formations (Text-figure 1). MECL, supplied shale and carbonaceous shales of the drill cores for palynological investigation to acertain the age of these sediments.

Lithologically there is no marked distinction for the Karharbari and Barakar sediments in the subsurface samples but the palynological investigation supports their distinct presence.



Text-figure 1—Showing details of lithology of Bore-holes MWS-23 and MWS-33.

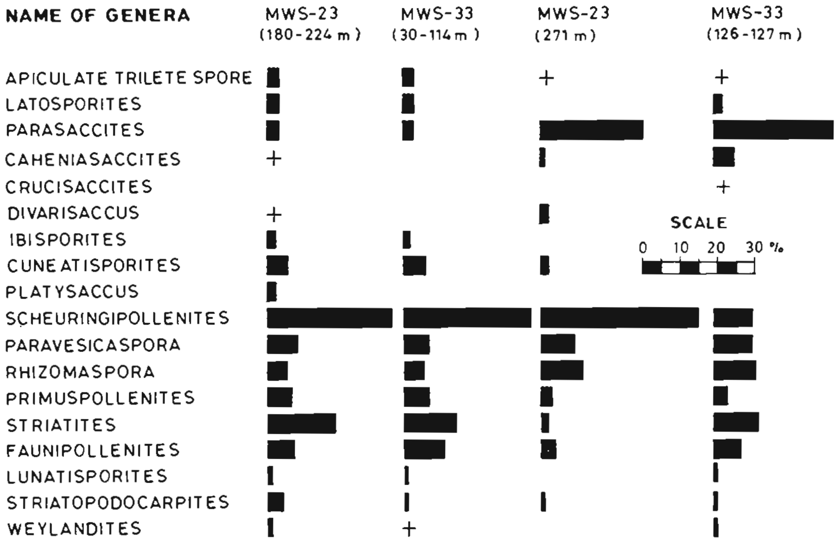
PALYNOLOGICAL ASSEMBLAGES

Studies of the composition of palynofossils (Text-figure 2) indicate two distinct assemblages. They have been described as Assemblage A and B.

Assemblage A–In the bore-hole MWS-33, at the depth of 126-127 m, a palynofossil assemblage is found showing 33 per cent of *Parasaccites* in association with non-striate bisaccate pollen (52%). The non-striate bisaccates are represented by *Scheuringipollenites, Paravesicaspora, Rhizomaspora* and *Primuspollenites*. The Karharbari forms—*Crucisaccites* and *Caheniasaccites* are also present. The striate bisaccate forms constitute only 10 per cent of the assemblage.

In the bore-hole MWS-23, at the depth 271 m, a comparable assemblage is known which shows the presence of 28 per cent radial monosaccate *Parasaccites* in association with nonstriate bisaccates (65%). The striate bisaccates are only 5 per cent of the assemblage. In the overall composition both the assemblages resemble each other, particularly in the predominance of *Parasaccites* and non-striate bisaccates, and paucity of striate bisaccates.

Assemblage B–In bore holes MWS-33 (at the depth of 30-114 m) and MWS-23 (at a depth of 18-224 m), the palynological assemblages are nearly alike in composition. The assemblage contains apiculate trilete spores, monolete spores, nonstriate bisaccate pollen, striate bisaccate pollen and sulcate



Text-figure 2—Distribution of pollen and spores in Bore-holes MWS-23 and MWS-33 from Wardha Valley Coalfield.

forms. Nonstriate bisaccate pollen are nearly 55 per cent, of these the most common form is *Scheuringipollenites* (34%). The striate bisaccates are 18 per cent of the total. Besides, the assemblge has nearly each of 5 per cent apiculate trilete spores, monolete *Latosporites* and radial monosaccate pollen *Parasaccites.*

COMPARISON

Bharadwaj (1974) on the basis of qualitative and quantitative occurrence of *Sporae dispersae* suggested a palynological zonation of the Lower Gondwana. According to his scheme the Assemblage - A recorded in the bore holes is palynologically comparable to that of the Upper Karharbari Formation in the presence of radial monosaccates and non-striate disaccate rich assemblage. On the other hand, the Assemblage B compares to Barakar-I palynozone having a non-striate and striate bisaccate rich assemblage. On the basis of palynoassemblage, the sediments at the depth of 180-224 m in MWS-23 correlate with that from the depth 30-114 m in MWS-33 and represent the Lower Barakar Formation. The sediments at depth of 126-127 m in MWS-33 correlate with those at the depth of 271 m in MWS-23 and thus represent the Karharbari Formation.

REFERENCES

Agashe SN & Chitnis SR 1972. Palynology of a Permian coal seam from Hindustan Lalpeth Colliery, Chandrapur District, Maharashtra, India. *In* : Ghosh AK *et al.* (Editors)—*Proceedings of the Seminar on Paleopalynology and Indian Stratigraphy* : 21-29.

Agashe SN & Geetha KR 1979. Palaeopalynological studies of Lower Gondwana strata with particular reference to certain coal seams from Kamptee Coalfield, Nagpur District, Maharashtra State. *Geophytology* 9(1-2) : 116-123.

Agashe SN, Gowda PRN, Suresh FC & Geetha KR 1984. Recent advances in palaeobotanical studies on Lower Gondwana strata of Chandrapur District, Maharashtra. *In* : Sharma AK *et al.* (Editors)—*Proceedings of Symposium on Evolutionary botany and biostratigraphy, Calcutta 1979. Current Trends In Life Sciences* **10** : AK Ghosh Commemoration Vol. : 369-382. Todays & Tomorrow Printers & Publ., New Delhi.

Agashe SN & Suresh FC 1979. Palaeopalynological studies on the Lower Gondwana strata with particular reference to coal bearing beds in Chandrapur District, Maharashtra State, India. *Geophytology* 9(1-2) : 121-129.

Anand-Prakash & Khare RC 1976. Petrology and palynostratigraphy of some Wardha Valley coals, Maharashtra, India. *Palaeobotanist* **23**(2) : 124-138.

Bharadwaj DC 1974. Palynological subdivision of Damuda Valley. *In* : Surange KR, Bharadwaj DC & Lakhanpal RN (Editors)—*Aspects & appraisal of Indian palaeobotany* : 392-396. Birbal Sahni Institute of Palaeobotany, Lucknow.

Lele KM 1984. Studies in the Talchir flora in India-12. Basal Talchir palynofossils from Penganga Valley and their biostratigraphic value. *In* : Sharma AK *et al.* (Editors)— *Proceedings of Symposium on Evolutionary botany and biostratigraphy, Calcutta 1979. Current trends in life sciences* **10** : AK Ghosh Commemoration Vol. : 262-267. Today & Tomorrows Printers & Publ., New Delhi.

Raja Rao CS 1982. Coal resources of India (Tamil Nadu, Andhra Pradesh, Orissa and Maharashtra). *Bull. geol. Surv. India,* ser. A **40**(2) : 184-194.

Comparative study between *Ginkgoites tigrensis* Archangelsky and *Ginkgo biloba* Linn. leaves

Liliana Villar de Seoane

Liliana Villar de Seoane 1997. Comparative study between *Ginkgoites tigrensis* Archangelsky and *Ginkgo biloba* Linn. leaves. *Palaeobotanist* 46(3) : 1-12.

A comparative study between leaves of *Ginkgoites tigrensis* Archangelsky 1965, which belong to the family Karkeniaceae and those of *Ginkgo biloba* L. included within the family Ginkgoaceae is realized, using light microscopy (LM) and scanning and transmission electron microscopy (SEM and TEM). The fossil cuticles occur in the sediments located in Baqueró Formation (Lower Cretaceous), Santa Cruz Province, Argentina. The morphological, anatomical and ultrastructural analyses indicate great similarities between fossil and extant leaves.

Key-words—Ginkgoalean leaves, Baqueró Formation, Lower Cretaceous, Santa Cruz Province, Argentina.

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RESUMEN

En el presente trabajo se realiza el estudio comparado entre hojas de la especie fósil *Ginkgoites tigrensis* Archangelsky 1965, perteneciente a la familia Karkeniaceae, y de la especie actual *Ginkgo biloba* L. perteneciente a la familia Ginkgoaceae, ambas familias incluidas dentro del orden Ginkgoales. Para efectuar el análisis cuticular se utilizó microscopía óptica (MO) y microscopía electrónica de barrido y transmisión (MEB y MET). Los restos fósiles analizados fueron extraídos de sedimentitas organógenas hlladas en la Formación Baqueró de la Provincia de Santa Cruz (Cretácico Inferior). Los resultados obtenidos con los análisis realizados, han demostrado la existencia de grandes semejanzas morfológicas, anatómicas y ultraestructurales entre las hojas de las especies *Ginkgoites tigrensis* y *Ginkgo biloba*.

सारॉंश

गिन्क्गोइटिस टाइग्रेन्सिस आर्केन्जेल्सकी एवं *गिन्क्गो बाइलोबा* लिन्नॅयस की पत्तियों का तुलनात्मक अध्ययन

लिलिआना विलर दॅ सिओने

प्रकाश सूक्ष्मदर्शी, क्रमवीक्षण एवं पारगमन इलेक्ट्रान सूक्ष्मदर्शी के अध्ययन के आधार पर *गिन्क्गोइटिस टाइग्रेन्सिस* आर्केन्जेल्सकी 1965 (कार्केनिएसी कुल) एवं *गिन्क्गो बाइलोबा* लिन्नॅयस (गिन्क्गोएसी कुल) की पत्तियों का तुलनात्मक अध्ययन किया गया है। ये अश्मित उपचर्म अर्जेन्टीना में सान्ता क्रुज़ प्रदेश की बाकेरो शैल-समूह के अवसादों से प्राप्त हुई थीं। आकारिकीय, शारीरीय एवं परासंरचनात्मक विश्लेषण से अश्मित एवं वर्तमान दोनों ही प्रकार की पत्तियों में काफी समानता देखने को मिली है।

THE generic concept of *Ginkgo* (Lower Jurassic to modern times) and *Ginkgoites* (Upper Triassic to Lower Cretaceous) in the sense of Harris (1935) includes recent and fossil specimens of congeneric state in the genus *Ginkgo* L.

Seward (1919) founded the genus *Ginkgoites* for fossil leaves belonging to vegetative remains generically identical with the modern genus *Ginkgo* or closely related to it. A change of concept has been undertaken by Florin (1936) who stressing the importance of anatomical structures of the epidermis, did not consider to apply the name of *Ginkgoites* as Seward did, merely because the plant was fossil. According to Florin, the generic name of *Ginkgoites* is used when the remains differ considerably from modern *Ginkgo*.

The purpose of this paper is to describe the morphology, anatomy and ultrastructure of the leaves of the fossil species *Ginkgoites tigrensis* Archangelsky 1965 (Karkeniaceae) and to compare them with those of the extant species *Ginkgo biloba* L. (Ginkgoaceae), using light microscopy (LM) and scanning and transmission electron microscopy (SEM and TEM). Both families belong to the order Ginkgoales. The species *Ginkgoites tigrensis* was described by Archangelsky (1965) with light microscopy (LM).

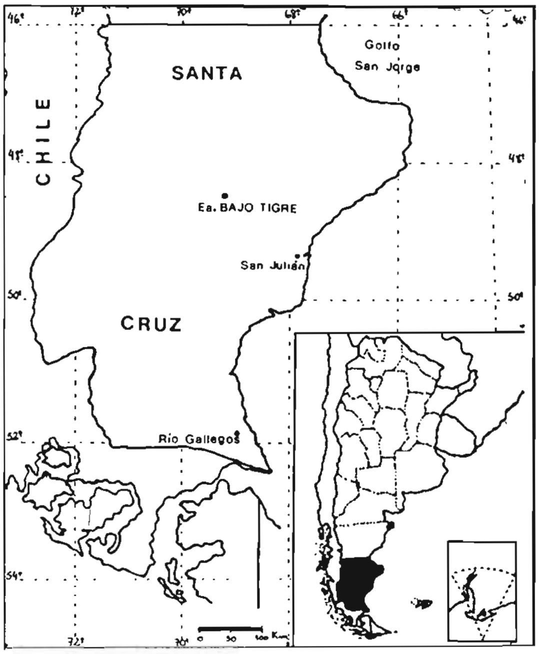
In Argentina, ginkgophyte leaves have been recorded from the Lower Permian of Chubut Province (Cúneo, 1987). The genus *Ginkgoites* occurs in the Triassic of Neuquén and Mendoza Province (Frenguelli, 1946), the Lower Jurassic of Chubut Province (Feruglio, 1933), the Upper Jurassic and Lower Cretaceous of the Lago San Martín, Santa Cruz Province and Graham Land, Antarctica (Halle, 1913), and in the Tertiary strata of Chubut Province (Archangelsky, 1965) and Río Negro Province (Berry, 1938). The studied cuticles were found in the Baquer6 Formation, Santa Cruz Province, associated with seed-bearing structures belonging to the species *Karkenia incurva* Archangelsky 1965.

Among living plants there is no more striking example of a species which recalls the past than *Ginkgo biloba* that occurs naturally in Chekiang Province, China; only known in cultivation in Japan, Korea and Manchuria where it is used principally around temples. Used as a street tree in Japan and introduced into Europe from Japan in 1727 (Gifford & Foster, 1989).

For the first time, Kaempfer (1712) described this tree and gave the generic name *Ginkgo*. In 1690, he travelled to Orient, where he saw "an uncommon tree in Europe, with adiantiform leaves". In 1771, Linnaeus adopted the genus given by Kaempfer and established the species *G. biloba*. In 1900, Seward and Gowan realized a complete description of the "Maidenhair tree". More recently, the species *Ginkgo biloba* was studied by Chamberlain (1935), Sporne (1965), Napp-Zinn (1966), Gifford and Foster (1989) and Page (1990) with general descriptions. Krüssmann (1985) analyzed its anatomy in relation with the environment.

MATERIAL AND METHODS

The fossil materials occur in the Baquer6 Formation, Estancia Bajo Tigre. This Formation is located to the south of the Deseado River, between the parallels 47°-49° and the meridians 68°-69° 30', Santa Cruz Province, Argentina (Text-figure 1). In the Estancia Bajo Tigre the fossil plants occur in lenticular beds of brownish colour. Paleobotanical and palynological studies (Archangelsky & Gamerro, 1966a, 1966b) for the Baquer6 Formation suggested a Lower Cretaceous age, 120 million years (Archangelsky, 1967). Fossils are mainly represented by well preserved leaves. Cuticles were prepared for both light and electron microscopy. The material was easily separated from the matrix and cleaned with dilute sodium hypochlorite.



Text-figure 1—Map showing the location of the Estanicia Bajo Tigre (Baquer6 Formation).

PLATE 1

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1-6. *Ginkgoites tigrensis* Archangelsky

1. General view of the leaves. BA Pb 11557. Scale bar = 1 cm.
2. Internal abaxial epidermis. BA Pb MEB 50. Scale bar = 100 µm.
3. Stomata (arrows) on the external abaxial epidermis. BA Pb MEB 50. Scale bar = 50 µm.
4. Details of cells in the internal adaxial epidermis. BA Pb MEB 50. Scale bar = 50 µm.
5. Details of a stoma. BA Pb MEB 50. Scale bar = 10 µm.
6. Details of guard cells. BA Pb MEB 50. Scale bar = 10 µm

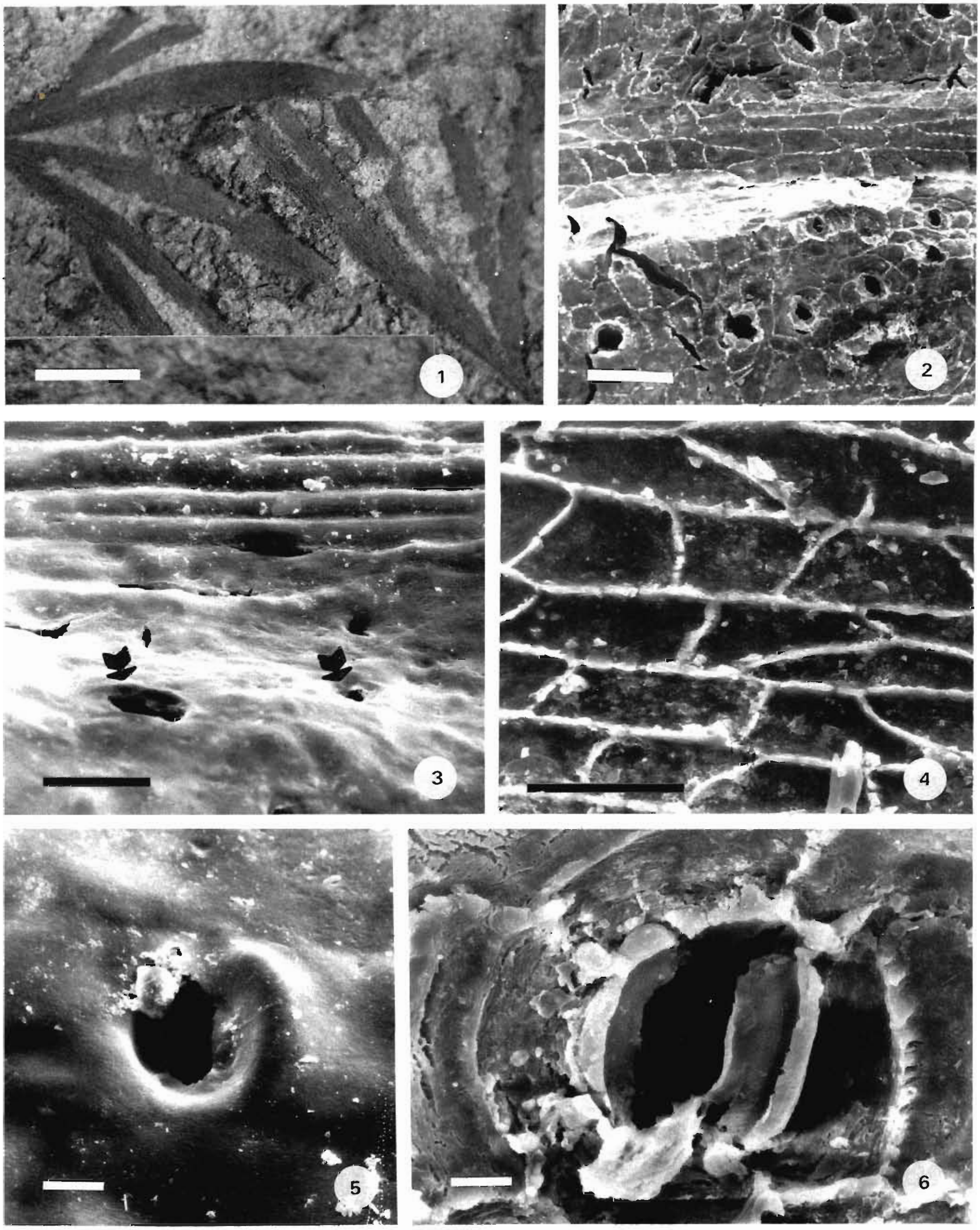


PLATE 1

The recent material was collected at the Buenos Aires Botanical Garden. Fossil and extant leaves were mounted in glycerine-jelly for observation with light microscopy, or directly on cylindrical stubs and coated with gold-palladium for scanning electron microscopy (SEM). Observations were made with a JEOL T-100 SEM at the La Plata Natural History Museum.

For transmission electron microscopy (TEM) cuticle fragments were embedded in Spurr low viscosity resin (Spurr, 1969). Sections were cut with a diamond knife and mounted in single hole grids coated with Formvar. Observations were made on a Zeiss EM 109 of the Electronic Microscopy Service at the Cellular Biology Department, Medicine Faculty, Buenos Aires University.

The fossil type specimens are deposited at the Paleobotanical Collection of the Buenos Aires Natural History Museum (BA Pb) and the recent specimens at the Plant Biology Department, Natural Sciences Faculty, Buenos Aires University. Hickey's classification (1974) was used for the morphological descriptions, whilst terminology of Holloway (1982a, 1982b) and Lyshede (1978, 1982) was used for the ultrastructural analysis.

SYSTEMATIC DESCRIPTION

Family—Karkeniaceae

Genus—*Ginkgoites* Seward 1919

Type species—*Ginkgoites obovata* (Nathorst) Seward 1919

Ginkgoites tigrensis Archangelsky 1965

Pl. 1, figs 1-6; Pl. 2, figs 1-4

Ginkgoites tigrensis Archangelsky, *Bull. Brit. Mus. (Nat. Hist.) Geol.*, 10 (5), pp. 125-128, pl. 3, fig. 22 and pl. 4, figs 23-26 (1965).

Specimens studied—BA Pb 11556, 11557, 11558, 11559, 11560, 11561, 11581, 11582, 11583, 11584, 11585, 11586, 11587 and 11588; BA Pb Pm 237, 238, 239, 240 and 253; BA Pb MEB 50; BA Pb MET 153.

Locality—Meseta Baqueró, Estancia Bajo Tigre.

Stratigraphic horizon—Baqueró Formation, Lower Cretaceous.

Emended diagnosis—Ultrastructurally, the external wall of the epidermis is composed by a cuticular membrane and a cellular wall. A thin cuticle proper, a compact upper layer and a reticulate lower layer formed the cuticular membrane. Cellular wall with a lower electronic density.

Description—The leaves are simple and small to medium. They are flabelliform, up to 4.5 cm long and 5 cm wide. The laminae are divided in three to six segments. The segments are loriform, up to 4 cm long and 0.7 cm wide, united by only one decurrent base. They have rounded apex and straight margins (Pl. 1, fig. 1). The petioles are slender, up to 3 cm long and 0.1 cm wide. The veins radiate from the base, dichotomously forked, with a concentration of about 18-20 veins per centimetre, up to 14 present in each segment. Two veins seem to be present in the petioles.

The leaf surfaces are covered with epicuticular waxes. Adaxial epidermis has rectangular to isodiametric cells, 31-70 µm long and 18-26 µm wide. They often occur in rows, have microgranular surface, their walls are thickened and have irregular margins with sinuosities up to 2.5 µm wide (Pl. 1, fig. 4). Stomata absent on the petiole and the base of the lamina, but present on segments between veins. They are irregularly disposed.

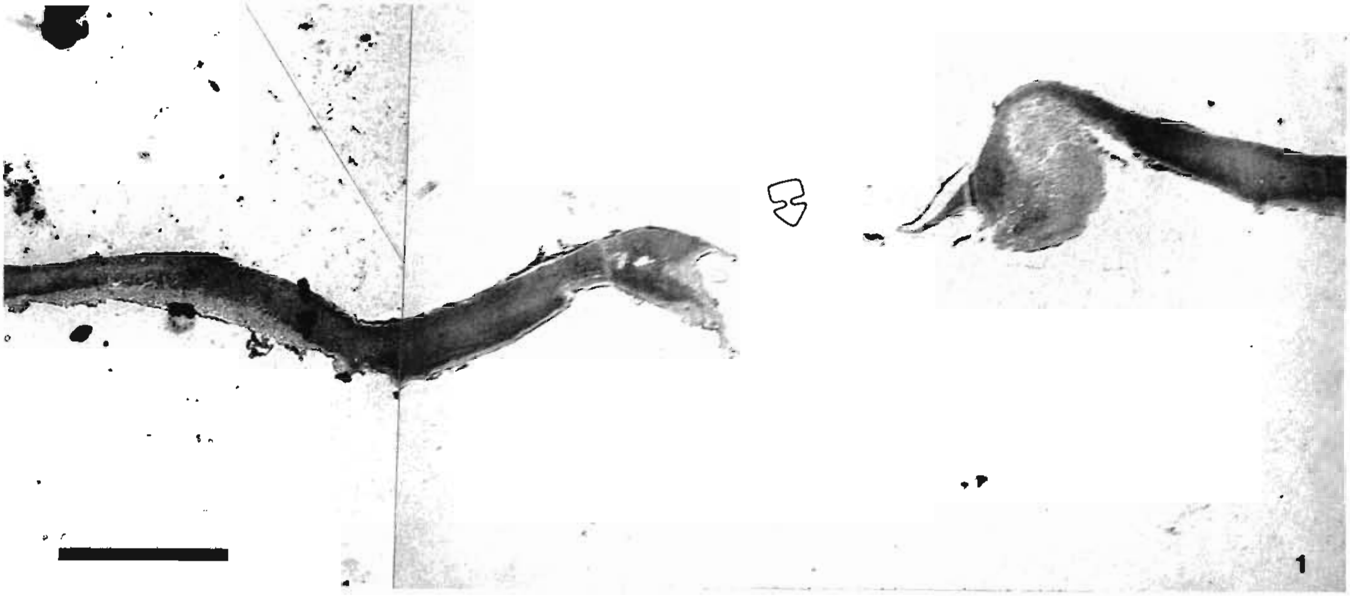
Abaxial epidermis has rectangular to isodiametric cells, 39-78 µm long and 18-34 µm wide. The cells have the same characters and disposition in the

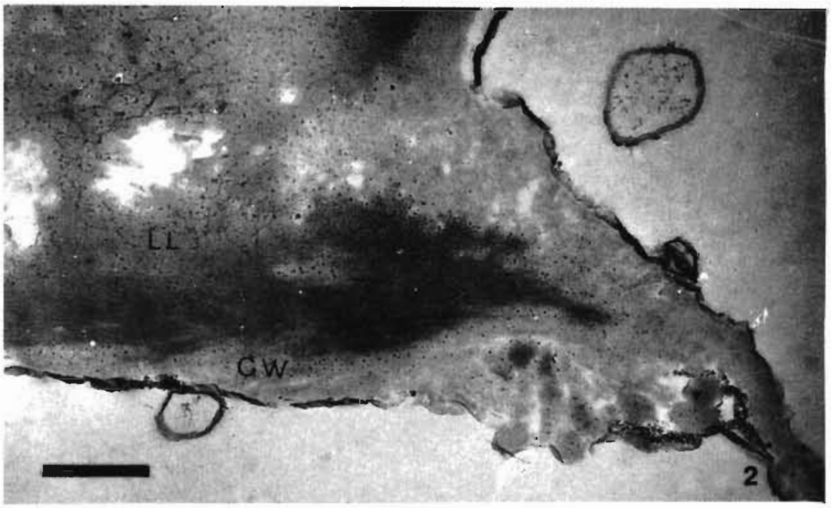
PLATE 2 ⟶

C = cuticle proper; UL = upper layer; LL = lower layer; CW = cellular wall.

1-4. *Ginkgoites tigrensis* Archangelsky

1. TS section of the external wall of the epidermis with stoma (arrow). BA Pb MET 153. Scale bar = 10 µm.
2. TS section of a stoma. BA Pb MET 153. Scale bar = 1 µm.
3. TS section of a periclinal wall. BA Pb MET 153. Scale bar = 1 µm.
4. TS section of the external wall of the epidermis. Detail. BA Pb MET 153. Scale bar = 1 µm.





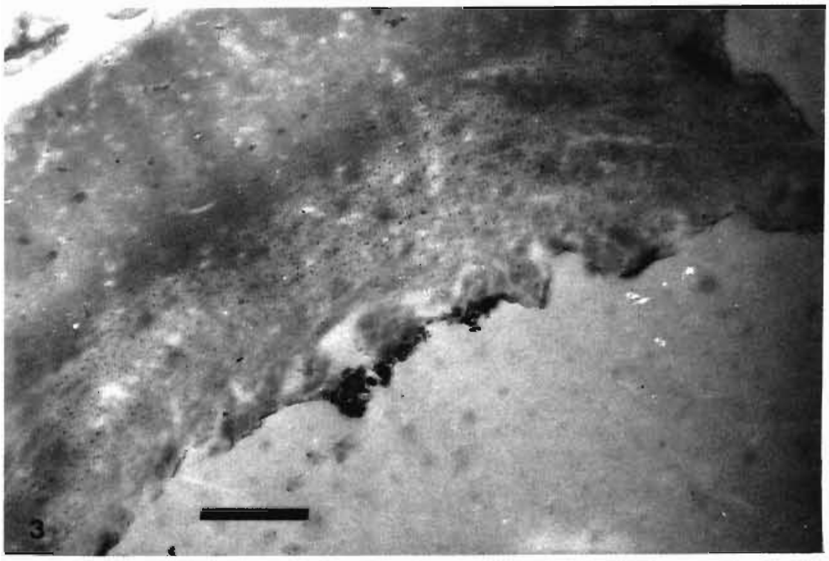


PLATE 2

adaxial epidermis, but the walls are more thin (Pl. 1, fig. 2).

Stomata are irregularly disposed (Pl. 1, fig. 3). Stomatal apparatus up to 62 μm in diameter and are circular or oval on both cuticles. They are actinocytic or tetracytic with 6 or 4 subsidiary cells, respectively. The subsidiary cells have striate walls that form a ring of 2-3 μm high surrounding the guard cells (Pl. 1, fig. 5). Guard cells slightly sunken in a pit and cutinized (Pl. 1, fig. 6).

Ultrastructurally, the external wall of the epidermis is composed by a cuticular membrane and a cellular wall (Pl. 2, fig. 1). The cuticle proper is 0.25 μm thick (Pl. 2, fig. 4), the upper layer is 1.0 μm thick, compact and homogeneous and the lower layer is 1.5 μm thick, slightly reticulate with thin channels irregularly distributed (Pl. 2, figs 2-4). The channels are anastomosed. Near the cellular wall they are parallel to the surface, but near the upper layer they may arch up to 90^0 and are perpendicular to the surface. Both layers have small and irregular holes (Pl. 2, figs 3, 4). The rest of the cellular wall is 1.5 μm thick and has a lower electronic density (Pl. 2, fig. 4). The anticlinal walls have an important development of the upper layer. The periclinal walls of the stomata have the lower layer very developed.

Comparisons—*Ginkgoites ticoensis* Archangelsky 1965, the other species described in the Baqueró Formation, differs from *Ginkgoites tigrensis* in shape, size and anatomical structures. *Ginkgoites ticoensis* has smaller leaves divided in 4 segments, smaller segments with 12 veins per centimetre, polygonal epidermal cells with a strong hollow papilla that not form rows and smaller stomata only present in the abaxial cuticle. Ultrastructurally, Taylor, W. *et al.* (1989) studied cuticle fragments of *Ginkgoites tigrensis* finding "approaching the outer cuticle surface, a well developed poly-lamellate region of 25-44 nm in overall extent". That poly-lamellate region has not been found in the cuticles described in the present paper.

Ginkgoites digitata (Brgn.) from the Lower Jurassic of Chubut Province, differs in having entire leaves, bilobed or divided in several segments (Feruglio, 1933); *Ginkgoites patagonica* Berry 1938 from the Lower Tertiary of Neuquén Province, has leaves deeply divided in several segments; *Ginkgoites crassipes* Feistmantel from the Lower Permian of Chubut Province, differs in having entire leaves; *Ginkgoites eximia* Feruglio 1942 from Piedra Shotel, Chubut Province (Lower Jurassic), has entire and bilobed leaves with long petioles; *Ginkgoites taeniata* (Geinitz) Frenguelli 1946 from the Triassic of Neuquen Province, has small leaves divided in few segments, small stomata only present in the abaxial cuticle and few stomata and papillae in the adaxial cuticle; and *Ginkgoites truncata* Frenguelli 1946 from Potrerillos Basin, Mendoza Province (Upper Triassic), differs in having entire and triangular leaves with truncate apex.

Family—Ginkgoaceae

Genus—*Ginkgo* Linnaeus 1771

Type species—*Ginkgo biloba* Linnaeus 1771

Ginkgo biloba Linn.

Pl. 3, figs 1-6; Pl. 4, figs 1-4

Description—The leaves are simple and small to medium. Laminae flabelliform, up to 8 cm wide, entire, but more frequently bilobed, or subdivided into several wedge-shaped lobes. Leaves with rounded apex slightly serrate, straight margins and decurrent base (Pl. 3, fig. 1). The petioles are slender, up to 3 cm long and 0.1 cm wide. The veins are radially disposed from the base. They are subparallel, dichotomously forked, with a concentration of about 18-20 veins per centimetre. Two veins are present in the petioles. The foliage leaves occur on long shoots or crowded at the apex of short shoots.

PLATE 3

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1-6. *Ginkgo biloba* L.

1. Leaf. BA 74784. Scale bar = 0.5 cm.
2. Details of adaxial epidermal cells. BA Pb MEB 51. Scale bar = 50 μm.
3. Stomata (arrows) on the abaxial epidermis. BA Pb MEB 51. Scale bar = 100 μm.
4. Details of the stomata (arrows). BA Pb MEB 51. Scale bar = 50 μm.
5. Details of the guard cells. BA Pb MEB 51. Scale bar = 10 μm.
6. Details of the subsidiary cells. BA Pb MEB 51. Scale bar = 10 μm.

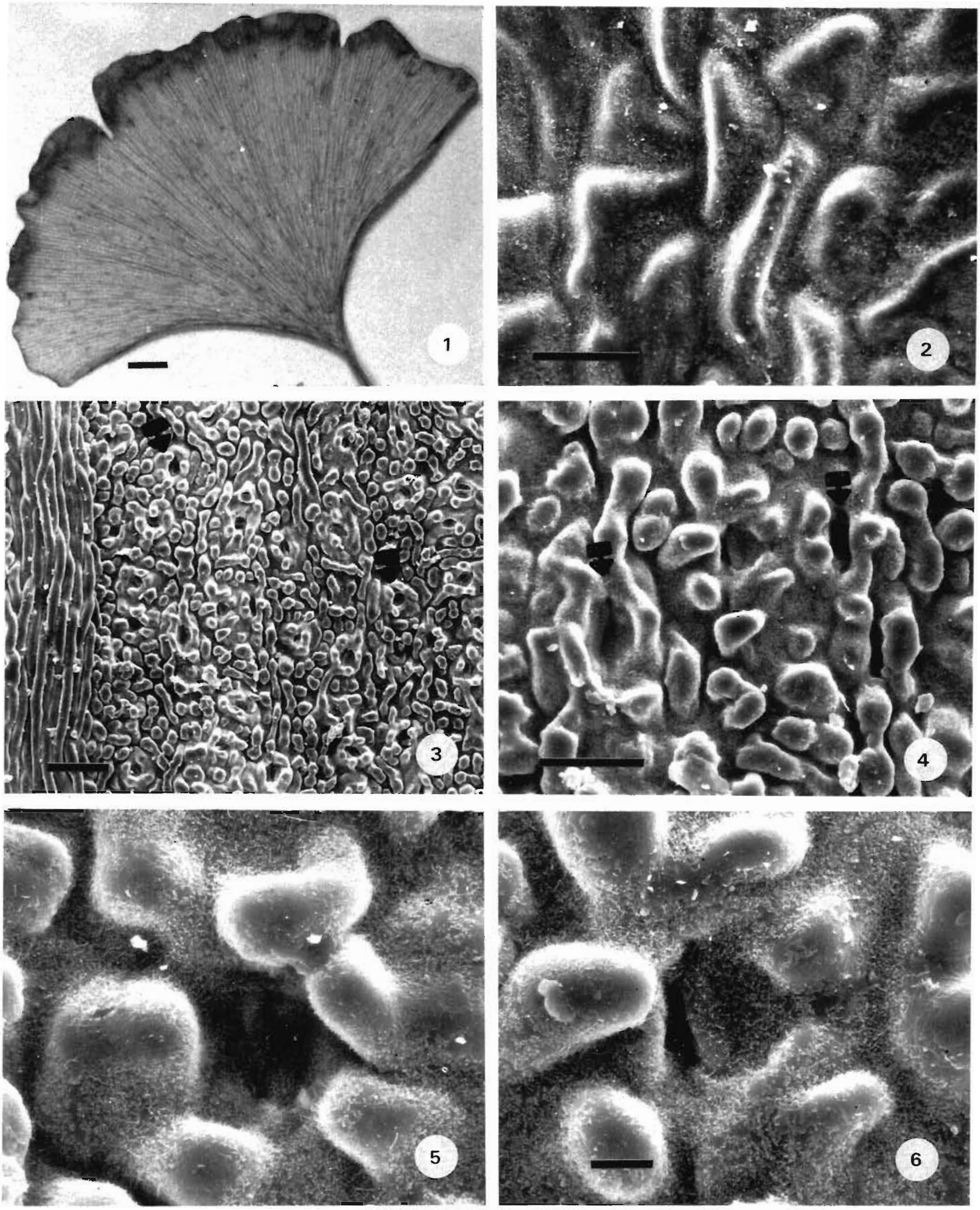

PLATE 3

Surface covered with abundant epicuticular waxes of thin and short fibrous aspect (Pl. 3, figs 5, 6). Adaxial and abaxial epidermis are formed by rectangular to polygonal cells irregularly disposed (Pl. 3, figs 2, 3). Their walls are slightly thickened and sinuous. Each abaxial epidermal cell forms one or two papillae of 17 µm in diameter and 15-28 µm height (Pl. 3, fig. 4).

Stomata on the abaxial epidermis, irregularly disposed between veins. Actinocytic stomatal apparatus, up to 90 µm in diameter, with 6 to 7 subsidiary cells (Pl. 3, figs 5, 6). Each subsidiary cell forms a papilla oriented to the pit. Guard cells sunken, with cuticular ridge surrounding the mouth (Pl. 3, figs 5, 6).

Ultrastructurally, the external wall of the epidermis is formed by a cuticular membrane and a cellular wall. A thin cuticle proper, a compact upper layer and a reticulate lower layer formed the cuticular membrane (Pl. 4, figs 1, 2). The cuticle proper is 0.25 µm thick; the upper layer, up to 0.75 µm thick, is compact and homogeneous (Pl. 4, fig. 4). The lower layer, up to 1.0 µm thick, is reticulate, with pectinaceous microchannels that are perpendicular to the surface. The cellular wall is lamellate, up to 2.0 µm thick, with superposed lamellae separated by translucent channels that anastomose, and are parallel to the surface (Pl. 4, fig. 4). The anticlinal walls have an important development of the upper layer (Pl. 4, fig. 3). The subsidiary and guard cells have a thick cuticle and their cellular wall is very lignified, especially the external periclinal wall.

DISCUSSION

The order Ginkgoales appears in the Upper Paleozoic. The oldest fossil materials from the Lower Permian were represented by different types of leaves which are referred to three genera: *Trichopitys* Saporta, *Phylladoderma* Zalessky and *Sphenobaiera* Florin.

During the Mesozoic, the Ginkgoales have their greatest prominence, especially in the Jurassic and Lower Cretaceous, their polymorphic leaves were grouped in two families, the Ginkgoaceae and the Phoenicopsiaceae. The family Ginkgoaceae was represented by *Ginkgo* L., *Ginkgoidium* Yokoyama, *Ginkgoites* Seward and *Baiera* F. Braun; whilst the family Phoenicopsiaceae was represented by *Phoenicopsis* Heer, *Culgoweria* Florin, *Windwardia* Florin, *Eretmophyllum* Thomas, *Stephenophyllum* Florin, *Pseudotorellia* Florin, *Arctobaiera* Florin, *Hartzia* Harris, *Czekanowskia* Heer, *Sphenobaiera* Florin and *Glossophyllum* Kräusel During the Upper Cretaceous, the order Ginkgoales begins to disappear and in the Lower Cenozoic the group was only represented by the family Torelliaceae with the genera *Torellia* Heer (Tralau, 1968).

The oldest fossils belonging to the genus *Ginkgo* were found in the Lower Jurassic of Fergana in the southern Asiatic part of the Soviet Union, and were described as *G. digitata* (Brik, 1953; Vasiljevskaja, 1956). During the Lower Cretaceous, the polymorphy in foliar remains indicates the rise of new species. At the Middle Tertiary, the genus retained its circumpolar distribution, being known throughout Eurasia and Northern America. At the Upper Miocene, *Ginkgo* becomes to be extinct in North America and during the Pliocene the genus seems to be confined to Eurasia, taking place in China between the Upper Pliocene and the modern times.

At the beginning of the Mesozoic, there exist several lineages of Ginkgoales, characterized by different leaves and seed-bearing structures. Accord-

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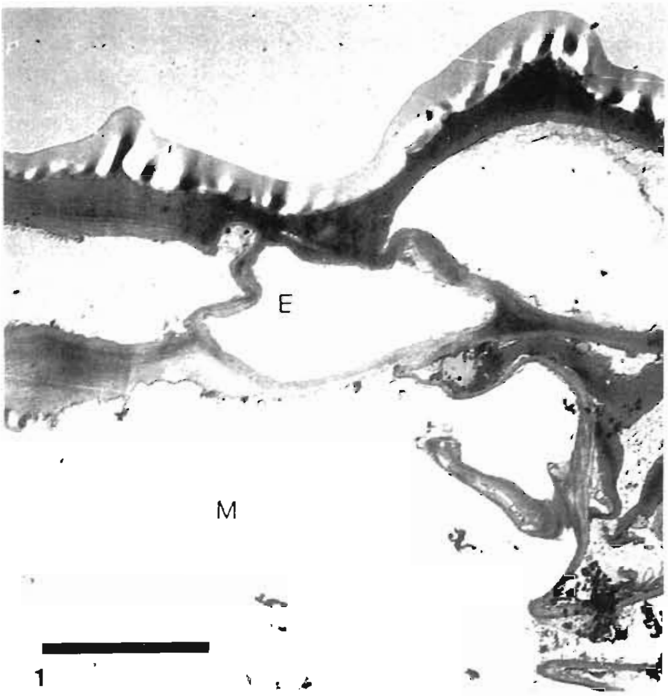
PLATE 4 ⟶

E = epidermis; M = mesophyll; C = cuticle proper; UL = upper layer;
LL = lower layer; CW = cellular wall.

1-4. *Ginkgo biloba* L.

1. TS section of the abaxial epidermis. BA Pb MET 161. Scale bar = 10 µm.
2. TS section of the abaxial epidermis. Detail. BA Pb MET 161. Scale bar = 1 µm.
3. TS section of an anticlinal wall (arrows). Detail. BA Pb MET 161. Scale bar = 1 µm.
4. TS section of the external wall of the epidermis. Detail. BA Pb MET 161. Scale bar = 1 µm.



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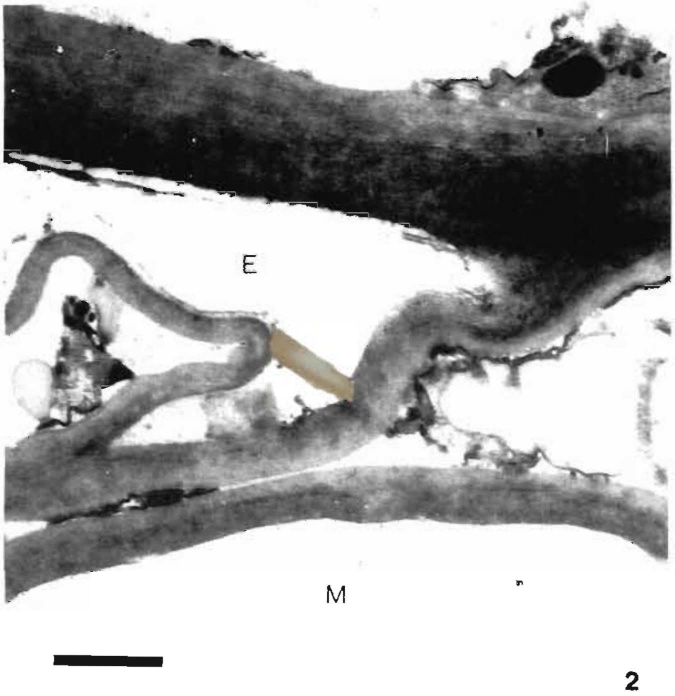

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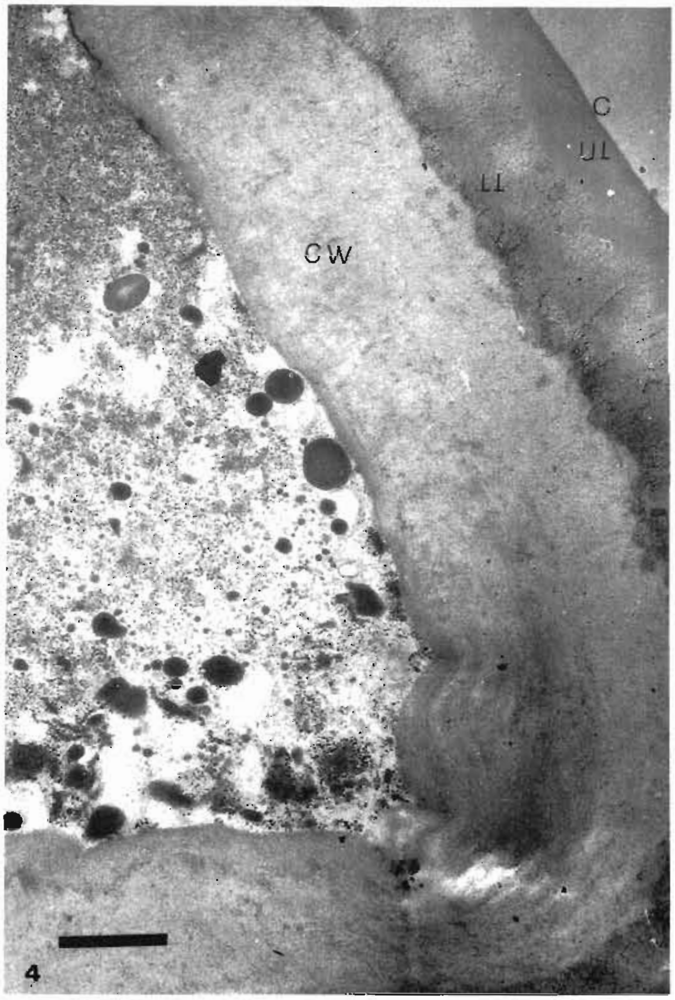

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PLATE 4

ing to the inflorescence associated, the leaves were re-grouped in four different families, such as Trichopityaceae, Umaltolepidaceae, Karkeniaceae and Ginkgoaceae (Zhou Zhiyan,1991).

The Trichopityaceae was the oldest family and disappeared at the end of the Paleozoic; the Umaltolepidaceae and Karkeniaceae were Mesozoic families that disappeared in the Upper Cretaceous; and the Ginkgoaceae is the modern family with the only one living species *Ginkgo biloba.*

The family Trichopityaceae was represented by *Trichopitys heteromorpha* Saporta 1875 and Florin (1949) described the species *T. heteromorpha* from the Lower Permian of Lodêve (France), as vegetative shoots with leaves spirally arranged and divided in 4 to 8 segments. In their middle region the long shoots carry furcated ovulate shoots with 3 to 20 terminal, inverted and orthotropous ovules.

Krassilov (1970, 1972) studied the tafoflora from the Bureja River Basin of Siberia (Upper Jurassic-Lower Cretaceous). Within the order Ginkgoales, he described two different types of female inflorescences (*Karkenia* and *Umaltolepis*) and several types of leaves. *Umaltolepis vachrameevii* from the Talunjan Formation of this area (Upper Jurassic) was described as the Type species, but there is another species of *Umaltolepis, U. rarinervis* from the Ulgar Formation of the same area (Lower Cretaceous). This type of female reproductive organ consists of a stalk and a terminal bract. This bract is elongated, entire or divided into two lobes that abaxially had a single seed. These structures were associated to leaves of the *Pseudotorellia*-type, with laminae undivided, roundish apex and stomata on abaxial epidermis only. The other species *Karkenia asiatica* is composed of a central axis with erect or incurved ovules, densely packed and associated to leaves of *Eretmophyllum* Thomas and *Sphenobaiera*-type. *Eretmophyllum* has undivided leaves with roundish apex, stomata on abaxial epidermis only and rounded papillae whilst, *Sphenobaiera* has small leaves deeply lobed.

Stanislavsky (1971, 1973) described *Toretzia angustifolia* from the Upper Triassic of Novoraick Formation (Ukraine). The vegetative shoots bear buds covered with scales spirally arranged. 2 to 3 ovule-bearing organs are given off from the axils of bracts on the short shoots. The ovules are inverted. The genera *Umaltolepis* and *Toretzia* belong to the family Umaltolepidaceae and *Karkenia* to the family Karkeniaceae.

Zhou and Zhang (1988) described *Yimaia recurva* from the Middle Jurassic Yima Formation, Henan, Central China. The fertile shoots were composed of a peduncle and up to 9 terminal ovules which were large, sessile, contiguous, orthotropous but mostly recurved. *Yimaia* was associated to primary short shoots with *Baiera*-type leaves. These leaves were deeply divided into numerous narrow lobes, forming as a whole one third to one fourth of a circle.

Also, Zhou and Zhang (1988, 1989) described the species *Ginkgo yimaensis* from the Middle Jurassic Yima Formation of Henan, Central China. It differs from *G. biloba* L., in having more deeply divided laminae and normally more (2-4) seeds which were attached terminally to pedicels rather than directly to the peduncle as in the case of the extant species. The extant species has female flowers long stalked, solitary, axillary, with 2 opposing ovules at the end of the thickened stalk apex. The genera *Yimaia* and *Ginkgo* belong to the family Ginkgoaceae.

GENERAL CONCLUSIONS

The family Karkeniaceae was proposed by Krassilov 1970 and includes a single genus with two species from the Upper Jurassic and Lower Cretaceous strata of Siberia and Argentina. *Karkenia incurva* Archangelsky 1965 is the only ginkgoalean fossil known outside Laurasia. *Karkenia* was associated with sessile leaves during the Upper Jurassic and petiolate leaves during the Lower Cretaceous.

In the Baqueró Formation, the family Karkeniaceae is represented by the leaves of *Ginkgoites tigrensis* and the associated ovule-bearing organ *Karkenia incurva.* This structure is composed of a central axis and up to 100 small, incurved and orthotropous ovules, densely packed. On the basis of the close relationship between the Karkeniaceae and Ginkgoaceae, the genus *Ginkgoites* was compared with the extant genus *Ginkgo.*

Morphologically, the leaves of fossil and extant genera are different. The fossil leaves are smaller and divided in several segments whilst, the extant leaves are longer and entire, but more frequently bilobed or subdivided into several wedge-shaped lobes.

The anatomical analysis between *Ginkgoites* and *Ginkgo* has indicated several affinities. The two genera have fan-shaped leaves with veins radially disposed from the base, epicuticular waxes and rectangular to polygonal epidermal cells with sinuous and thick walls. The fossil genus has a smooth epidermal surface and actinocytic or tetracytic stomatal apparatus with a ring surrounding the guard cells whilst, the extant genus has a papillose epidermal surface and actinocytic stomatal apparatus with papillae oriented to the pit.

Ultrastructurally, the comparison of the external wall of the epidermis between *Ginkgoites* and *Ginkgo* has demonstrated that both the genera have a thin cuticle proper, a compact and homogeneous upper layer and a reticulate lower layer. However, *Ginkgoites* has thicker upper and lower layers than *Ginkgo.* The existence of morphological, anatomical and ultrastructural similarities in both of the fossil and living genera corroborates a close relationship between the Karkeniaceae and Ginkgoaceae leaves.

ACKNOWLEDGEMENTS

Thanks are due to Dr Sergio Archangelsky for useful comments and providing the fossil material; to Dr Elena Ancibor for valuable discussions; to Isabel Farías for technical assistance in the preparation of materials for TEM; La Plata Natural History Museum for the SEM and Cellular Biology Department (Medicine, UBA) for the TEM.

REFERENCES

Archangelsky S 1965. Fossil Ginkgoales from the Ticó flora, Santa Cruz Province, Argentina. *Bull. Brit. Mus. (Nat. Hist.) Geol.* **10**(5): 119-137.

Archangelsky S 1967. Estudio de la Formación Baqueró, Cretácico Inferior de Santa Cruz, Argentina. *Rev. Mus. La Plata (N.S.) Pal.* **5**: 63-171.

Archangelsky S & Gamerro JC 1966a. Estudio palinológico de la Formación Baqueró (Cretácico), provincia de Santa Cruz. II. *Ameghiniana* **4**(6): 201-209.

Archangelsky S & Gamerro JC 1966b. Estudio palinológico de la Formación Baqueró (Cretácico), provincia de Santa Cruz. III. *Ameghiniana* **4**(7): 229-236.

Berry EW 1938. Tertiary flora from the Río Pichileufú, Argentina. *Special Paper Geol. Soc. Americana* **12**: 1-140.

Brik MJ 1953. *The Mesozoic flora of the Vostotjno-Fergana coal basin.*

Cúneo R 1987. Sobre la presencia de probables Ginkgoales en el Pérmico Inferior de Chubut, Argentina. *Actas VII Simposio Argentino Paleobot. Palinol.* : 47-49. Buenos Aires.

Chamberlain J 1935. *Gymnosperms structure and evolution.* The University of Chicago Press, Chicago.

Feruglio E 1933. Fossili Liassici della Valle del Rio Genua (Patagonia). *In: Giorn. di Geologia (Ann. R. Mus. Geol. Bologna)* **9**: 1-64. Imola.

Feruglio E 1942. La Flora Liásica del Valle del Río Genoa. Ginkgoales et Gymnospermae incertae sedis. *Notas del Museo de La Plata. Paleontol.* **7**(40): 93-110.

Florin R 1936. I. Die fossilen Ginkgophyten von Franz-Joseph-Land nebst Erörterungen über vermeintliche Cordaitales mesozoischen Alters, and III. Allgemeiner Teil. *Palaeontographica* **B81-82**.

Florin R 1949. The morphology of *Trichopitys heteromorpha* Saporta, a seed plant of Palaeozoic age, and the evolution of the female flowers in the Ginkgoinae. *Acta Horti Bergiani* **15**(5): 79-109.

Frenguelli J 1946. La Flora del Gondwana Superior en la Argentina. *Notas del Museo de La Plata. Paleontol.* **11**(87): 101-127.

Gifford EM & Foster AS 1989. *Morphology and evolution of vascular plants.* Freeman WH (Editor). New York.

Halle TG 1913. Some Mesozoic plant-bearing deposits in Patagonia and Tierra del Fuego and their floras. *K. svensk. VetenskAkad. Handl.* **51**(3): 1-58.

Harris TM 1935. The fossil flora of Scoresby Sound, East Greenland, 4. Ginkgoales, Coniferales, Lycopodiales and isolated fructifications. *Medd. Grönland* **112**, 1.

Hickey L 1974. Clasificación de la arquitectura de las hojas de Dicotiledóneas. *Bol. de la Soc. Arg. de Bot.* **16**(1-2): 1-150.

Holloway PJ 1982a. Structure and histochemistry of plant cuticular membranes: an overview. *In* : Cutler DF, Alvin KL & Price CE (Editors)—*The plant cuticle* : 1-31. London.

Holloway PJ 1982b. The chemical constitution of plant cutins. *In* : Cutler DF, Alvin KL & Price CE (Editors)—*The plant cuticle*: 45-85. London.

Kaempfer L 1712. *Amaenitates exoticae.*

Krassilov VA 1970. Approach to the classification of Mesozoic "Ginkgoalean" plants from Siberia. *Palaeobotanist* **18**: 12-19.

Krassilov VA 1972. *Mesozoic flora from the Bureja River (Ginkgoales and Czekanowskiales).* Moskow.

Krüssmann G 1985. *Manual of cultivated conifers.* Hans-Dieter Warda (Editor), Oregon.

Linnaeus CA 1771. *Mantissa Plantarum.* Holmiae.

Lyshede OB 1978. Studies on outer epidermal cell walls with microchannels in a xerophytic species. *New Phytologist* **80**: 421-426.

Lyshede OB 1982. Structure of the outer epidermal wall in xerophytes. *In* : Cutler DF, Alvin KL & Price CE (Editors)—*The plant cuticle*: 87-97. London.

Napp-Zinn K 1966. Anatomie des Blattes. I. Blattanatomie der Gymnospermen. *Handbuck der Pflanzenanatomie.* 2nd Edn. Berlin.

Page CN 1990. Coniferophytina (Conifers and ginkgoids). In: *The families and genera of vascular plants,* **1**. Kubitzki K (Editor)—Springei-Verlag, Berlin.

Saporta G de 1875. Sur la découverte de deux types nouveaux de Coniferes dans les schistes permiens de Lodéve (Hérault). *C.R. Acad. Sci. Paris* **80**: 1017-1022.

Seward AC 1919. *Fossil plants : A text-book for students of Botany and Geology,* IV. Cambridge.

Seward AC & Gowan J 1900. The Maidenhair Tree (*Ginkgo biloba* L.). *Annals Bot.* **14**(53): 109-154.

Sporne KR 1965. *The morphology of gymnosperms.* The structure and evolution of primitive seed-plants. Hutchinson Univ. Library, London.

Spurr AR 1969. A low-viscosity epoxy embedding medium for electron microscopy. *J. Ultrastruct. Res.* : 26-31.

Stanislavsky FA 1971. *Fossil flora and stratigraphy of Upper Triassic sediments in the Donetz Basin (Rhaetian Flora from Raick).* Naukova Dumka, Kiev.

Stanislavsky FA 1973. The new genus *Toretzia* from the Upper Triassic of the Dontez Basin and its relation to the genera of the order Ginkgoales. *Paleontol. Zh.* **1**: 88-96.

Taylor WA, Taylor TN & Archangelsky S 1989. Comparative ultrastructure of fossil and living gymnosperm cuticles. *Rev. Palaeobot. Palynol.* **59**: 145-151.

Tralau H 1968. Evolutionary trends in the genus *Ginkgo*. *Lethaia* **1**: 63-101.

Vasiljevskaja ND 1956. *New Lower Jurassic plants from eastern Fergana.* T. 15.

Zhou Zhiyan 1991. Phylogeny and evolutionary trends of Mesozoic ginkgoaleans—a preliminary assessment. *Rev. Palaeobot. Palynol.* **68**: 203-216.

Zhou Zhiyan & Zhang Bole 1988. Two new ginkgoalean female reproductive organs from the Middle Jurassic of Henan Province. *Kexue Tongbao* (*Sci. Bull.*) **33**(14): 1201-1203.

Zhou Zhiyan & Zhang Bole 1989. A Middle Jurassic *Ginkgo* with ovule-bearing organs from Henan, China. *Palaeontographica* **B211**: 113-133.

Investigation on plant fossils from Seria Naka in the Himalayan foot-hills of Uttar Pradesh, India

M. Prasad, J.S. Antal & V.D. Tiwari*

Prasad M, Antal JS & Tiwari VD 1997. Investigation on plant fossils from Seria Naka in the Himalayan foot-hills of Uttar Pradesh, India. *Palaeobotanist* **46** (3) : 13-30.

A floral assemblage consisting of leaf-impressions recovered from the Lower Siwalik sediments of Seria Naka, about 30 km north-west of Tulsipur town in Gonda District of Uttar Pradesh, India has been described and discussed in the present paper. The assemblage comprises 10 taxa belonging to seven dicotyledonous families — Anonaceae, Flacourtiaceae, Polygalaceae, Sapindaceae, Anacardiaceae, Fabaceae and Ebenaceae. An analysis of the floral assemblage with respect to the distribution pattern of modern equivalent taxa reveals the prevalence of warm and humid climate in the region during the deposition of these sediments. The fossil flora also indicates that tropical evergreen forests with few moist deciduous plants were flourishing around Seria Naka in the Himalayan foot-hills during Middle Miocene in contrast to the mixed deciduous type of present day forests. Further, the presence of some Malayan elements like *Goniothalamus meboldii, Mitrephora macrophylla* and *Nephelium glabrum* is phytogeographically important supporting the view of migration of some taxa from South-east Asia to Indian subcontinent during Neogene.

Key-words—Megafossils, Leaf-impressions, Angiosperms, Palaeoclimate, Phytogeography, Lower Siwalik, Middle Miocene, India.

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सारांश

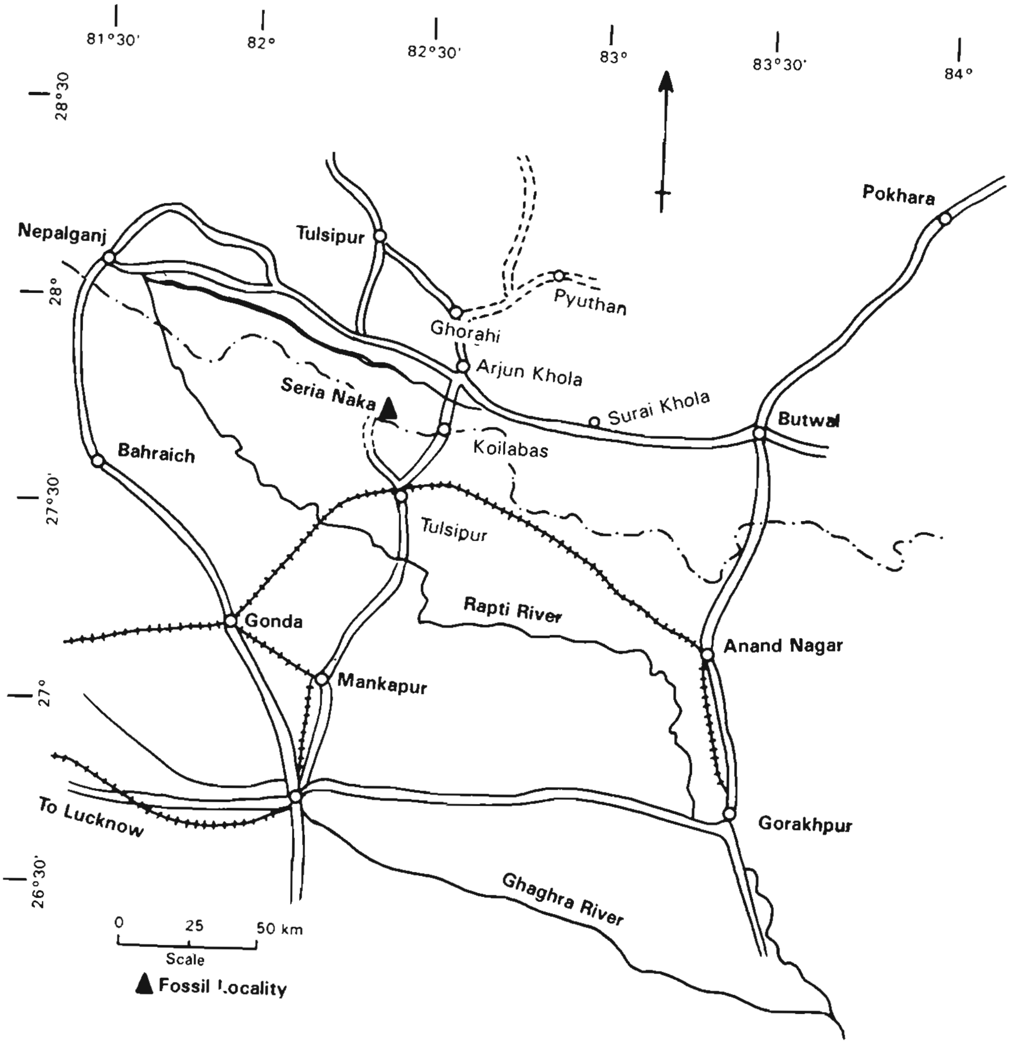
उत्तर प्रदेश (भारत) के हिमालय गिरि-पादों में सीरिया नाका से प्राप्त अश्मित पौधों का अध्ययन

महेश प्रसाद, जसवन्त सिंह अन्तल एवं वी. डी. तिवारी

उत्तर प्रदेश के गोंडा जनपद में तुलसीपुर कस्बे के लगभग 30 किलोमीटर उत्तर पश्चिम में सीरिया नाका के शिवालिक अवसादों से उपलब्ध पर्ण-छापों का इस शोध-पत्र में वर्णन किया गया है। इस समुच्चय में एनोनेसी, फ्लेकोर्शिएसी, पोलीगैलेसी, सेपिन्डेसी, एनाकार्डिएसी, फैबेसी एवं एबीनेसी नामक सात द्विबीजपत्री कुलों के 10 वर्गक सम्मिलित हैं। वर्तमान समतुल्य वर्गकों के वितरण के आधार पर किये गये विश्लेषण से इन अवसादों के निक्षेपण के समय उष्ण और नम जलवायु का होना इंगित होता है। उपलब्ध वनस्पतिजात से यह भी प्रदर्शित होता है कि मध्य मायोसीन काल में हिमालय गिरि-पादों में स्थित सेरिया नाका के आस-पास कुछ पर्णपाती अवयवों से युक्त उष्णकटिबन्धीय सदाहरित वन विद्यमान थे जबकि आजकल वहाँ मिश्रित पर्णपाती प्रकार के वन विद्यमान हैं। इसके अलावा *गोनिओथैलेमस मीबोल्डाई, मिट्रेफ़ेरा मैक्रोफ़िल्ला* एवं *निफ़ेलिश्म ग्लेब्रम* नामक कुछ मलाया के तत्वों की उपस्थिति पादप भौगोलिक दृष्टि से महत्वपूर्ण है जिससे निओजीन काल में दक्षिण पूर्व एशिया से भारतीय उपमहाद्वीप में कुछ वर्गकों के आगमन की पुष्टी होती है।

THE Himalayan foot-hills have resulted from the tectonic processes that have been taking place in the Himalayan orogeny since the Cenozoic era. The Siwalik Basin, a part of the Himalayan foot-hills, was formed as a foredeep in front of the newly risen Himalaya during Middle Miocene orogeny and was the site of deposition of the Siwalik sediments (Saxena & Verma, 1976). The Siwalik System is 5-6 km thick (Wadia, 1975; Saxena, 1976; Krishnan, 1982; Mukherjee, 1984) and is composed mainly of sandstones, grits and conglomerates. On the basis of litho-biostratigraphical/palaeontological studies the Siwalik System has been divided into three groups — the Lower, Middle and Upper Siwaliks ranging in age from Middle Miocene to Lower Pleistocene.

The fossil locality Seria Naka is situated about 30 km north-west of Tulsipur town at Indo-Nepal



Text-figure 1 — Map showing the fossil locality.

PLATE 1

(All figures are of natural size unless otherwise mentioned)

1. *Mitrephora miocenica* sp. nov.; Fossil leaf, Specimen no. BSIP 37776.
2. *Mitrephora macrophylla* Oliver.; Modern leaf.
3. *Mitrephora miocenica* sp. nov.; A part of fossil leaf magnified to show the details of venation. x 2.
4. *Mitrephora macrophylla* Oliver.; A part of modern leaf magnified to show similar details of venation. x 2.
5. *Goniothalamus siwalicus* sp. nov.; Fossil leaf showing its shape, size and venation pattern; Specimen no. BSIP 37778.
6. *Goniothalamus meboldii*; Modern leaf showing similar shape, size and venation pattern.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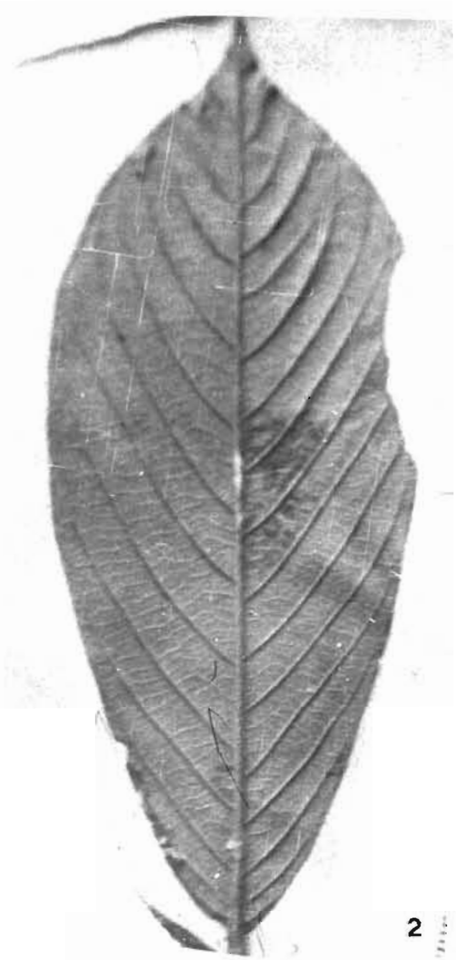
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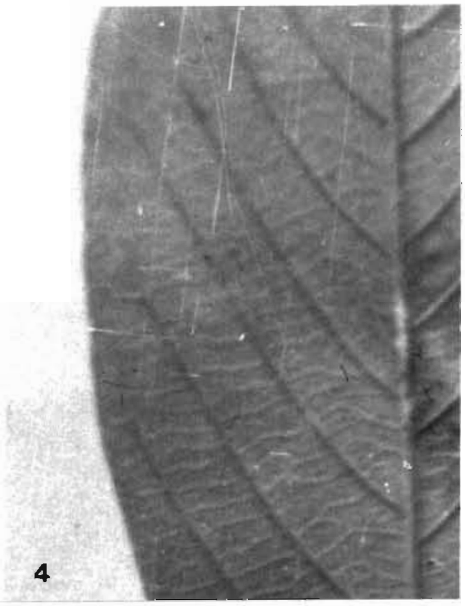
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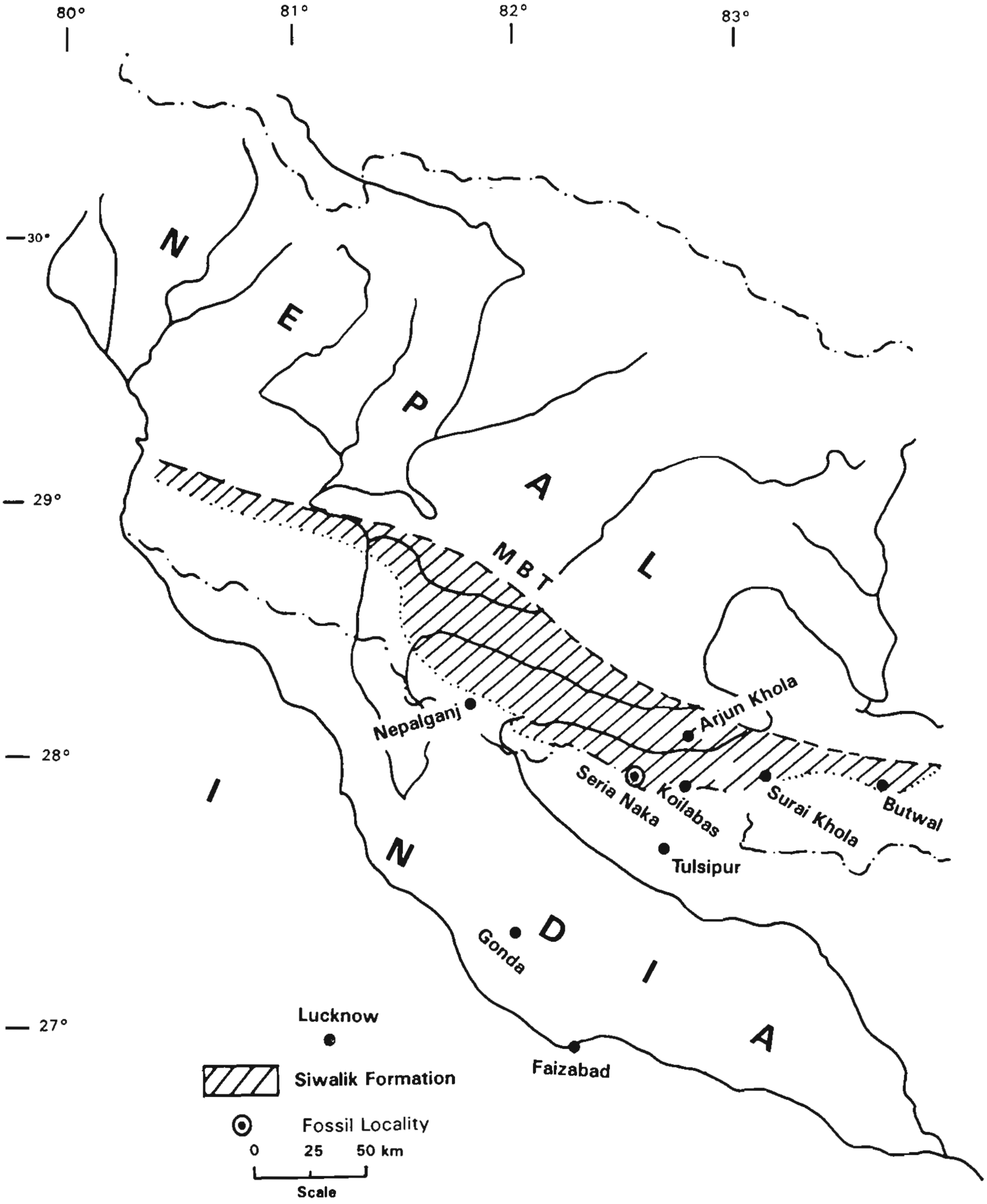
PLATE 1



Text-figure 2—Geological map showing Siwalik Formation around Seria Naka area (after Glennie & Zeigler, 1964).

border in the Gonda District of Uttar Pradesh. The Siwaliks occur here as foot-hills running in north east direction (Text-figures 1, 2). The geological/palaeontological studies of this particular area have not been carried out so far. Nevertheless, on the basis of lithology of exposed sections these sediments are considered as Lower Siwaliks of Middle Miocene age.

A large number of plant fossils including woods, leaves, fruits, seeds and flowers have been reported from the Siwalik sediments at different places, viz., Mohand, Hardwar, Kalagarh, Kathgodam, Tanakpur and Koilabas (at Indo-Nepal border) in Uttar Pradesh (Awasthi, 1992; Prasad, 1994a, 1994b, 1994c, 1994d). Unfortunately, the fossiliferous area Seria Naka remained untouched and there is no report of plant fossils from this area, although this area is very rich in plant fossils especially leaf-impressions and fruit and seed-impressions. Recently in January 1997, a number of well-preserved leaf-impressions were collected from the locality and investigation on these leaf-impressions has been undertaken to work out in detail the fossil assemblage of this area to reconstruct the history of past vegetation, palaeoclimate and phytogeography of the region during Siwalik period.

MATERIAL AND METHOD

Out of a number of specimens, 21 well-preserved leaf-impressions were collected from two well exposed sections situated about 0.5 km upstream from Seria Naka Village in a small rivulet "Seria". The leaf-impressions are devoid of cuticle and preserved mostly in shales and fine-grained sandstones. The leaf-impressions have been studied morphologically with the help of either hand lens or low power microscope under reflected light. A lot of herbarium sheets of several extant families and genera were examined at the Herbarium of Central National Herbarium, Sibpur, Howrah in order to identify them. For description the terminology given by Hickey (1973) and Dilcher (1974) has been followed. Photographs of the leaves of modern comparable species have been provided to show similarity with the fossil leaves. The specimens and their photonegatives are preserved in the Museum of Birbal Sahni Institute of Palaeobotany, Lucknow, India.

SYSTEMATIC DESCRIPTION

Family — Anonaceae

Genus — *Mitrephora* (Bl.) Hook.f. & Thoms.

Mitrephora miocenica sp. nov.
Pl. 1, figs 1, 3

This species is based on single specimen with counter part.

Description— Leaf simple, symmetrical, narrow obovate, preserved length 10.5 cm, width 4.2 cm; apex seemingly acuminate; base nearly obtuse, equilateral; margin entire; texture chartaceous; petiole 0.3 cm visible, normal; venation pinnate, eucamptodromous; primary vein (1°) single, prominent, stout, almost straight; secondary veins (2°) about 11 pairs visible, less than 0.2 to 1.7 cm apart; uniformly curved up to somewhat greater height seemingly unbranched; alternate to sub-opposite, angle of divergence acute 50°-55°, moderate, basal secondaries arise closely with comparatively more angle; intersecondary veins present, rare, simple; tertiary veins (3°) fine with angle of origin usually RR rarely AO, percurrent, branched, oblique to right angle in relation to midvein, alternate to opposite and close; quaternary veins (4°) still fine, with angle of origin usually RR forming orthogonal to sometime polygonal meshes.

Holotype — Specimen no. BSIP 37776.

Locality — Seria Naka Village about 30 km northwest of Tulsipur town, Gonda District, Uttar Pradesh.

Horizon & Age — Lower Siwalik, Middle Miocene.

Affinities—The most characteristic features of the fossil leaves such as narrow obovate shape, acuminate apex, obtuse base, eucamptodromous venation, curving up of secondary veins to somewhat greater height and percurrent, branched tertiary veins indicate its close resemblance with the modern leaflets of the genus *Mitrephora* of the family Anonaceae. A large number of herbarium specimens of this genus have been studied and it was found that the present fossils show close similarity with the leaves of *M. macrophylla* Oliver (CN Herbarium Sheet nos. 13318 & 13303; Pl. 1, figs 2, 4) of the family Anonaceae.

So far, two fossil leaves resembling the genus *Mitrephora* (Bl.) Hook.f. & Thoms. have been described under *Mitrephora siwalica* Antal & Awasthi 1993. Of them, one is from the Lower-Middle Siwalik sediments of Oodlabari, Darjeeling District, West Bengal (Antal & Awasthi, 1993) and other from Middle Siwalik of Surai Khola, western Nepal (Prasad & Awasthi, 1996). These two known fossil leaves differ from the present fossil leaves in being small size with fewer secondaries (5-6 pairs). As the present fossil leaf is entirely different from already known species, they have been described under a new specific name *Mitrephora miocenica.*

Mitrephora macrophylla Oliver, with which the fossil shows close resemblance, is a large tree occurring in the evergreen forest of Malaya.

Genus — *Melodorum* (= *Fissistigma*) Dunal.

Fissistigma senii Lakhanpal 1969
Pl. 3, fig. 1

There is only one specimen in the collection.

Description — Leaf simple, symmetrical, elliptic, preserved length 6.5 cm, width 2.7 cm; apex acute; base acute, normal, equilateral; margin entire; texture chartaceous; petiole invisible; venation pinnate, eucamptodromous; primary vein (1°) single, prominent, stout, curved; secondary veins (2°) about 9 pairs visible, less than 0.3 to 1.2 cm apart, uniformly curved up, unbranched, usually alternate, angle of divergence about 45°, acute, moderate; tertiary veins (3°) fine, angle of origin usually RR, percurrent, branched, oblique to nearly right angle in relation to midvein, predominantly alternate and close to nearly distant; quaternary veins (4°) not fairly preserved.

Holotype — Specimen no. BSIP 37777.

Locality — Seria Naka Village about 30 km northwest of Tulsipur town, Gonda District, Uttar Pradesh.

Horizon & Age—Lower Siwalik, Middle Miocene.

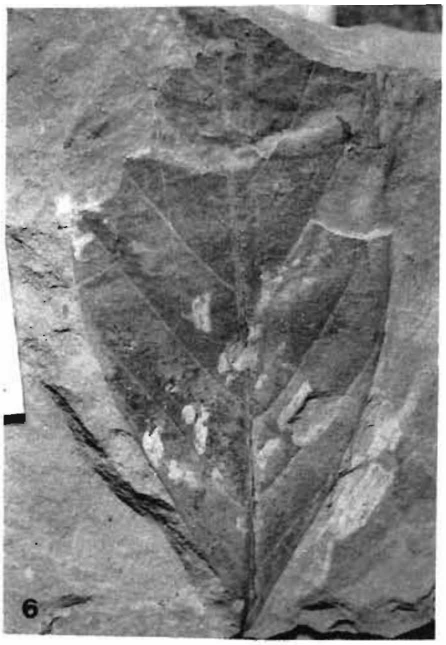
Affinities — The distinguishing features of the fossil leaf like elliptic shape, acute base and apex, entire margin, eucamptodromous venation and percurrent tertiaries arising at right angle indicate that the fossil leaf shows similarity with the modern leaves of *Melodorum (= Fissistigma) wallichii* H.f. & T. of the family Anonaceae (CN Herbarium Sheet no. 383; Pl. 3, fig. 2). So far, only two fossil leaves showing similarity with the genus *Fissistigma* are known. Lakhanpal and Awasthi (1992) reported a fossil leaf under *Fissistigma siwalika* from the Siwalik sediments near Jawalamukhi, Himachal Pradesh. This fossil is large in size (14.5 x 5.3 cm) having oblanceolate shape with rounded apex. So, it is entirely different from the present fossil. Earlier, Lakhanpal (1969) described a fossil leaf as *Fissistigma senii* from the same locality in Himachal Pradesh showing close resemblance with *Fissistigma wallichii.* As the present fossil leaf from Seria Naka shows closest similarity with *F. wallichii* and also almost similar to *F. senii* Lakhanpal 1969 in shape, size and venation pattern, it has therefore been placed under the same species.

PLATE 2

⟶

(All figures are of natural size unless otherwise mentioned)

1. *Flacourtia seriaensis* sp. nov.; Fossil leaf showing its shape, size, serrate margin and venation pattern; Specimen no. BSIP 37779.
2. *Flacourtia catafracta* Roxb.; Modern leaf showing similar shape, size and venation pattern.
3. *Securidaca miocenica* sp. nov.; Fossil leaf showing its shape, size and venation pattern; Specimen no. BSIP 37780.
4. *Securidaca inappendiculata* Hask.; Modern leaf showing similar shape, size and venation pattern.
5. *Securidaca miocenica*; A part of fossil leaf magnified to show details of venation. x 2.5.
6. *Nephelium palaeoglabrum* sp. nov.; Fossil leaf showing its shape, size and venation pattern; Specimen no. BSIP 37781.
7. *Nephelium glabrum* Moronh.; Modern leaf showing similar shape, size and venation pattern.
8. *Nephelium palaeoglabrum* sp. nov.; Another fossil leaf showing variation in shape and size; Specimen no. BSIP 37782.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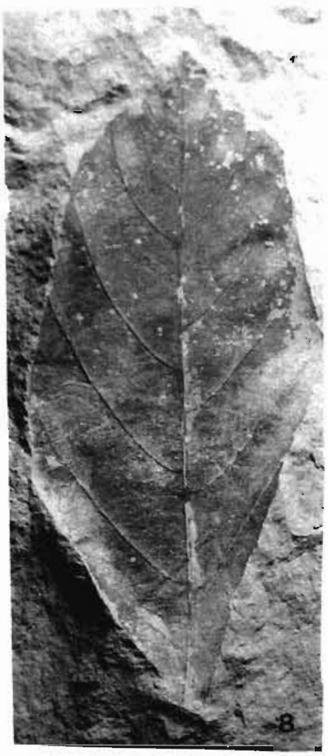
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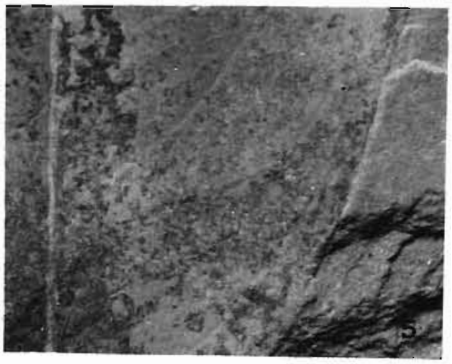
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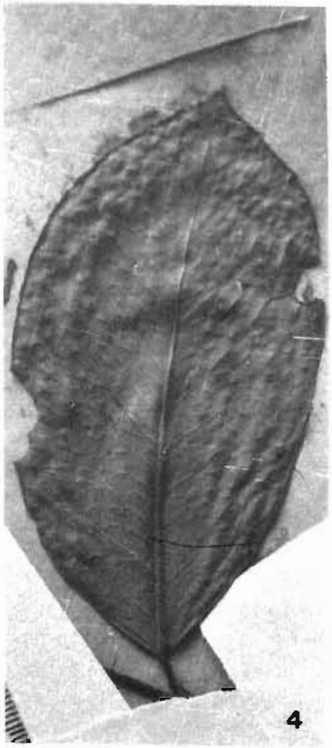
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PLATE 2

Fissistigma wallichii (H.f. & T.) Merril, with which the fossil shows similarity, is a large woody climber found in eastern Bengal, Assam and Sylhet (Hooker, 1872).

Genus —*Goniothalamus* Hook.f. & Thoms.

Goniothalamus siwalicus sp. nov.
Pl. 1, fig. 5

There is only one specimen in the collection.

Description— Leaf simple, symmetrical, narrow elliptic, preserved length 7.4 cm, width 2.4 cm; apex broken, seemingly acute; base acute, equilateral; margin entire; texture chartaceous; petiole not preserved; venation pinnate, brochidodromous; primary vein (1°) single, prominent, almost straight; secondary veins (2°) about 9 pairs visible, less than 0.4 to 1.3 cm apart, curved up near the margin and joined to their superadjacent secondary at wide-acute angle, unbranched, almost alternate, angle of divergence about 60°-90°, acute to right angle, basal secondaries arise nearly right angle while upper secondaries arise at acute angle, intersecondary veins present, simple; tertiary veins (3°) not clearly seen.

Holotype — Specimen no. BSIP 37778.

Locality — Seria Naka Village about 30 km northwest of Tulsipur town, Gonda District, Uttar Pradesh.

Horizon & Age — Lower Siwalik, Middle Miocene.

Affinities — The diagnostic features of the present fossil leaf such as narrow elliptic shape, acute base, entire margin, brochidodromous venation, right angle divergence of secondary veins and presence of intersecondary veins strongly suggest its resemblance with the modern leaves of *Uvaria* and *Goniothalamus* of the family Anonaceae. After critical examination of the Herbarium sheets of different species of these genera it has been found that the present fossil leaf comes closest with the extant *Goniothalamus meboldii* Bl. (CN Herbarium Sheet no. 13141, Pl. 1, fig. 6).

A fossil leaf resembling the genus *Goniothalamus* has already been described as *Goniothalamus chorkholaensis* Prasad & Awasthi 1996 from the Siwalik sediments of Surai Khola, Nepal. On comparison with already known species it was found that the present fossil is different in the nature of secondary veins arising more straightly in *G. chorkholaensis* and also the intersecondary veins are more in number. Thus, in being different from the known species a new specific name *G. siwalicus* is given to the present fossil leaf.

The extant species *G. meboldii* Bl., with which the present fossil shows closest similarity, now grows in the Malayan region.

Family—Flacourtiaceae

Genus—*Flacourtia* Commers.

Flacourtia seriaensis sp. nov.
Pl. 2, fig. 1

This species is represented by only one specimen.

Description— Leaf simple, symmetrical, narrow ovate, preserved length 3.8 cm, width 2 cm; apex seemingly acute; base broken; margin serrate; texture chartaceous; petiole not preserved; venation

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PLATE 3 ⟶

(All figures are of natural size unless otherwise mentioned)

1. *Fissistigma senii* Lakhanpal; Fossil leaf showing shape, size and venation pattern; Specimen no. BSIP 37777.
2. *Fissistigma wallichii* H.f. & T.; Modern leaf showing similar shape, size and venation pattern.
3. *Mangifera someshwarica* Lakhanpal & Awasthi; Fossil leaf — Specimen no. BSIP 37783.
4. *Mangifera indica* Linn.; Modern leaf showing similar shape, size and venation pattern.
5. *Mangifera someshwarica* Lakhanpal & Awasthi; A part of fossil leaf magnified to show details of venation. x 1.5.
6. *Mangifera indica* Linn.; A part of modern leaf magnified to show similar details of venation. x 1.5.


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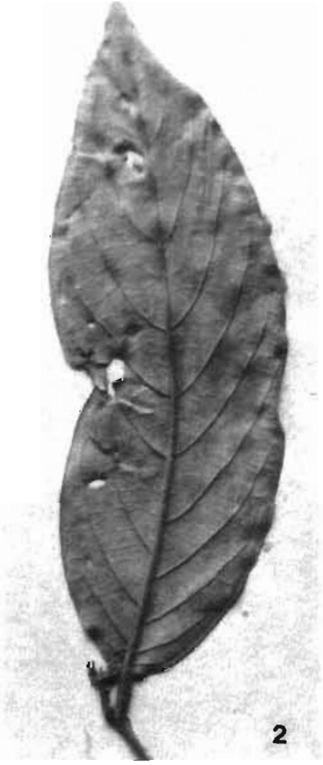
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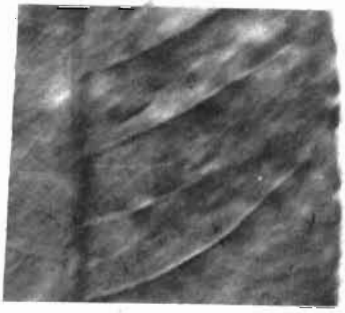
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PLATE 3

pinnate, craspedodromous to eucamptodromous; primary vein (1°) single, stout, not very prominent, almost straight; secondary veins (2°) about 6 pairs visible, less than 0.5 to 1.2 cm apart, uniformly curved up, sometimes branched near the margin, alternate, angle of divergence about 55°, acute, moderate, intersecondary veins present, simple; tertiary veins (3°) fine, poorly preserved with angle of origin AO to RR, percurrent, branched, oblique in relation to midvein, alternate to opposite and close.

Holotype — Specimen no. BSIP 37779.

Locality — Seria Naka Village about 30 km northwest of Tulsipur town, Gonda District, Uttar Pradesh.

Horizon & Age — Lower Siwalik, Middle Miocene.

Affinities — The most characteristic features of the present fossil leaf are narrow ovate shape, acute apex, serrate margin, craspedodromous to eucamptodromous venation, moderate angle of divergence, presence of intersecondary veins and percurrent tertiaries. These features collectively indicate its affinity with the family Flacourtiaceae specially the genus *Flacourtia* Comm. ex. L' Herit. A large number of herbarium sheets (about 15 species) of this genus were studied in order to find out its specific affinity. Ultimately, it has been concluded that the present fossil shows closest resemblance with the extant species *Flacourtia catafracta* Roxb. in shape, size and venation pattern (CN Herbarium Sheet nos. 259, 32999, 33000; Pl. 2, fig. 2).

Two fossil leaves, viz., *F. nepalensis* Awasthi & Prasad and *F. tertiara* Prasad & Awasthi showing affinity with the genus *Flacourtia* Commers. are already known from the Siwalik sediments of Surai Khola, Nepal (Awasthi & Prasad, 1990; Prasad & Awasthi, 1996). Of these, former is entirely different from the present fossil in being small size (2.3 x 1.3 cm) with obovate apex. While the later is larger in size (9.0 x 3.6 cm) and possesses different nature of secondary veins which run nearly half the distance of lamina before terminating at the margin. Thus, in being different from already known species it is described as a new species *Flacourtia seriaensis*. The specific epithet is after a small Seria River in the area.

The extant taxon *F. catafracta* Roxb., with which fossil resembles closely, is a small tree growing in damp forest in Dehradun (Uttar Pradesh), Bengal, Assam, Chittagong, south India, Myanmar, Phillippine and Malaya regions (Gamble, 1972; Hooker, 1872; Ridley, 1967).

Family—Polygalaceae

Genus—*Securidaca* Linn.

Securidaca miocenica sp. nov.

Pl. 2, figs 3, 5

This species is represented by three specimens in the collection.

Description — Leaf simple, symmetrical, elliptic, preserved size 6.5 x 3.4 cm, 7.0 x 3.5 cm, 6.0 x 3.0 cm; apex seemingly acuminate; base acute to obtuse, almost equilateral; margin entire; texture

PLATE 4 ⟶

(All figures are of natural size unless otherwise mentioned)

1. *Mangifera someshwarica* Lakhanpal & Awasthi; Another fossil leaf showing variation in shape and size; Specimen no. BSIP 37784.
2. *Mangifera indica* Linn.; Another modern leaf showing similar variation in shape and size.
3. *Dracontomelon seriaense* sp. nov.; Fossil leaf showing its shape, size and venation pattern; Specimen no. BSIP 37785.
4. *Dracontomelon sylvestre* Blume.; Modern leaf showing similar shape, size and venation pattern.
5. *Dalbergia miovolubilis* sp. nov.; Fossil leaf — Specimen no. BSIP 37786.
6. *Dalbergia volubilis* Roxb.; Modern leaf.
7. *Dalbergia miovolubilis* sp. nov.; A part of fossil leaf magnified to show details of venation. x 2.
8. *Dalbergia volubilis* Roxb.; A part of modern leaf magnified to show similar details of venation. x 2.
9. *Diospyros tulsipurensis* sp. nov.; Fossil leaf showing its shape, size and venation pattern — Specimen no. BSIP 37787.
10. *Diospyros pruriens* Dalz.; Modern leaf showing similar shape, size and venation pattern.


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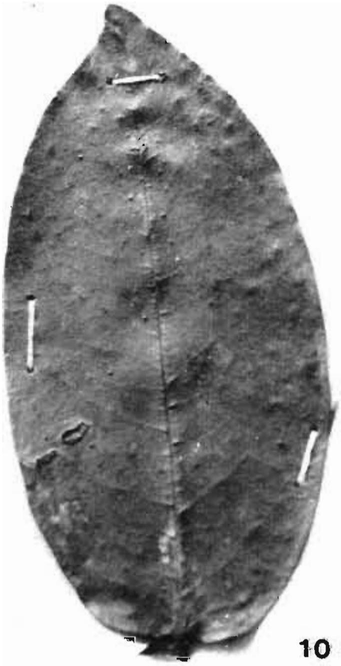
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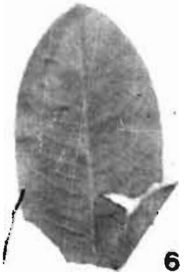
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PLATE 4

chartaceous; petiole broken; venation pinnate, eucamptodromous; primary vein (1°) single, prominent, stout, almost straight; secondary veins (2°) 8 pairs visible, less than 0.3 to 1.4 cm apart, uniformly curved up, seemingly unbranched, alternate to subopposite, angle of divergence about 55°, moderate, acute, intersecondary veins frequent, simple; tertiary veins (3°) not clearly seen.

Holotype — Specimen no. BSIP 37780.

Locality — Seria Naka Village about 30 km northwest of Tulsipur town, Gonda District, Uttar Pradesh.

Horizon & Age — Lower Siwalik, Middle Miocene.

Affinities — The elliptic shape, acuminate apex, acute to obtuse base, entire margin, eucamptodromous venation, moderate angle of divergence of secondary veins and abundant intersecondary veins of the present fossil strongly suggest its affinity with the modern leaves of *Securidaca inappendiculata* Hask. (*S. tavoyana* Wall.) of the family Polygalaceae (CN Herbarium Sheet no. 36383; Pl. 2, fig. 4).

As far as the authors are aware there is no record of fossil leaf of the genus *Securidaca* from Indian Tertiary sediments. Therefore, the present fossil leaf has been described under a new species *Securidaca miocenica.*

The taxon *Securidaca inappendiculata* Hask., with which the fossil shows affinity, is a large woody climber growing in eastern Bengal, Aracan and Tenasserim. It is also found in the Kachar Hills near Myitkyina and Java (Gamble, 1972; Hooker, 1872).

Family — Sapindaceae

Genus — *Nephelium* Linn.

Nephelium palaeoglabrum sp. nov.
Pl. 2, figs 6, 8

This species is represented by five specimens in the collection.

Description — Leaf simple, symmetrical, narrow obovate to elliptic; preserved size 7.3 x 3.5 cm, 7.5 x 3.0 cm, 10.2 x 5.0 cm, 7.4 x 3.6 cm and 8.5 x 3.4 cm; apex acute; base acute; equilateral; margin entire; texture chartaceous; petiole 0.5 cm visible, normal; venation pinnate, craspedodromous to eucamptodromous; primary vein (1°) single, prominent, stout, almost straight; secondary veins (2°) 6 to 7 pairs visible, less than 0.8 to 1.5 cm apart, uniformly curved up and become finer before joining the superadjacent vein, unbranched, usually alternate, rarely subopposite; intersecondary veins absent; tertiary veins (3°) fine with angle of origin usually RR, branched, percurrent, oblique to nearly right angle in relation to midvein, predominantly alternate, close; quaternary veins (4°) poorly preserved, angle of origin RR, branched forming orthogonal to polygonal meshes.

Holotype — Specimen no. BSIP 37781.

Paratype — Specimen no. BSIP 37782.

Locality — Seria Naka Village about 30 km northwest of Tulsipur town, Gonda District, Uttar Pradesh.

Horizon & Age — Lower Siwalik, Middle Miocene.

Affinities — Narrow obovate to elliptic shape, acute apex and base, entire margin, craspedodromous to eucamptodromous venation and percurrent tertiaries which are oblique to nearly right angle in relation to midvein are the diagnostic features of the present fossil leaves. Besides, the fossil leaf is also characterised by uniformly curved up secondaries which become finer before joining the superadjacent veins. These features collectively indicate that the present fossil leaves show closest resemblance with the modern leaves of *Nephelium glabrum* Noronh. of the family Sapindaceae (CNH Herbarium Sheet no. 95476; Pl. 2, fig. 7).

So far, three fossil leaves resembling the genus *Nephelium* have been described from the Tertiary sediments of India and abroad. They are *Nephelium jovis* Unger 1867 from the Tertiary of Europe, *N. verbeerkianum* Geyler 1875 from Tertiary of Borneo and *N. oligocenicum* Awasthi & Mehrotra 1995 from the Oligocene of Makum Coalfield, Assam, India.

On comparison of these known fossil leaves with that of the present fossil leaf it has been found that the present fossil leaf is different from already known fossils either in shape, size or in venation pattern. In being different from known species this fossil leaf is described as *Nephelium palaeoglabrum* sp. nov. The name of species is after modern comparable species *N. glabrum.*

Nephelium glabrum Noronh., with which fossil shows closest affinity, is an evergreen tree found to grow in Malayan archipelago (Hooker, 1872).

Family — Anacardiaceae

Genus — *Mangifera* Linn.

Mangifera someshwarica Lakhanpal & Awasthi 1984
Pl. 3, figs 3, 5; Pl. 4, fig. 1

There are three specimens in the collection.

Description — Leaves simple, symmetrical, very narrow, elliptic, preserved size 14.2 x 4 cm, 9.5 x 2.7 cm, 9.9 x 2.7 cm; apex acute; base acute, equilateral; margin almost entire; texture thick chartaceous; petiole not preserved; venation pinnate, eucamptodromous; primary vein (1°) single, prominent, stout; secondary veins (2°) more than 22 pairs visible, less than 0.4 to 1.6 cm apart, uniformly curved up, towards margin become more fine before joining the superadjacent vein, unbranched, alternate to opposite, angle of divergence 70° to 90°, acute to right angle, basal secondaries arise at right angle, intersecondary veins present, frequent, simple to composite; tertiary veins (3°) still fine, with angle of origin RR to AO, percurrent, branched, oblique in relation to midvein, alternate to opposite, close; quaternary veins (4°) very fine, usually arise at right angle forming rectangular to polygonal meshes.

Specimen — Nos. BSIP 37783 and 37784.

Locality — Seria Naka Village about 30 km northwest of Tulsipur town, Gonda District, Uttar Pradesh.

Horizon & Age — Lower Siwalik, Middle Miocene.

Affinities — The important features of the fossil leaves are very narrow elliptic shape, acute apex and base, entire margin, eucamptodromous venation, right angle divergence of secondary veins, presence of frequent intersecondary veins and percurrent, branched tertiaries. These features collectively indicate that these fossil leaves belong to the family Anacardiaceae. Among this family the genus *Mangifera* Linn. shows resemblance with the fossil specimens. A large number of herbarium sheets of different species of *Mangifera* were examined in which *Mangifera indica* Linn. shows closest affinity with the fossil leaves (C N Herbarium Sheet no. 8493; Pl. 3, figs 4, 6).

So far, six fossil leaves resembling *Mangifera indica* Linn. have been described from the Tertiary sediments of India and abroad. Of them, two are described under *Mangifera takashimensis* Matsuo 1967 in which one is from the Palaeogene of Kyushu and the other from the Eocene of Southwest Honshu, Japan. The remaining three leaves have been described under *Mangifera someshwarica* Lakhanpal & Awasthi 1984. They are from the Siwalik sediments of Bhikhnathoree, Bihar (Lakhanpal & Awasthi, 1984), Surai Khola, Nepal (Awasthi & Prasad, 1990), Koilabas, Nepal (Prasad, 1994b) and from Oligocene sediments of Makum Coalfield, Assam, India (Awasthi & Mehrotra, 1995). Out of these, the identification of leaves described under *M. takashimensis* appears to be doubtful (Awasthi & Prasad, 1990). As the present fossil leaves resemble modern taxon *M. indica* Linn. and very near to the fossil leaves already known from Siwaliks of Surai Khola, Nepal and Oligocene of Makum Coalfield, Assam, India, they have been described under *Mangifera someshwarica* Lakhanpal & Awasthi 1984.

The modern comparable taxon *Mangifera indica* Linn. is a large evergreen tree growing in sub-Himalayan tract and in the outer hills of Kumaon and Garhwal. It also grows in Chittagong Hills tract in Bangladesh, Myanmar, Thailand, Vietnam and Malaya Peninsula (Gamble, 1972).

Genus — *Dracontomelon* Blume

Dracontomelon seriaense **sp. nov.**
Pl. 4, fig. 3

This species is represented by a single specimen.

Description — Leaf simple, somewhat asymmetrical, narrow ovate, preserved length 8.5 cm, width 3.9 cm; apex acute; base obtuse, slightly inequilateral; margin entire; texture thick, chartaceous; petiole not preserved; venation pinnate, eucamptodromous; primary vein (1°) prominent, stout slightly curved; secondary veins (2°) 14 pairs visible, less than 0.4 to 1.2 cm apart, uniformly curved up, unbranched, alternate to subopposite, angle of divergence 50°-80°, wide-acute, basal secondaries arise less acutely; intersecondaries frequently present, simple; tertiary veins (3°) fine with angle of origin RR, percurrent, branched, sometimes straight to sinuous, oblique in relation to midvein, predominantly alternate and close; quaternary veins (4°) still fine with angle of origin acute to right angle, branched, forming orthogonal to polygonal meshes.

Holotype — Specimen no. BSIP 37785.

Locality — Seria Naka Village about 30 km northwest of Tulsipur town, Gonda District, Uttar Pradesh.

Horizon & Age — Lower Siwalik, Middle Miocene.

Affinities — Slightly asymmetrical narrow ovate shape, acute apex, obtuse and inequilateral base, entire margin, eucamptodromous venation, wide acute angle of divergence of secondary veins, presence of intersecondary veins and percurrent straight to sinuous tertiary veins suggest that the present fossil leaf shows close resemblance with the modern leaves of *Dracontomelon sylvestre* Blume of the family Anacardiaceae (CN Herbarium Sheet no. 10096; Pl. 4, fig. 4).

As far as the authors are aware, there is no record of fossil leaf resembling the genus *Dracontomelon* from the Tertiary sediments of India and other places. Therefore, it forms the first record from the Siwalik sediments of Seria Naka and has been described as *Dracontomelon seriaense* sp. nov., the specific name is after a local small river Seria.

Dracontomelon sylvestre Blume, with which fossil shows closest affinity, is a large tree found to grow in Borneo.

Family—Fabaceae

Genus—*Dalbergia* Linn.f.

Dalbergia miovolubilis sp. nov.

Pl. 4, figs 5, 7

This species is represented by three specimens.

Description — Leaflet simple, symmetrical, wide-elliptic, preserved size 2.3 x 1.5 cm, 3.3 x 2.2 cm, 2.9 x 2.0 cm; apex nearly obtuse; base broken; margin entire; texture chartaceous; petiole not preserved; venation pinnate, eucamptodromous; primary vein (1°) single, prominent, moderate, almost straight; secondary veins (2°) about 7 pairs visible, less than 0.5 cm apart, uniformly curved up, unbranched but sometimes branched, alternate, angle of divergence about 50°, intersecondary veins frequent, simple; tertiary veins (3°) fine with angle of origin RR-AO, percurrent, branched, oblique in relation to midvein, alternate to opposite, close; quaternary veins (4°) not preserved.

Holotype — Specimen no. BSIP 37786.

Locality—Seria Naka Village about 30 km northwest of Tulsipur town, Gonda District, Uttar Pradesh.

Horizon & Age — Lower Siwalik, Middle Miocene.

Affinities — The characteristic features of the present fossil leaflets such as small size, wide elliptic shape, nearly obtuse apex, entire margin, eucamptodromous venation, acute angle of divergence of secondary veins, presence of intersecondaries and percurrent tertiaries collectively indicate its affinity with the modern leaflets of the genus *Dalbergia* Linn.f. of the family Fabaceae. The herbarium sheets of more than 20 species of the genus were studied critically in order to find out the specific affinity of these fossil leaflets. Out of these, the modern leaflets of *Dalbergia volubilis* Roxb. (CN Herbarium Sheet no. 28172; Pl. 4, fig. 6) show closest resemblance with the fossil leaflets in shape, size and venation pattern.

Fossil leaflets resembling the genus *Dalbergia* Linn.f. have been described under the genera *Dalbergia* Linn.f. and *Dalbergites* Berry. So far, 40 species of *Dalbergia* Linn.f. and 3 species of *Dalbergites* Berry have been recorded from different parts of the world (Prasad, 1990, 1994a, 1994b). Firstly, the occurrence of *Dalbergia* in the Siwalik sediments in India is known by a fruit resembling *D. sissoo* (Lakhanpal & Dayal, 1966). Later on four fossil leaflets, viz., *Dalbergia* sp. (Lakhanpal & Awasthi, 1984) from Siwalik sediments of Bhikhnathoree, *Dalbergia miosericea* Prasad 1990 and *D. siwalika* Prasad 1994a from the Siwalik sediments of Koilabas, Nepal and *Dalbergia* cf. *D. sissoo* from Siwalik sediments of Hardwar, Uttar Pradesh, India (Prasad, 1994b) were described from the Siwalik sediments of India and Nepal. Of these, three fossil leaflets, *Dalbergia* sp. (Lakhanpal & Awasthi,1984). *Dalbergia* cf. *D. sissoo* Prasad and *D. siwalika* Prasad have been compared with a single modern taxon *Dalbergia sissoo* and are entirely different from the present fossil leaflets in shape, size and venation pattern. The other species *D. miosericea* Prasad described from the Siwalik sediments also differs in being possessing emarginate apex. The present fossil leaflets have also been compared with other available known species described from outside the Indian subcontinent and found that none of them comes close to the present fossil leaflets. Thus, these fossil leaflets have been described under a new species — *Dalbergia miovolubilis*. The specific name indicates that the fossils show resemblance with modern species *D. volubilis*.

The modern comparable taxon *D. volubilis* Roxb. is a large climbing shrub growing in central and eastern Himalaya from Kumaon to Sikkim, Bihar, Central Provinces, Chhota Nagpur, south and west India (Gamble, 1972).

Family — Ebenaceae

Genus — *Diospyros* Linn.

Diospyros tulsipurensis sp. nov.
Pl. 4, fig. 9

This species is represented by a single specimen.

Description — Leaf simple, symmetrical, wide elliptic, preserved length 8.4 cm, width 3.8 cm; apex wide acute; base obtuse; margin entire; texture chartaceous; petiole broken; venation pinnate, eucamptodromous to brochidodromous; primary vein (1°) single, prominent, stout, straight, thicker in the basal part; secondary veins (2°) about 9 pairs visible, less than 0.3 to 1.5 cm apart, uniformly curved up, alternate to opposite, seemingly unbranched, angle of divergence about 60°-90°, acute to right angle, few basal secondaries arise nearly at right angle; intersecondaries present, simple; tertiary veins (3°) fine with angle of origin usually RR, percurrent, branched, usually oblique in relation to midvein, in the apical part towards margin the tertiaries are nearly right angle in relation to midvein, opposite to alternate and close; quaternary veins (4°), very fine, arising usually at right angle from tertiary veins, branched forming meshes.

Holotype — Specimen no. BSIP 37787.

Locality — Seria Naka Village about 30 km northwest of Tulsipur town, Gonda District, Uttar Pradesh.

Horizon & Age — Lower Siwalik, Middle Miocene.

Affinities — The most important features of the present fossil leaf are wide elliptic shape, wide acute apex, obtuse base, entire margin, eucamptodromous to brochidodromous venation, acute to right angle of divergence of secondary veins, presence of intersecondary veins and percurrent tertiaries with right angle in relation to midvein near the margin. These features suggest that the present fossil leaf belongs to the genus *Diospyros* of Ebenaceae. In view of specific identification, the herbarium sheets of all the available species were examined and found that the modern leaves of *Diospyros pruriens* Dalz. show closest affinity with the fossil leaf (CN Herbarium Sheet nos. 58781, 62672; Pl. 4, fig. 10).

Fossil leaves resembling the genus *Diospyros* Linn. have been described under the genera *Diospyros* Linn. and *Diospyrophyllum* Velenovsky. The former includes about 70 species described from all over

Table 1–Present day distribution of modern equivalents of fossil taxa from the Lower Siwalik sediments of Seria Naka

Fossil taxa	Modern equivalents taxa	Present day distribution
Anonaceae		
Mitrephora miocenica sp. nov.	*Mitrephora macrophylla* Oliver.	Malaya
Fissistigma senii Lakhanpal	*Fissistigma wallichii* H.f. & T.	North east region
Goniothalamus siwalicus sp. nov.	*Goniothalamus meboldii* Bl.	Malaya
Flacourtiaceae		
Flacourtia seriaensis sp. nov.	*Flacourtia catafracta* Roxb.	North India, S. India, Philippines, Malaya, *Myanmar and Bangladesh*
Polygalaceae		
Securidaca miocenica sp. nov.	*Securidaca inappendiculata* Hask.	North-east India, South India & Java
Sapindaceae		
Nephelium palaeoglabrum sp. nov.	*Nephelium glabrum* Noronh.	Malaya
Anacardiaceae		
Mangifera someshwarica Lakhanpal & Awasthi	*Mangifera indica* Linn.	India, Bangladesh, Myanmar, Thailand, Vietnam and Malaya
Dracontomelon seriaensis sp. nov.	*Dracontomelon sylvestre* Blume	Borneo
Fabaceae		
Dalbergia miovolubilis sp. nov.	*Dalbergia volubilis* Roxb.	Central and eastern Himalaya, *Central, South and West India*
Ebenaceae		
Diospyros tulsipurensis sp. nov.	*Diospyros pruriens* Dalz.	Western Ghat, Wynaad and Andamans

the world (Prasad, 1987, 1990, 1994c, 1994d; Antal & Awasth, 1993; Prasad & Awasthi, 1996). However, *Diospyrophyllum* Velenovsky consists of single species *Diospyrophyllum provectum* which goes back to the Upper Cretaceous of Bohemia (Velenovsky, 1884). So far, six species have been reported from the Siwalik sediments of both India and Nepal. They are *Diospyros koilabasensis* Prasad 1990 (also from West Bengal; Antal & Awasthi, 1993) and *D. pretoposia* Prasad 1990 from the Siwalik sediments of Koilabas, western Nepal; *D. miokaki* Hu & Chaney and *D. miocenicus* Prasad from the Siwalik sediments of Surai Khola, western Nepal (Awasthi & Prasad, 1996; Prasad & Awasthi, 1996); and *D. palaeoebenum*

Table 2 — Distribution of modern equivalents of fossil flora of Seria Naka in different tropical forest types

Taxa	1	2	3	4	5	6
Mitrephora macrophylla	+	+				
Fissistigma wallichii	+	+	+			
Goniothalamus meboldii	+	+				
Flacourtia catafracta		+	+			
Securidaca inappendiculata	+	+	+			
Nephelium palaeoglabrum	+					
Mangifera indica	+	+	+		+	
Dracontomelon sylvestre	+	+				
Dalbergia volubilis			+		+	
Diospyros pruriens	+		+	+		

1. Evergreen, **2.** Semi-evergreen, **3.** Moist deciduous, **4.** Littoral and swamp forest, **5.** Dry deciduous, and **6.** Thorn forest.

Prasad 1994c and *D. kathgodamense* Prasad 1994d from Siwaliks of Kathgodam, Uttar Pradesh. The present fossil leaf has been compared with above known species and found that it is entirely different from them in possessing secondaries in the basal part which arise from midvein almost at right angle. This feature is not found in any of above known species of *Diospyros*. Therefore, the present fossil leaf has been described under a new species *Diospyros tulsipurensis*; the specific name indicates the nearest Tulsipur town from the fossil locality.

The modern taxon *D. pruriens* Dalz., with which the fossil shows closest affinity, is a common tree of the forest of Western Ghat from North Kanara, southwards ascending to about 1,000 m in the Wynaad and Andamans (Gamble, 1972).

DISCUSSION

Floral analysis, palaeoclimate and phytogeography

The present fossil assemblage recovered from the Lower Siwalik sediments of Seria Naka in the Himalayan foot-hills of Gonda District, Uttar Pradesh, India is represented by angiospermous leaf-impressions consisting of 10 species. They belong to 10 genera of seven dicotyledonous families. Out of them, the genus *Securidaca* of family Polygalaceae is new to the fossil record of the Tertiary sediments of India. The assemblage is represented by medium to large trees (7 species) and climbers (3 species). Herbs are totally absent. The Seria Naka fossil flora mostly consists of evergreen taxa (Table 2) which indicate that a tropical evergreen forest was flourishing in and around the area during deposition. On the contrary, mixed deciduous forest grows these days in the area. The present day distribution of the comparable taxa shows that they occur mostly in evergreen and sometimes moist deciduous forests of north-east India, Bangladesh, Myanmar and South-east Asian region (Malaya, Java, Phillipines & Borneo; Table 1). It may therefore be surmised that a warm and humid climate prevailed in the Seria Naka area at the time of sedimentation, in contrast to the relatively present day dry climate. Most of the species, except *Mangifera indica* and *Dalbergia volubilis*, do not grow in the Himalayan foot-hills in this region. This indicates a change in climate after the deposition of Siwaliks. These changes in climate since Middle Miocene may be due to uplift of Himalaya and shallowing of the Tethys Sea which progressively changed from a marine through estuarine to fresh water environment (Mukherjee, 1984). The observation on the physiognomic characters of the fossil assemblage recovered from the Siwalik sediments of Seria Naka has also been carried out in order to infer the climate of the area. The present assemblage includes the texa with entire margin, except *Flacourtia catafracta* with higher venation density and most of them have medium size leaves. Further, the extended leaf tips (drip tips), an important physiognomic feature, have also been found in *Mitrephora miocenica, Fissistigma senii, Securidaca miocenica, Mangifera someshwarica, Dracontomelon seriaensis* and *Diospyros tulsipurensis*. These foliar physiognomic characters of fossil leaves indubitably indicate the prevalence of tropical climate during the Siwalik sedimentation (Wolf, 1969; Richards, 1952; Givnish, 1979).

The analysis of present day distribution of the assemblage recovered from Seria Naka indicates that out of 10 genera, only two genera now grow along the foot-hills, while the remaining other taxa have migrated to other suitable regions like north - east India, south India, Myanmar, Bangladesh and South east Asian region (Malaya, Java & Philipines) where they received favourable climate and higher rainfall (Brandis, 1971; Hooker, 1872; Gamble, 1972; Kanjilal, 1928; Desch, 1957). The occurrence of four taxa, viz., *Mitrephora macrophylla, Goniothalamus meboldii, Nephelium glabrum* and *Dracontomelon sylvestre* in the South-east Asian regions indicates that either these taxa have migrated from South-east Asian region to the Indian subcontinent during Palaeocene and flourished along the Himalayan foot-hills or they must have originated themselves in the Indian subcontinent and flourished around Seria Naka area; then migrated to South-east Asian region after Middle Miocene due to change in climate caused by the uplift of Himalaya. Likewise, the floral exchange between India and South-east Asia must have taken place as indicated by the presence of taxa like *Flacourtia catafracta, Securidaca inappendiculata, Mangifera indica* and *Dracontomelon sylvestre* both in India and South-east Asia.

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REFERENCES

Antal JS & Awasthi N 1993. Fossil flora from the Himalayan foot-hills of Darjeeling District, West Bengal and its palaeoecological and phytogeographical significance. *Palaeobotanist* **42** (2) : 14-60.

Awasthi N 1992. Changing patterns of vegetation through Siwalik succession. *In* : Venkatachala BS & Singh HP (Editors)—*Four Decades of Indian Palaeobotany. Palaeobotanist* **40** : 312-327.

Awasthi N & Mehrotra RC 1995. Oligocene flora from Makum Coalfield, Assam, India. *Palaeobotanist* **44** : 157-188.

Awasthi N & Prasad M 1990. Siwalik plant fossils from Surai Khola, western Nepal. *Palaeobotanist* **38** : 298-318.

Brandis D 1971. *Indian Trees.* Bishen Singh Mahendra Pal Singh, Dehradun.

Desch HF 1957. *Manual of Malayan timbers I. Malayan Forest Rec.* **15** : 1-328.

Dilcher DL 1974. Approaches to identification of angiosperm leaf remains. *Bot. Rev.* **40** (1) : 1-157.

Gamble JS 1972. *A manual of Indian timbers.* Bishen Singh Mahendra Pal Singh, Dehradun.

Geyler H Th 1875. Uber fossile Pflanzen von Borneo. *Palaeontographica Suppl.* **3** : 1-84.

Givnish T 1979. On the adaptive significance of leaf form. *In* : Solbrig OT, Jain S, Johnson GB & Raven PC (Editors) —*Topic on plant population biology* : 375-407. New York, Columbia, Univ. Press.

Gleinnie KW & Zeigler MA 1964. The Siwalik Formation in Nepal. *22nd Int. geol. congr.* **15** : 82-95.

Hickey LJ 1973. Classification of architecture of dicotyledonous leaves. *Am. J. Bot.* **60** : 17-33.

Hooker JD 1872. *The flora of British India.* Vol. **I.** Kent.

Kanjilal UN 1928. *The forest flora of the Siwalik and Jaunsar forest division U.P.* Manager of Publications, Delhi.

Krishnan MS 1982. *Geology of India and Burma.* 6th edn.

Lakhanpal RN 1969. Fossil *Fissistigma* from the Lower Siwaliks near Jwalamukhi, India. *In* : Santapau H *et at.* (Editors) — *J. Sen Mem. Vol.* : 311-312. Bot. Soc. Bengal, Calcutta.

Lakhanpal RN & Awasthi N 1984. A Late Tertiary florule from near Bhikhnathoree in West Champaran District, Bihar. *Proc. Symp. Evol. Bot. Biostratigr. Calcutta 1979 (AK Ghosh Comm. Vol.)* **10** : 587-596.

Lakhanpal RN & Awasthi N 1992. New species of *Fissistigma* and *Terminalia* from the Siwalik sediments of Balugoloa, Himachal Pradesh. *Geophytology* **21** : 49-52.

Lakhanpal RN & Dayal R 1966. Lower Siwalik plants from near Jawalamukhi, Punjab. *Curr. Sci.* **35** (8) : 209-211.

Matsuo H 1967. Palaeogene flora of north western Kyushu Part I. The Takashima flora. *Ann. Sci. Kanazawa Univ.* **4** : 15-90.

Mukherjee PK 1984. *A text book of geology.* 10th edn. Calcutta.

Prasad M 1987. *Studies on plant fossils from the Siwalik Group. Unpublished Ph.D. Thesis.* Lucknow Univ., Lucknow.

Prasad M 1990. Fossil flora from the Siwalik sediments of Koilabas, Nepal. *Geophytology* **19** (1) : 79-105.

Prasad M 1994a. Angiospermous leaf remains from the Siwalik sediments of Hardwar, Uttar Pradesh and their bearing on palaeoclimate and phytogeography. *Him. Geol.* **15** : 83-94.

Prasad M 1994b. Plant megafossils from the Siwalik sediments of Koilabas, central Himalaya, Nepal and their impact on palaeoenvironment. *Palaeobotanist* **42** (2) : 126-156.

Prasad M 1994c. Morphotaxonomical study on angiospermous plant remains from the foot-hills of Kathgodam, north India. *Phytomorphology* **44** (1 & 2) : 115-126.

Prasad M 1994d. Siwalik (Middle Miocene) leaf-impressions from the foot-hills of Himalayas, India. *Tertiary Res.* **15** (2) : 53-90.

Prasad M & Awasthi N 1996. Contribution to the Siwalik flora from Surai Khola sequence, western Nepal and its palaeoecological and phytogeographical implications. *Palaeobotanist* **43** (3) : 1-42.

Richards PW 1952. *The tropical rain forest : an ecological study.* Cambridge Univ. Press, Cambridge.

Ridley HN 1967. *The flora of Malaya Peninsula I.* Asher, Amsterdam.

Saxena SP 1976. Geology, structure and tectonics in part of Kumaun and Garhwal Himalaya, Uttar Pradesh — a review. Himalayan Geology seminar, Section II A, New Delhi September, 1976. *In : Proc. Misc. publ. no. 41 Part III. Geological surv. India, Calcutta* : 353-360.

Saxena SP & Verma RN 1976. Basement fault in the Siwalik Basin and the Main Boundary Fault. *In : Seminar on Tectonics and Metallogy of south and east Asia, Calcutta, 1974. Misc. publ. no. 34, Part I Geol. Surv. India, Calcutta* : 175-183.

Unger F 1867. Die fossile flora von kumi auf der Insel Euboea. *Denkschr. Math. Naturw. K. Akad. Wiss.* **27** : 1-66.

Velenovsky J 1884. Die flora fer Bohmischen Kreide Formations. *Beitr. Palaeont. Geol. Ost. Ung.* **3** (1) : 49-61.

Wadia DN 1975. *Geology of India.* 4th edn. Tata McGraw Hill, New Delhi.

Wolf JA 1969. Palaeogene flora from the Gulf of Alaska region. *U.S. Geol. open file report.*

Taphonomic constraints on preservation of cuticles in compression fossils : fungi induced ultrastructural changes in cuticular membranes

Usha Bajpai

Bajpai Usha 1997. Taphonomic constraints on preservation of cuticles in compression fossils: fungi induced ultrastructural changes in cuticular membranes. *Palaeobotanist* **46** (3): 31-34.

A comparative investigation has been made of the ultrastructure of the cuticular membrane recovered from healthy and fungal-infected leaves of *Thinnfeldia indica* Feistmantel, a fossil taxon to understand the nature of changes brought about in the cuticular membrane by the fungi. In general, the structural configuration of both the cuticular membranes is similar. In the infected leaf, precursors of cutin accretions are irregularly present at the sub-cuticular surface. These accretions are interpreted as possible results of breakdown of the cutin due to the secretion of an enzyme by the fungi infecting the leaf. It thus seems that the fungi, besides edaphic factors, do play a role in the break-down of the cutin and thus constrain the preservation of the cuticular membranes.

Key-words — Cuticular membrane, Ultrastructure, Taphonomy, *Thinnfeldia*.

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साराँश

संपीडनाश्मों की उपचर्मों के परिरक्षण में जैवसादिकीय अवरोध : उपचर्मीय झिल्लीयों में कवकों द्वारा व्युत्पादित परासंरचनात्मक परिवर्तन

ऊषा बाजपेयी

उपचर्मीय झिल्ली में कवकों द्वारा किये गये परिवर्तनों को जानने के लिए *थिन्फेल्डिआ इन्डिका* फाइस्टमॅन्टेल नामक एक अश्मित वर्गक की स्वस्थ एवं संक्रामित पत्तियों से प्राप्त उपचर्मीय झिल्ली की परासंरचना का तुलनात्मक अन्वेषण किया गया है। सामान्यतः दोनों ही उपचर्मीय झिल्लीयों में संरचनात्मक सदृशता एक जैसी ही है। ऐसा देखा गया है कि संक्रामित पत्ती में क्यूटिन संवर्धन करने वाले पूर्वग उप-उपचर्मीय सतह पर अनियमित रूप से विद्यमान रहते हैं। ये पूर्वग सम्भवतः पत्ती को संक्रामित करने वाले कवकों द्वारा स्रावित एन्जाइमों के कारण क्यूटिन के टूट जाने से बनते हैं। अतएव ऐसा प्रतीत होता है कि क्यूटिन के ह्रास में, मृदीय प्रभावों के अलावा, कवकों की प्रमुख भूमिका है और इसीलिए उपचर्मीय झिल्ली परिरक्षित नहीं हो पाती।

THE remarkable resistance of cutin, the major component of the plant cuticles, to most inorganic and organic chemicals under normal conditions has enabled the plant cuticles to persist through the aeons, right from Late Devonian (375 million years approximately) to Recent. The stability of the 'cutin' is due to the presence of 'cutan', a highly aliphatic non-saponifiable biomacromolecule, that has a high fossilisation potential (Nip *et al*., 1986). However, not all the fossil leaves have a cuticle preserved, and in many a case the preservation of the cuticle is highly unsatisfactory. Tegelaar *et al*. (1991) have expressed the opinion that cutan is not necessarily present in the cuticle of all the species, and this may be a reason for potential bias in the preservation of the cuticular membranes of leaf fossils. The plant surface mostly carries a microflora which grows in the environment provided by the leaf surface, i.e., 'phyllosphere' (Last, 1955). The phyllosphere is colonised by bacteria and fungi which penetrate the plant tissue either through natural openings in the cuticle, i.e., stomata, or through openings caused by wounds. Many fungi penetrate directly through the cuticle by release of enzyme cutinase which weakens the thick cutin layer and helps the entry of the hyphae. Though the process of fungal colonisation of the leaf tissue is understood to some extent, yet no study, more so on the fossil leaves, has been made to know if any changes are brought about in the ultrastructure of the cuticular membranes by the fungal infection. An attempt has been made here to document differences in the ultrastructure of healthy and fungi-infected cuticular membranes of *Thinnfeldia indica* Feistmantel 1876.

MATERIAL AND METHOD

The cuticular membranes were recovered by acid-alkali processing of specimens of *Thinnfeldia indica* Feistmantel, a presumed pteridospermous leaf collected from the Early Cretaceous Sivaganga Formation exposed in a water-well near Naicolam, Tiruchirapalli District, Tamil Nadu (Maheshwari, 1986). Epiphyllous microthyriaceous fungal remains on these leaves have been earlier reported and studied under the light microscope (Bajpai & Maheshwari, 1988). Ultrastructure of the fungi-infected cuticular membrane has been studied by Maheshwari and Bajpai (1996). Here we document the ultrastructure of the cuticular membranes recovered from a healthy (i.e., uninfected) leaf and compare it with that of the infected leaf to understand the taphonomic changes in the cuticular membrane.

For processing the cuticular membranes for ultrastructural studies, the method described in Maheshwari and Bajpai (1997) was followed in general. A variety of staining techniques was employed to attain good contrast. A large number of sections of the cuticular membrane have been cut and were picked on uncoated Copper grids for examination under the Transmission Electron Microscope.

OBSERVATIONS

Transmission electron micrographs of the ultrathin sections of an uninfected leaf of *Thinnfeldia indica* reveal that the leaf, at the air-leaf interface, is covered with remnants of the epicuticular wax (Pl. 1, fig. 6). Beneath the epicuticular wax is the cuticular membrane proper which is amorphous in composition and is structurally homogeneous (Pl. 1, figs 6, 7). The thickness of the cuticular membrane is not uniform all over. This cuticle conforms to Type-6 of Holloway's classification of the cuticle types in the leaves of modern plants. The inner face of the cuticular membrane that is in contact with the epidermis develops cuticular pegs or anticlinal flanges (Pl. 1, figs 6, 7). These pegs/flanges are pointed at the tips and have wide bases. The cuticular flanges are located between the walls of adjacent epidermal cells (Cutter, 1978). Cuticular flanges have also been reported in another fossil leaf, *Ticoa harrisii* from the Early Cretaceous of Argentina (Archangelsky, Taylor & Kurmann, 1986). Several ovoid gaps are seen in the matrix of the cuticular membrane which are the result of not very highly satisfactory impregnation of the embedding medium.

The cuticular membrane of *T. indica* leaf that is infected with epiphyllous fungi is also covered by remnants of the epicuticular wax at the leaf-air interface (Pl. 1, fig. 5). The matrix of the cuticular membrane is amorphous (Pl. 1, figs 1, 2); at certain places electron dense spots are seen which in all probability are particles of the stain uranyl acetate (Pl. 1, fig. 4). The inner region of the cuticular membrane appears to have been formed of aggregations of irregular bodies (Pl. 1, fig. 3), which have the same density as the other region (Pl. 1, fig. 4). This region is termed here as the 'disturbed zone'. These irregular bodies were possibly formed by the break down of cutin at the sub-cuticular surface due to the action of some enzyme (?cutinase) released by the

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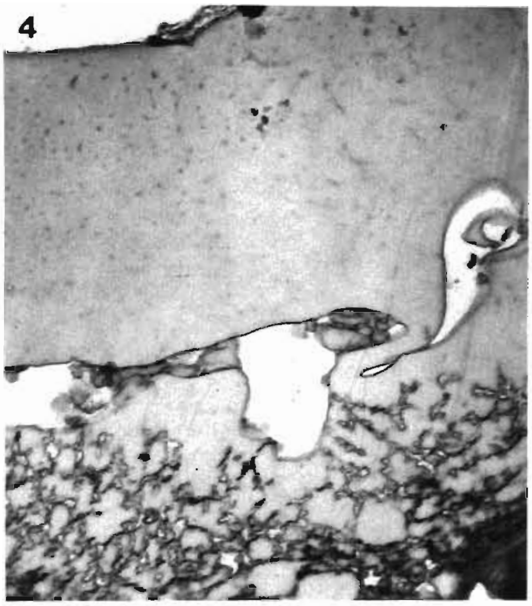
PLATE 1 →

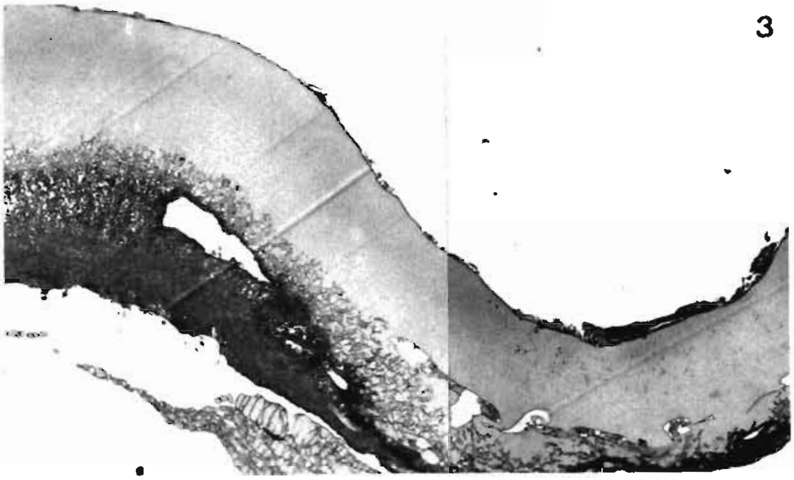
1-3. *Thinnfeldia indica* Feistmantel, micrographs of cross-section of an infected cuticular membrane showing 'disturbed' sub-cuticular layer. 1, x 4400; 2, x 7100; 3, x 7100.

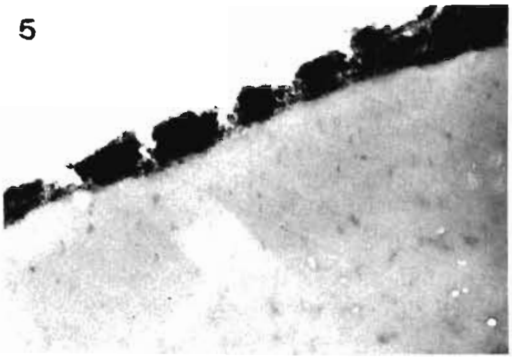
4. A part of the same enlarged further to show the amorphous matrix and aggregations of irregular bodies at the sub-cuticular level, x 21000.

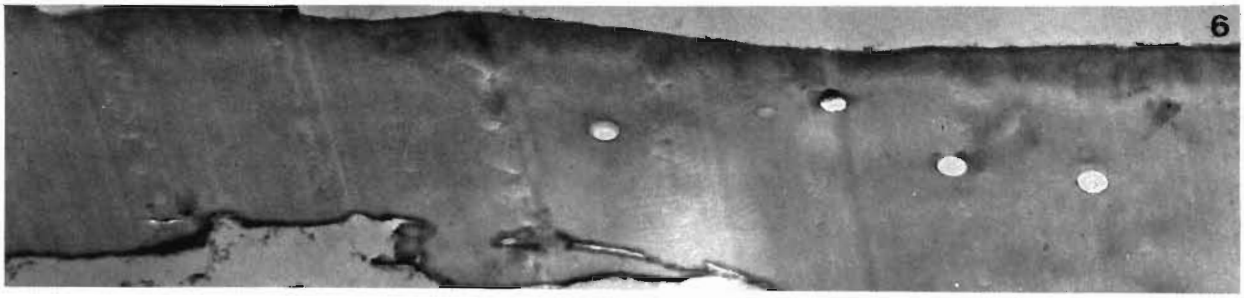
5. Epicuticular wax on the infected cuticular membrane, x 21000.

6-7. Micrograph of the cuticular membrane of an uninfected leaf showing the amorphous matrix and cuticular pegs, x 8800.









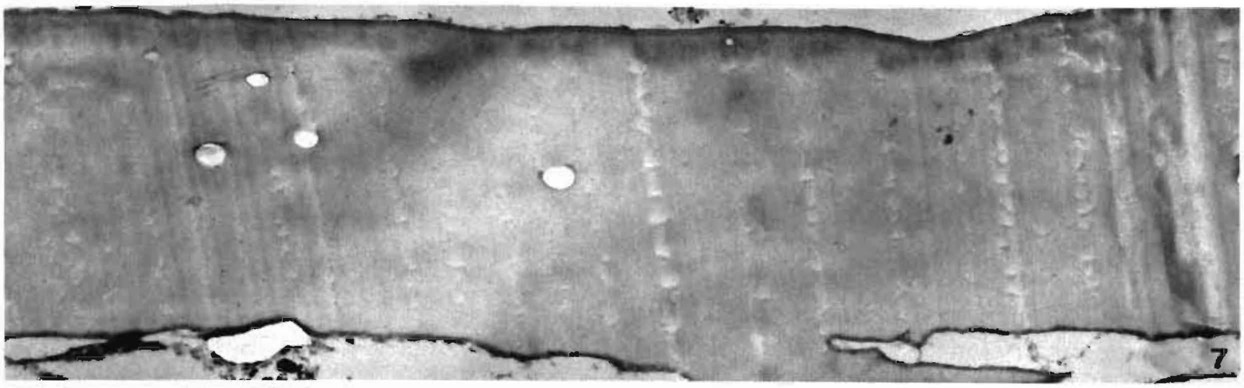


PLATE 1

infecting fungi. Certain other structural deformities of the amorphous matrix are also seen in the disturbed zone as discussed by Maheshwari and Bajpai (1996).

REMARKS

As a result of the available information on the fine structure of uninfected and infected cuticular membranes of *Thinnfeldia indica,* it has been classified under the Holloway's Type-6. Both the cuticular membranes described here possess an amorphous homogeneous region of significant thickness. The well-developed anticlinal flanges indicate a machinery to minimise water loss from the leaf surface, but whether this information supports the views that the climate of the region during the Early Cretaceous was warm tropical is open to question. From the palaeogeographical maps of that period it is evident that India lay in the sub-temperate zone, south of the palaeoequator.

Degradation of the epicuticular waxes may be due to burial and diagenesis. The consistency in the fine structure of both the normal and infected cuticular membranes demonstrates that diagenetic factor did not disturb the structural identity but the fungal infection did result in degradation of the cuticular membrane on the inner surface. Fungi are known to secrete cutin-hydrolysing enzymes, such as, cutinase (Kolattukudy, 1980).

The most common plant fossils are compression fossils of leaves that have lost their carbonified crust. Such fossils frequently occur in argillaceous shales, and in extremely rare cases in arenaceous sediments. The carbonified crust consists of an almost unaltered cuticle and badly crushed unidentifiable remnants of other tissues of the leaf. How and when the cuticle is lost from the compression fossils is yet not very clearly known. It is possible that the cuticle along with other tissues of the leaf is lost during transport due to abrasion, or more likely it is lost due to microbial activities during diagenesis.

A host of phytopathogens is known to grow under natural conditions on both living and dead plants. In the fossil record, fungal plant pathogens have a long history. In the Gondwana deposits, epiphyllous fungi and bacteria have been reported on certain Permian and younger leaves. It has been found that such leaves invariably do not have a sufficiently well-preserved cuticle. In such cases the initial breakdown of the cuticle by cutinase is probably followed by a bacterial attack as has recently been observed in a *Glossopteris* leaf from a grey shale associated with a Late Permian coal (Bajpai & Tewari, 1990). It would thus seem that degradation of the cuticle in compression fossils is induced by fungi , and in later stages is taken over by bacteria.

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REFERENCES

Archangelsky S, Taylor TN & Kurmann MH 1986. Ultrastructural studies of fossil plant cuticles: *Ticoa harrisii* from the early Cretaceous of Argentina. *Bot. J. Linn. Soc.* **92:** 101-116.

Bajpai U & Maheshwari HK 1988. Epiphyllous fungi from the Gondwana. *In:* Venkatachala BS & Maheshwari HK (Editors)—*Concepts, limits and extension of the Indian Gondwana. Palaeobotanist* **36**:210-213.

Bajpai U & Tewari R 1990. Plant fossils from upper beds of Raniganj Formation in Jharia Coalfield. *Palaeobotanist* **38**: 43-48.

Cutter EG 1982. *Plant anatomy.* Part I. *Cells and tissues.* Edward Arnold, London, 1978.

Holloway PJ 1982. Structure and histochemistry of plant cuticular membranes: an overview. *In:* Cutler DF, Alvin KL & Price CE (Editors) —*The plant cuticle* : 1-32. Academic Press, London.

Kolattukudy PE 1980. Biopolyester membranes of plants: cutin and suberin. *Science* **208**: 990-1000.

Last FT 1955. *Trans. Br. mycol. Soc.* **38**: 221 (not seen in original).

Maheshwari HK 1986. *Thinnfeldia indica* Feistmantel and associated plant fossils from the Tiruchirapalli District, Tamil Nadu. *Palaeobotanist* **35**:13-21.

Maheshwari HK & Bajpai U 1996. Biochemical degradation of the cuticular membrane in an Early Cretaceous frond: a TEM study. *Curr. Sci.* **70**:933-935.

Maheshwari HK & Bajpai U 1997. Ultrastructure of the "cuticular membrane" in two Late Triassic corystospermaceous taxa from India. *Palaeobotanist* **45**: 41-49.

Nip M, Tegelaar EW, de Leeuw JW, Schenk PA & Holloway PJ 1986. A new non-saponifiable highly aliphatic and resistant biopolymer in plant cuticles. *Naturwissenschaften* **73**: 579-585.

Tegelaar EW, Kerp H, Visscher H, Schenk PA & de Leeuw JW 1991. Bias of the paleobotanical record as a consequence of variations in the chemical composition of higher vascular plants. *Paleobiology* **17**: 133-144.

Evolution and comparison of the Gondwana flora and the Cathaysia flora

Shaila Chandra & Sun Keqin

Chandra Shaila & Sun Keqin 1997. Evolution and comparison of the Gondwana flora and the Cathaysia flora. *Palaeobotanist* **46** (3) : 35-46.

By the Late Palaeozoic, during the Late Carboniferous and Permian, the global vegetation was distinguishable into four main geobotanical provinces : Euramerican, Angara, Gondwana and Cathaysia. The largest of these four provinces was the Gondwana Supercontinent comprising two segments—(i) Western Gondwana consisting of South America and Africa possibly Iran-Afganistan, and (ii) Eastern Gondwana consisting of Antarctica, Australia and India. The Cathaysia flora is the main flora of the Carboniferous and the Permian mainly distributed in present day China, Korea, Japan, Laos, Thailand, Indonesia and Malaysia. It is generally accepted that a typical Gondwana flora is of Early Permian to Late Triassic in age. India and China are most important and significant and well studied regions for Gondwana and Cathaysia floras in Asia. A comparative account of the Gondwana and Cathaysia flora, their origin, development and extinction are reviewed and discussed in the foregoing pages. Mixed floras of Cathaysian and Gondwanian affinities from Qinghai-Xizang Plateau (Tibet) and Kashmir are also reviewed and discussed.

Key-words— Evolution, Gondwana flora, Cathaysia flora.

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सारांश

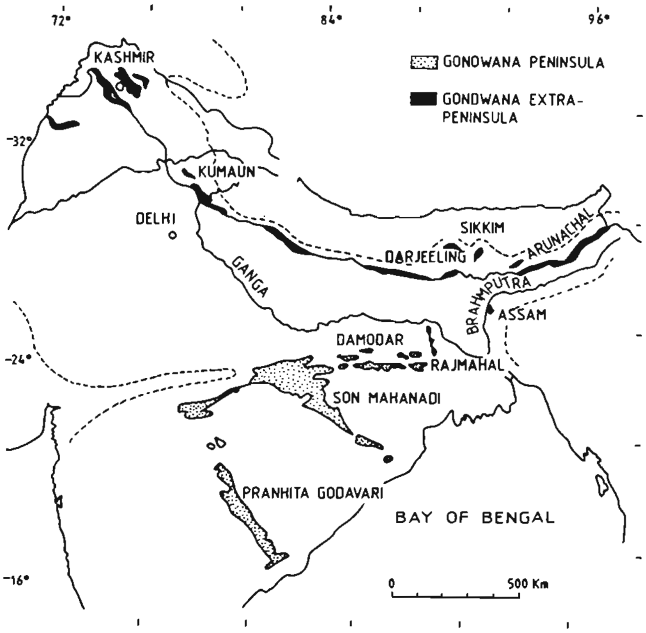
गोंडवाना एवं कैथेसिआ वनस्पतिजातों का विकास और तुलना

शैला चन्द्रा एवं सन केकिन

अनंतिम कार्बनीफेरस से परमियन काल तक भूमण्डलीय वनस्पति को यूरामेरिकन, अंगारा, गोंडवाना और कैथेसिआ नामक चार भूवनस्पतिक प्रदेशों में विभाजित किया जा सकता है। इन सभी में गोंडवाना महाद्वीप सबसे बड़ा था। इसके दो भाग थे (1) पश्चिमी गोंडवाना जिसमें दक्षिण अमेरिका एवं अफ्रीका, सम्भवतया ईरान और अफगानिस्तान थे, (2) पूर्वी गोंडवाना जिसमें अंटार्कटिका, ऑस्ट्रेलिया एवं भारत थे। कार्बनीफेरस काल का मुख्य वनस्पतिजात कैथैसिआ वनस्पतिजात था। परमियन वनस्पतिजात मुख्यतया चीन, कोरिया, जापान, लाओस, थाइलैंड, इंडोनेशिया एवं मलेशिया में मिलता है। सामान्यतया यह माना जाता है कि गोंडवाना वनस्पतिजात प्रारम्भिक परमियन से अनंतिम ट्रायेसिक आयु का है। गोंडवाना एवं कैथेसिआ वनस्पतिजातों के अध्ययन हेतु भारत एवं चीन दो मुख्य देश हैं। इस शोध-पत्र में कैथेसिआ और गोंडवाना वनस्पतिजातों की तुलना, उनकी उत्पत्ति, विकास एवं विलुप्तीकरण पर विवेचना की गई है। इसके अतिरिक्त कैथेसिआ और गोंडवाना के वनस्पतिजातों से सजातीयता व्यक्त करने वाले मिश्रित वनस्पतिजातों पर भी विवेचना की गई है।

LOWER GONDWANA FLORA OF INDIA

THE Gondwana of India can broadly be classified into two main areas—Peninsular and Extra-peninsular (Map 1). The flora is generally divided into Lower Gondwana and Upper Gondwana and sometimes a third as Middle Gondwana in between the Lower and Upper. The Lower Gondwana flora is known as the Glossopteris flora after its main element *Glossopteris* and is richly preserved in five formations—Talchir, Karharbari, Barakar, Barren Measures or Kulti and Raniganj in ascending order (Table 1). The Lower Gondwana is typically developed in a series of basins in the Damodar, Son-Mahanadi and Narmada grabens. The Extra-peninsular occurrences are in Kashmir, Kumaun Hills, Bhutan, Sikkim, Darjeeling and as far as Assam in the north east. The



Map 1—Peninsular and extra-peninsular Gondwana basins of India.

base of the Peninsular Gondwana is characterised by glacial or fluvio-glacial boulder beds which is recognisable in all the intracratonic basins of the country. After the ice cap receded, the glacial event was followed by deposition of sands, shales, marshes and lacustrine environments for about 40 million years. There were occasional incursions of the sea which left behind intermittent thin marine deposits.

The Lower Gondwana flora includes few characteristic plants, most of them are largely restricted to the Gondwana countries. The botanical relationship of most of the fossil forms is tentative as few are known with their fructifications. The flora is mainly represented by bryophytes, lycophytes, arthrophytes, filicophytes and amongst the gymnosperms Cordaitales, Cycadales, Coniferales, Ginkgoales and Glossopteridales. The peninsular Lower Gondwana taxa are shown in Table 2. A complete upto-date list of taxa in various basins has recently been given by Maheshwari (1992).

As is evident there are still important gaps in our knowledge regarding Lower Gondwana plants. Recent observations prove the existence of bacteria, algae and fungi in various formations. The bryophytes appeared quite early in the Permian but their absence in the Middle and the Late Permian is intriguing though they are recorded again in Triassic and Jurassic. The lycopods as such are rarely reported from the late Early Permian and existed right up to the Late Permian. Lycopods do not show variety in forms though they are present in appreciable number throughout as evidenced by spores

Table 1 — Lower Gondwana Formations of India

			LITHOSTRATIGRAPHIC UNITS					
STANDARD SCALE			DAMODAR VALLEY	SATPURA BASIN	SON VALLEY	RAJMAHAL REGION	WARDHA VALLEY	MAHANADI VALLEY
PERMIAN	TATARIAN		RANIGANJ FORMATION	BIJORI FORMATION	PALI FORMATION	RANIGANJ FORMATION	KAMTHI FORMATION	KAMTHI FORMATION
	KAZANIAN		KULTI FORMATION	MOTUR FORMATION			KULTI FORMATION	KULTI FORMATION
	ARTINSKIAN	UPPER	BARAKAR FORMATION	BARAKAR FORMATION	BARAKAR FORMATION	BARAKAR FORMATION	BARAKAR FORMATION	BARAKAR FORMATION
		LOWER	KARHARBARI FORMATION	KARHARBARI FORMATION	KARHARBARI FORMATION			KARHARBARI FORMATION
	SAKMARIAN		TALCHIR FORMATION	TALCHIR FORMATION	TALCHIR FORMATION	TALCHIR FORMATION	TALCHIR FORMATION	TALCHIR FORMATION

Table 2 — Lower Gondwana flora of peninsular India

Bryophyta	-		*Hepatites*	
			Umariaphyllites	
			Talchirophyllites	
			Sakasenaphyllites	
Lycophyta	-		*Cyclodendron*	
Arthrophyta	-		Common	Rare
			Phyllotheca	*Barakaria*
			Lelstotheca	*Gondwanophyton*
			Schizoneura	*Bengalia*
			Raniganjia	*Benlightfootia*
			Trizygia	
Filicophyta	-		Common	Rare
			Neomariopteris	*Trithecopteris*
			Damudopteris	*Leleopteris*
			Dizeugotheca	*Gondwanidium*
			Asansolia	*Cuticulatopteris*
			Damudosaurus	*Cuticulatopteris*
Gymnospermophyta	-	Cordaitales	Common	Rare
			Noeggerathiopsis	*Cordaites*
			(=Pantophyllum)	*Euryphyllum*
		Coniferales	Common	Rare
			Buriadia	*Walkomiella*
				Paranocladus
				Searsolia
		Cycadales	Common	Rare
			Pseudoctenis	*Senia*
				Pteronilssonia
		Ginkgoales	Common	Rare
				Ginkgophyllum
				Platyphyllum
				Handapaphyllum
				Saportaea
				Rhipidopsis
				Psygmophyllum
				Ginkgoites
		Glossopteridales	Leaf forms	
			Common	Rare
			Glossopteris	*Palaeovittaria*
			Gangamopteris	*Rhabdotaenia*
			Noeggerathiopsis	*Belemnopteris*
				Rubidgea
				Surangephyllum
			Fertile forms	
			Common	Rare
			Dictyopteridium	*Denkania*
			Plumsteadiostrobus	*Jambadostrobus*
			Scutum	*Venustostrobus*
			Ottokaria	*Veekaysinghia*
			Lidgettonia	*Birbalia*
			Eretmonia	*Senotheca*
			Glossotheca	*Nesowalesia*
				Kendostrobus
				Indocarpus
Woods		*Dadoxylon* and many others of unknown affinities		
Root		*Vertebraria*		
Scales	-	*Sceroma* and many others		

and megaspores. Arthrophytes seem to be an ancient group of plants persistently and uniformly represented by stems and spores throughout the Permian and variety of forms in the Middle and Late Permian. Fern and fern allies also developed in the same pattern as arthrophytes showing their maximum development in the Late Permian. The class gymnosperms with its several orders evolved steadily throughout the Permian. Conifers appeared quite early on the scene but they never formed conspicuous vegetation and their occurrence is also very localised. Cordaitales and allied forms show steady development in Early and Late Permian but they were altogether absent in the Middle Permian. Cycads and Ginkgoales appeared much later in the Permian and never formed a uniform and conspicuous vegetation. *Gangamopteris* of the Glossopteridales appeared first in the Early Permian and formed major constituent of the vegetation along with *Noeggerathiopsis*. *Glossopteris* appeared almost simultaneously and quickly occupied the major part of the land forming conspicuous vegetation of the Middle and Late Permian and lingered up to the Triassic (Chandra, 1992). The basic pattern of the Gondwana flora was laid in the Talchir as patchy not so dense vegetation in pockets under cold deglaciated conditions. The first lowland, coal-swamp, deciduous forest dominated by *Gangamopteris/ Noeggerathiopsis* shrubs and trees developed during Karharbari period under not so cold but humid conditions. *Glossopteris* dominated dense, deciduous, lowland coal swamp forests appeared during Barakar time under warm and humid climatic conditions. The first upland floras appeared in the Kulti time were not so dense forest under warm, but not so humid conditions. Again there was shift of floras in the low lying river valleys in the Raniganj time to give rise to very dense, swampy vegetation dominated by *Glossopteris* and allied forms under very warm and humid conditions. At the same time some of the *Glossopteris* dominated deciduous forests developed in upland areas under warm but not so humid climate represented by Kamthi. It can be seen that arborescence or tree habit, production of spore/ pollen and development of dispersal mechanism, production of seeds and their dispersal mechanism and wide varieties of plant communities to grow under varied ecological conditions all developed steadily and simultaneously throughout the Lower Gondwana (Chandra, 1992).

Lower Gondwana Flora of Kashmir

The Permian Gondwana of Kashmir region, laid under terrestrial lakes and lagoons, is stratigraphically known as *Gangamopteris* beds. It includes five different floral and stratigraphical beds, viz., Nishatbagh, Vihi, Marahom, Munda and Mamal. These floral beds correlate with the Talchir, Karharbari and the Barakar formations of the Peninsular India. The flora comprises (Table 3) *Glossopteris, Gangamopteris, Pantophyllum (=Noeggerathiopsis), Palmatopteris, Cordaites, Neomariopteris* and *Schizoneura* and exclusive forms like *Gondwanophyton, Kashmiropteris, Kawizophyllum, Psygmophyllum* and *Lepidostrobus* (Kapoor, 1977; Bajpai & Maheshwari, 1987, 1995; Maheshwari, 1992). Like Peninsular India cool to warm and humid climatic conditions are presumed during Permian Gondwana times in Kashmir.

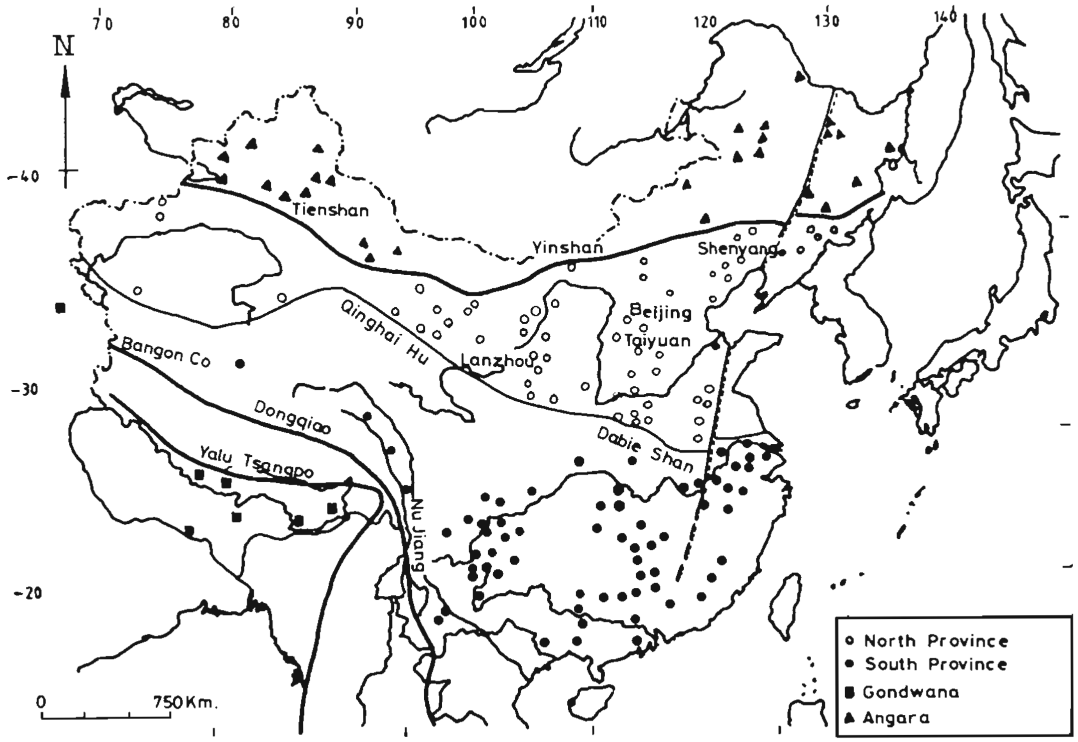
Table 3—Lower Gondwana flora from Kashmir

Exclusive Forms	
Glossopteris	*Gondwanophyton*
Gangamopteris	*Kashmiropteris*
Pantophyllum	*Kawizophyllum*
Palmatopteris	*Psygmophyllum*
Ceraites	*Lepidostrobus*
Neomariopteris	
Schizoneura	

Singh *et al.* (1982) and Pant *et al.* (1984) have reported a number of Cathaysian elements in the Permian of the Kashmir Valley. They are *Lobatannularia ensifolia, Parasphenophyllum thonii* var. *minor (=Sphenophyllum thonii* var. *minor), Rajahia mamalensis, Lobatannularia lingulata, Lobatannularia sinensis* var. *curvifolia, Sphenophyllum thonii* var. *archangelskyii* and *Sphenophyllum thonii* var. *waltonii*.

CATHAYSIA FLORA OF CHINA

The term Cathaysia flora was proposed by Halle (1935) for the entire Carboniferous and Permian plant succession in East Asia. China is one of the



Map 2—Northern and southern Permian subprovinces of China (after Li Xingxue & Yao Zhaoqi, 1985).

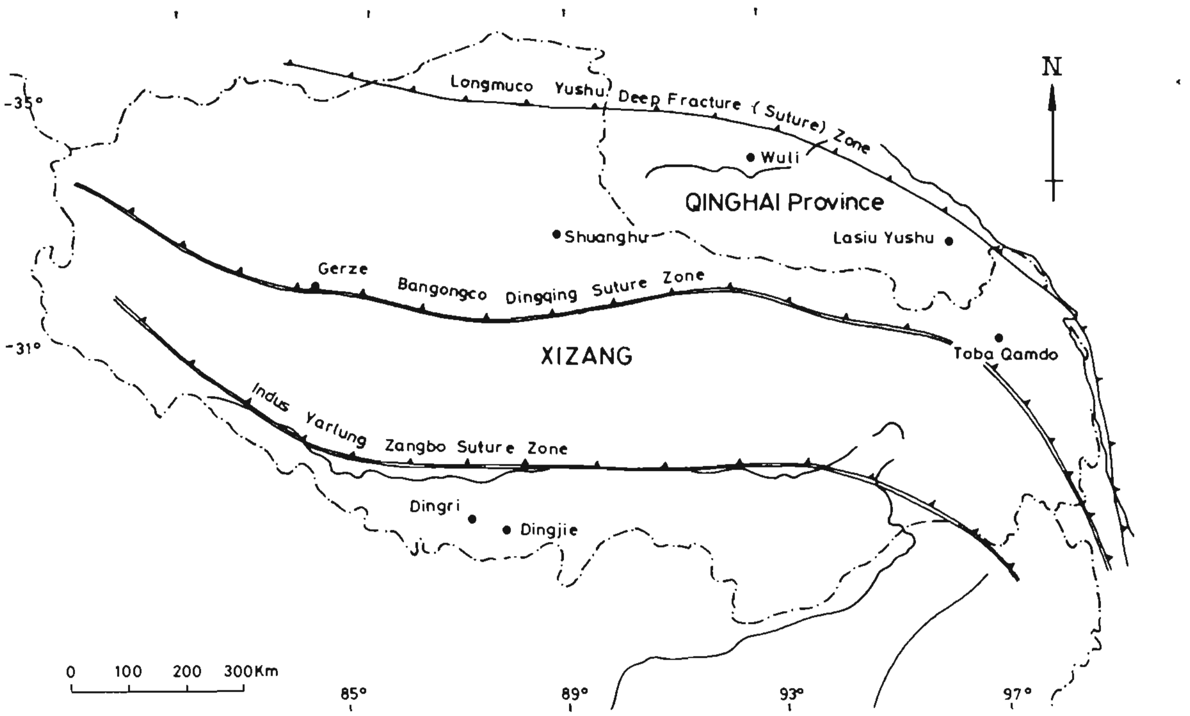
most important and significant location for the Cathaysia flora in Asia. The Chinese Cathaysian floral province is divided into northern and southern subprovinces (Map 2) with a geographical boundary along the Kunlun-Qinling Mountains (Li Xingxue & Yao Zhaoqi, 1985). The northern floral subprovince was located in an equatorial position and had a tropical climate during the Carboniferous and Permian. Fossil plants of north subprovince occur extensively through North China and are widely distributed in a number of major coalfields namely Hebei, Shanxi, Shandong and Inner Mongolia, etc. The Permo-Carboniferous section near Taiyuan is well exposed, rich in both animal and plant fossils

Table 4—Distribution of common fossil plants of the Permian in North China

SPECIES	EARLY PERMIAN		LATE PERMIAN	
	Lower Part	Upper part	Lower Part	Upper Part
Cathaysiodendron acutangulum	+			
Cathaysiodendron incertum	+			
Lepidodendron posthumii	+			
Lepidodendron oculus-felis	+	+	+	
Stigmaria ficoides	+	+		
Stigmaria rugulosa	+			
Sphenophyllum costa	+	+		
Sphenophyllum emarginatum	+	+	+	
Sphenophyllum kawasakii	+	+	+	
Sphenophyllum minor	+	+	+	
Sphenophyllum neofimbriatum		+		
Sphenophyllum oblongifolium	+	+		
Sphenophyllum rotundatum			+	

Contd.

Sphenophyllum sino-coreanum			
Sphenophyllum spathulatum	+		
Sphenophyllum thonii	+	+	
Sphenophyllum verticillatum	+	+	
Bowmanites laxus		+	+
Calamites cistii	+	+	
Calamites suckowii	+	+	
Annularia gracilescens	+	+	
Annularia mucronata		+	+
Annularia orientalis	+	+	+
Annularia stellata	+	+	
Lobatannularia ensifolia		+	+
Lobatannularia heianensis			+
Lobatannularia lingulata		+	+
Lobatannularia sinensis	+		
Tingia carbonica	+	+	
Tingia hamaguchii	+	+	
Tingia partita			+
Plagiozamites oblongifolius			+
Sphenopteris firma		+	+
Sphenopteris gothanii		+	+
Sphenopteris tenuis	+	+	
Pecopteris arborescens	+	+	+
Pecopteris candollioides	+		
Pecopteris hemitellioides	+	+	+
Pecopteris hirta		+	+
Pecopteris lativenosa	+	+	
Pecopteris norinii	+	+	
Pecopteris orientalis	+	+	
Pecopteris polymorpha	+		
Pecopteris taiyuanensis		+	
Pecopteris unita	+	+	
Fascipteris hallei		+	
Alethopteris norinii	+	+	+
Protoblechnum wongii		+	
Odontopteris chui	+	+	
Odontopteris subcrenulata	+	+	
Mariopteris hallei	+	+	+
Callipteridium kuraiense	+	+	
Emplectopteris triangularis	+	+	
Emplectopteridium alatum	+	+	
Cathaysiopteris whitei	+	+	
Gigantonoclea hallei			+
Taeniopteris angustifolia			+
Taeniopteris mucronata	+	+	
Taeniopteris multinervis	+	+	
Taeniopteris norinii		+	+
Taeniopteris schenkii	+	+	
Taeniopteris shansiensis		+	
Pterophyllum daihoense	+	+	+
Psygmophyllum multipartitum			+
Cordaites principalis	+	+	+
Cordaites schenkii	+	+	



Map 3—Localities of mixed Gondwana and Cathaysian elements in China (after Li Xingxue & Xinyuan, 1994).

and has been considered as the stratotype for the Late Palaeozoic in North China. It is the type section for the Cathaysia flora. The Permian common plants in the northern floral subprovince are listed in Table 4. In South China the Upper Carboniferous is mostly marine with no evidence of reliable plant fossils and during the Permian there were frequent changes in sea and land and volcanic erruptions. The marine and non-marine alternating coal-bearing deposits are mainly distributed in Hunan, Fujian, Jiangxi, Guangdong, Jiangsu, Yunnan, Ghizhou and Sichan, etc. The southern floral subprovince is characterised by *Otofolium, Rajahia, Annularia pingloensis* (Sze), *Pecopteris echinata* Gu & Zhi, *Gigantopteris nicotianaefolia* (Schenpz), *Gigantonoclea acunminatiloba* (Shin), *Gigantonoclea guizhouensis* Gu & Zhi, *Ulmania* cf. *bronnii* Goeppert and some peculiar fertile genera including *Pectinangium, Gigantonomia, Gigantotheca* and *Distchotheca* (Li Xingxue *et al.*, 1995) and none of which have been found in the northern floral subprovince, some peculiar organ genera are commonly known in North China such as *Nystroenia, Astrocupulites* and some unique plants like *Pseudorhipidopsis, Procycas,* etc. which are not known in the southern floral subprovince. It is noteworthy that *Otofolium* and *Rajahia* have been recorded in the northern subprovince (Shen Guanglong, 1995). It is worth emphasizing that some typical Cathaysian genera, such as *Gigantopteris, Otofolium* and *Rajahia* are of very rare occurrences in the northern floral subprovince, while *Emplecopteris* and *Yuania* are restricted to rare appearance in the southern floral subprovince. So far, *Emplectopteridium* has never been recorded in the southern floral subprovince. Minor differences between the northern floral subprovince and southern floral subprovince reflect variations in floristic composition and terrestrial ecosystem in time and space.

The common plant species between south and north China are *Fascipteris* spp., *Lobatannularia multifolia* Konno & Assama, *Annularia shirakii* Kaw, *Gigantonoclea lagrelii* (Halle), *Cladophlebis permica* Lee & Wang, *Plaziozamites oblongifolius* Halle and *Pterophyllum eratum* Gu & Zhi. The

Table 5—Flora from Qinghai-Xizang Plateau

Shuanghu District, Northern Xizang (Li *et al.*, 1982)
Lobatannularia sp.
Annularia pingloensis (Sze) Gu & Zhi
Rajahia (Pecopteris) calceiformis Li & Yao
Pecopteris shuanghuensis Li & Yao
Gigantonoclea guizhouensis Gu & Zhi
Gigantonoclea meridionalis Li & Yao
Rhizomopsis gmmifera Gothan & Sze
Compsopteris contracta Gu & Zhi var. *Punctinervis* Li & Yao
Toba in Qamdo, eastern Xizang (Li *et al.*, 1982a).
Lepidodendron oculis-felis (Abbado) Zeiller
Sphenophyllum koboense Kobatake
Sphenophyllum cf. *sino-coreanum* Yabe
Paracalamites stenocostatus Gu & Zhi
Annularia pingloensis (Sze) Gu & Zhi
Lobatannularia multifolia Konno & Asama
Schizoneura manchuriensis Konno
Rajahia (Pecopteris) calceiformis Li & Yao
Rajahia (Pecopteris) pseudohemitelioides Konno
Rajahia (Pecopteris) qamdoensis Li, Yao & Deng
Pecopteris andersonii Halle
Fascipteris (Ptychocarpus) densata Gu & Zhi
Fascipteris stena Gu & Zhi
Compsopteris contracta Gu & Zhi
Gigantopteris dictyophylloides Gu & Zhi
Gigantopteris cf. *nicotiannaefolia* Schenk
Gigantonoclea miridionalis Li & Yao
Gigantonoclea spp.
Rhizomopsis gemmifera Gothan & Sze
Rhipidopsis pani Chow
Lasiu of Yushu, Southern Qinghai (Li & Yao 1981)
Lobatannularia multifolia Konno & Asama
Annularia cf. *pingloensis* (Sze) Gu & Zhi
Rajahia (Pecopteris) calceiformis Li & Yao
Compsopteris cf. *contracta* Gu & Zhi etc.

Wuli Southwestern Qinghai (Li 1988)
Rajahia (Pecopteris) calceiformis Li & Yao
Gigantonoclea spp.
Pecopteris sp. etc.
Dingri and Dingjie districts, South Xizang (Li *et al.*, 1991), Mixed Cathaysia Gondwana elements
Trizygia speciosa Royle
Austroannularia qubuensis (Hsü) Rigby
Paracalamites australis Rigby
Sphenophyllum thonii var. *minor* Sterzel
Asterotheca sp.
Pecopteris unita Brongniart
Cladophlebis qubuensis (Hsii) Li
Glossopteris communis Feistmantel
G. dingriensis Rigby
G. indica Schimper
G. intermittens (Feistmantel)
Vertebraria indica Royle
Scale leaf
Gerze District, Xiagangjiang
Strongly ribbed arthrophytes (e.g. *Phyllotheca*)
Cordaitean leaf-imprints (e.g. *Noggerathiopsis*)
Pecopteris aff. *arcuata* Halle
? Plagiozamites oblongifolius Halle
Kashmir Valley (Singh *et al.*, 1982 & Pant *et al.*, 1984)—Mixed Gondwana Cathaysia elements
Lobatannularia ensifolia
Lobatannularia lingulata
Lobatannularia sinensis var. *curvifolia*
Parasphenophyllum thonii var. *minor*
Rajahia mamalensis
Sphenophyllum thonii var. *archangelskyii*
Sphenophyllum thonii var. *minor*
Sphenophyllum thonii var. *waltonii*

Cathaysia flora is thus mainly composed of lycopods, sphenopsids, ferns, pteridosperms and cordaitean gymnosperms.

Qinghai-Xizang (Tibet) Flora

The palaeobotanical studies of the Permian plants in Qinghai-Xizang plateau have been made during past two decades. The Permian localities situated to the north of the Bangongco-Dengquen (Dingquine) suture of central Xizang are characterised by Cathaysian elements and belong to the South China province Map 3. The important Cathaysian elements found in the Shuanghu District in northern Xizang (Li *et al.*, 1982a), Toba in Qamdo eastern Xizang (Li *et al.*, 1982), Lasiu Yushu southern Xizang (Li & Yao, 1981) and Wuli of south eastern Qinghai (Li, 1986) are listed (Table 5).

Another flora in Xiagangiang of Gerze District is dominated by many strongly ribbed stem casts or arthrophytes (e.g., *Phyllotheca*) and cordaitean leaf imprints (*Noeggerathiopsis*) a feature rarely known in the Cathaysian flora, resembling rather closely plant forms of Gondwana. The flora is also associated with some forms of Cathaysian flora such as *Pecopteris* aff. *arcuata* Halle, ?*Plagiozamites oblongifolius* Halle. Therefore Xiagangiang flora is considered as a mixed flora of Cathaysian-Gondwana affinity by the Chinese palaeobotanists, though the flora is poorly preserved to be identified even up to generic level.

The most important and significant Permian flora of Gondwana affinities is that from the Qubu Formation recorded in the Dingri and Dingjie districts of South Xizang during last two decades (Hsü, 1973, 1976, 1978; Li, 1983; Li *et al.*, 1991). The final list of plant types include *Trizygia speciosa* Royle, *Austroannularia qubuensis* (Hsü) Rigby (=*Lobatannularia*), *Paracalamites australis* Rigby, *Sphenophyllum thonii* var. *minor* Sterzel, *Asterotheca* sp., *Pecopteris unita* Brongniart, *Cladophlebis qubuensis* (Hsü) Li, *Glossopteris communis* Feistmantel, *Glossopteris dingriensis, Glossopteris indica* Schimper, *Glossopteris intermittens* Feistmantel, *Vertebraria indica* Royle, scale leaf and stem. Accordingly, the Qubu flora is correlated with the Early Permian Barakar (Li *et al.*, 1991) or Karharbari Formations (Hsü *et al.*, 1990).

The reports of the mixed occurrence of Gondwana and Cathaysian elements in Kashmir and Qinghai-Xizang (Tibet) plateau in recent years have created much rethinking about the concept of Gondwanaland. Crawford (1974) suggested a modified concept of "Greater Gondwanaland" based on finds of index fossils in the Triassic of Tibet like *Daphniopsis* and *Lystosaurus.* Accordingly he stretched the boundary not only into Tibet but further north up to Tarim Basin block and the north western part of China. Supposed finds of *Glossopteris* (Hsü, 1973, 1976, 1978; Li, 1983; Li *et al.*, 1991; Hsü *et al.*, 1990) in South Xizang supported Crawford's ideas. Geological data by Stocklin (1981) also strengthened this idea based on his belief about the non-existence of an ocean between Xizang and India during Permian and accordingly the Tethyan oceanic trough between India and Xizang appeared only in the Mesozoic. The Indian scientists (Pant *et al.*, 1984; Maheshwari & Bajpai, 1987; Bajpai & Maheshwari, 1995) believe that the northern boundary of Gondwana did not reach beyond the Indus-Yarlung-Zangbo suture line during the Permian. According to them the mixing of the two floras should have been on more uniform basis which is not so far reported. In the absence of reproductive structures it is also difficult to believe that the same plants were growing in southern Xizang as in Gondwana territory.

There is no doubt that based on the present evidences from Qubu flora in southern Xizang and Mammal flora from Kashmir some kind of intermixing of Cathaysian and Gondwana elements has taken place. Some of the arguments put forward by various authors explain that :

1. The mixing of the Gondwana elements in Cathaysia flora and Cathaysian elements in Gondwana flora is because of migrants from either side (Sahni, 1935; Wagner, 1962; Konno, 1966; Ahmad, 1978).
2. The mixing of such foreign elements in the pure floras may not be really related but they could represent similar looking homoplastic forms (Plumstead, 1973; Asama, 1967; Meyen, 1967; Pant, 1975).
3. The mixing is partly because of migrants and partly due to homoplasy (Meyen, 1967; Lacey, 1975).
4. The mixing is probably because of scattered islands between the Indian and the Tibetan plateau giving way to intermixing but not uniformly and therefore few elements of either side could make it to the other side (Nakazawa & Kapoor, 1977).
5. This mixing is controlled by climatic conditions, continental positions and plate tectonics.

It is premature to draw the northern limit of Gondwana on the basis of (i) few, fragmentary, ill preserved specimens from only few localities in Xizang or Kashmir; (ii) in the absence of structural details and reproductive parts in similar looking forms; (iii) in the possibility of inaccurate identifications of the floristic elements; (iv) in the absence of other parameters, like palaeontological, palynological and detailed sedimentological data.

ORIGIN OF CATHAYSIA AND GONDWANA FLORAS

The Cathaysia flora is mainly composed of lycopods, sphenopsids, ferns, pteridosperms and cordaitean gymnosperms as is obvious from the list of fossil plants from north China province. The Cathaysia flora was located in the equatorial region under a tropical climate during the Carboniferous and Permian. Sun Keqin (1995, 1996) put forward that some obvious changes in floral components of the Cathaysia area occurred during the transition from the Early Carboniferous to Late Carboniferous which resulted in extinctions of many typical plant elements of the Lepidodendropsis flora and occurrences of a number of forerunners of the Cathaysia flora. Therefore, the Cathaysia flora did not originate from the Euramerica flora but it is derived from the globally identical Lepidodendropsis flora of the Early Carboniferous. From the beginning of the Namurian A, the Cathaysia flora gradually separates from the Lepidodendropsis flora. The Cathaysia flora can be recognized as an independent flora in the Early Late Carboniferous (Namurian B to C), belonging to the Early Cathaysia flora. The flora is characterised by a variety of oriental species of lycopods and many characteristic elements of ferns and pteridosperms, etc. The range of the Cathaysia flora is generally agreed upon from the beginning of the early Late Carboniferous to the end of the Permian in age. The most obvious changes of dry climate and tectonic movements caused extinction of the Cathaysia flora by the end of the Late Permian (Sun Keqin, 1996).

The origin of Gondwana flora is still not well understood as there are few records prior to Permian. The ancestors of this flora and their geographical situation are still controversial. The ancestors of Gondwana flora cannot be traced back in Carboniferous or older strata as there are serious gaps in our knowledge. Plumstead (1973) believed that the protoglossopterideae, whose remains were found from the Carboniferous beds of South Africa, were the ancestors of glossopterids of the post glacial coal-bearing Gondwana strata. The idea was discarded by many workers as these Protoglossopterid plants were actually smaller forms of *Glossopteris* and recovered from the same beds as others. Sahni (1939) believed that almost sudden and enigmatic arrival and spread of the Glossopteris flora is deeply rooted in the glacial episode itself which presumably might have triggered genetic changes of rapid evolutionary significance. Accordingly there might have been mass mutational changes in the then existing Carboniferous flora giving rise to *Glossopteris* and allied forms. Unfortunately, fossil history cannot substantiate Sahni's contention atleast in India as there are no reports of Late Carboniferous depositions and fossil plants. The extinction of the Glossopteris flora was gradual as many of its elements lingered on in the Triassic. Pant (1987) considered that mutational changes might have been responsible for the coming of new elements along with migrants from other parts.

CONCLUSION

Summarising the comparison between the Gondwana and the Cathaysia floras :

1. Both the flora are represented by major group of plants like lycophytes, arthrophytes, filicophytes and gymnosperms. At generic and specific level the two floras have characteristic and exclusive forms.
2. Some intermixing has taken place perhaps at generic level.
3. The two floras have originated from the globally identical Early Carboniferous floras.
4. A typical Gondwana flora is of Early Permian to Late Triassic in age. The Cathaysia flora is early Late Carboniferous to Permian in age.
5. The climate of Gondwana flora was essentially cool to warm temperate gradually ameliorating while that of Cathaysia was tropical as it was

located at equatorial region during the Carboniferous and Permian.

6. The extinction of the Glossopteris flora is gradual as some of the forms linger on in the Triassic. The Cathaysia flora, due to dry climate and tectonic movements, vanished by the end of the Late Permian.

REFERENCES

Ahmad F 1978. "Gondwanaland", the concept that failed. *Seventh Birbal Sahni Memorial Lecture*: 1-27. Birbal Sahni Institute of Palaeobotany, Lucknow.

Asama K 1967. Parallelism in Palaeozoic plants between Gondwanaland and Cathaysia land. *IUGS Symp. on Gondwana Stratigraphy, Buenos Aires* **2** : 127-134.

Bajpai U & Maheshwari HK 1987. Late Palaeozoic plant-geography of the Peri-Gondwana and evolution of the Kashmir Basin. *J. geol. Soc. India* **46** : 303-308.

Chandra Shaila 1992. Changing patterns of the Permian Gondwana vegetation. *Palaeobotanist* **40** : 73-100.

Crawford AR 1974. A greater Gondwanaland. *Science* **184** : 1179-1181.

Halle T 1935. On the distribution of the Late Palaeozoic flora in Asia. *Geor. Ann.* **7** : 106-111.

Hsü J 1973. On the discovery of some plant fossils from Mt. Jolmo Lungma region, South Tibet and its significance. *Acta bot. sin.* **15**(2) : 254-258.

Hsü J 1976. On the discovery of Glossopteris flora from Southern Xizang (Tibet) and its significance in geology and palaeogeography. *Sci. geol. sin.* **10** : 323-331.

Hsü J 1978. On the palaeobotanical evidence for continental drift and Himalayan uplift. *Palaeobotanist* **25** : 131-145.

Hsü J, Rigby JF & Duan Shuying 1990. Revision of Glossopteris flora from southern Xizang. *Sci. geol. sin.* **3** : 233-242 (in Chinese with English abstract).

Kapoor HM 1977. Gondwana of Kashmir—A reappraisal. *IV International Gondwana Symposium, Calcutta*.: 443-462.

Konno E 1966. Some connection between the Cathaysian flora and the Glossopteris flora in India during the Late Permian age. *Palaeobotanist* **14** : 26-35.

Lacey WS 1975. Some problems of mixed floras in the Permian of Gondwanaland. *In* : KSW Campbell (Editor)—*Gondwana geology* : 125-134. ANU, Canberra.

Li Xingxue 1983. Notes on three new species of Glossopteris flora from Qubu Formation, southern Xizang (Tibet), with discussion on the age of the Formation. *Acta palaeont. sin.* **22**(2) : 130-138. Nanjing (Chinese with English summary).

Li Xingxue 1986. The mixed Permian Cathaysian Gondwana flora. *Palaeobotanist* **35**(3) : 211-222.

Li Xingxue, Rigby J & Wu Yiming 1991. *A biostratigraphical comparison between the Gondwana floras of southern Xizang 1988* (Rocha/ Campos A.C.—Editor) : 533-538. Univ. de Sao Paulo, Brazil.

Li Xingxue, Shen Guanglong, Tian Baolin, Wang Shijun & Quyang Shu 1995. Some notes on Carboniferous and Permian floras in China. *In* : Li Xingxue *et al.* (Editors)—*Fossil floras of China through the geological ages* : 244-302. Guangdong Sci. & Technology Press, Guangzhou, China.

Li Xingxue & Yao Zhaoqi 1981. Discovery of Cathaysian flora in the Qinghai-Xizang plateau with special reference to its Permian phytogeographical province. *In : Geol. and Ecol. studies of Qinghai-Xizang Plateau* (Liu Dongsheng *et al.*—Editors) **1** : 145-148. Science Press, Beijing; Gordon & Breach, New York.

Li Xingxue & Yao Zhaoqi 1985. Carboniferous and Permian floral provinces in East Asia. *In : C.R. Qeme Congr. Int. Stratigr. et Geol. Carb., Urbana 1979*, **5** : 95-1012. Southern Illinois Univ. Press.

Li Xingxue, Yao Zhaoqi & Deng Longhua 1982b. An early Late Permian flora from Toba, Qamdo District, eastern Xizang. *Palaeont. Xizang* ***V***:17-44 (Chinese with English summary).

Li Xingxue, Zhu Jianan, Duan Shuying & Hu Yufan 1982a. Late Permian plants from northern Xizang. *Palaeont. Xizang* **V** : 1-16 (Chinese with English summary).

Maheshwari HK 1992. Provincialism in Gondwana floras. *Palaeobotanist* **40** : 101-127.

Maheshwari HK & Bajpai U 1987. Northern limits of the eastern Gondwana : palaeobotanical evidence. *Palaeobotanist* **36** : 354-368.

Meyen SV 1967. New data on relation between Angara and Gondwana Late Palaeozoic floras. *In* : Amos AJ (Editor)—*Proc. 1st Gondwana Symp.* Mar del Plata, Argentina.

Nakazawa K & Kapoor HM 1977. Correlation of the marine Permian in the Tethys and Gondwana. *Fourth International Gondwana Symposium, Calcutta, Section VI, Key Paper* : 1-18.

Pant DD 1975. The theory of continental drift in the light of recent researches. *3rd Birbal Sahni Memorial Lecture* : 1-22. Birbal Sahni Institute of Palaeobotany, Lucknow.

Pant DD 1987. The origin, rise and decline of Glossopteris flora, with notes on its palaeogeographical northern boundary and age. *Palaeobotanist* **36** : 106-117.

Pant DD, Nautiyal DD & Srivastava PC 1984. The occurrence of Cathaysian elements in Glossopteris flora of Kashmir. *Phyta* **4, 5** : 47-52.

Plumstead EP 1973. The Late Palaeozoic Glossopteris flora. *In* : Hallam A (Editor)—*Atlas of Palaeogeography* : 187-205. Elsevier Sci. Pub. Co., Amsterdam, London, New York.

Sahni B 1935. The relation of the Indian Gondwana flora with those of Siberia and China. *2nd Congr. on Stratigraphy Carboniferous, Heerlen* **1** : 517-598.

Sahni B 1939. Recent advances in Indian palaeobotany (Presidential Address : Bot. Sec.)—*Proc. 25th Indian Sci. Congr., Calcutta, Pt II, Lucknow University Studies*, no. 2.

Shen Guanglong 1995. Permian floras. *In* : Li Xingxue *et al.* (Editors)—*Fossil floras of China through the geological ages* : 127-223. Guangdong Science & Technology Press, Guangzhou, China.

Singh G, Maithy PK & Bose MN 1982. Upper Palaeozoic flora of Kashmir. *Palaeobotanist* **30**(2) : 185-232.

Stocklin J 1981. The Himalayan orogeny : Facts and fiction. *Expanding Earth Symposium*, : 42-43. Univ. of Sydney.

Sun Keqin 1995. Origin of the Cathaysia flora. *Abstracts* : 18-19. International Conference on Diversification and Evolution of Terrestrial Plants in Geological Time (ICTPG), Nanjing.

Sun Keqin 1996. Origin of the Cathaysia flora in Asia. *Palaeobotanist* **43**(2).

Wagner RH 1962. On mixed Cathaysia and Gondwana flora from SE Anatolia (Turkey). *C.R. Geme. Congr. Stratigr. et Geol. Carb. Heerlen (1958)* **3** : 745-752.

Surmaspora Singh & Rao from the Neogene sediments of southern India : its stratigraphic and botanical significance

C.G.K. Ramanujam, P.R. Reddy & H. Ramakrishna

Ramanujam CGK, Reddy PR & Ramakrishna H 1997. *Surmaspora* Singh & Rao from the Neogene sediments of southern India : its stratigraphic and botanical significance. *Palaeobotanist* **46** (3) : 47-50.

The paper deals with the occurrence of *Surmaspora (S. karii)* from the subsurface Miocene sediments of Godavari Basin in Andhra Pradesh and Cauvery Basin in Tamil Nadu and highlights its stratigraphic and botanical significance.

Key-words—Palynology, *Surmaspora*, Miocene, South India.

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सारांश

दक्षिणी भारत के निओजीन कालीन अवसादों से प्राप्त *सुरमास्पोरा* सिंह व राव : इसका स्तरिकीय एवं वनस्पतिक महत्व

सी.जी.के. रामानुजम, पी.आर. रेड्डी एवं एच. रामकृष्ण

प्रस्तुत शोध-पत्र में तमिल नाडु में कावेरी द्रोणी तथा आँध्र प्रदेश में गोदावरी द्रोणी के उपसतही मायोसीन युगीन अवसादों से प्राप्त *सुरमास्पोरा (सु० कराई)* का वर्णन किया गया है तथा इसके स्तरिकीय एवं वनस्पतिक महत्व की विवेचना की गई है।

THE genus *Surmaspora* was instituted by Singh and Rao (1984) for fairly large trilete spores with laesural arms surrounded by prominently thick, ribbon-like labra, globular thickenings at ray ends and verrucate sculpture all over. Two species of *Surmaspora* are known so far, viz., *S. sinuosa* from the Surma Group (Lower Miocene) of Jaintia Hills, Meghalaya (Singh & Rao, 1984) and *S. karii* from the Meenakunnu phase II (Miocene) of Cannanore District in Kerala (Rao & Rajendran, 1996).

The present contribution deals with the occurrence of *Surmaspora (S. karii)* from the subcrops of Godavari Basin in Andhra Pradesh and Cauvery Basin in Tamil Nadu, and highlights the stratigraphic importance and botanical affinities of this spore type.

MATERIAL AND METHODS

The material consists of a number of borewell palynosamples from the onshore Narsapur well No. 2 (NSP 2) in the Godavari Basin of Andhra Pradesh; and a borewell RP-40, 10 km north-east of Jayamkondam in the Jayamkondam block and a few kilometers south of the III mine of Neyveli lignite (South Arcot District) in the Cauvery Basin of Tamil Nadu. Eighty six palynosamples (Neogene) covering the depth range 50 to 1180 m of NSP-2 borewell in the Godavari Basin were studied, of which 27 samples of clay and fine sandstone from the depth sequence 660 to 1000 m have yielded *Surmaspora* spores. From the borewell RP-40 near Jayamkondam in the Cauvery Basin the Miocene lignite samples (4) from the depth range 156.60 to 161.40 m have yielded *Surmaspora* spores. The samples consisting of carbonaceous clays and lignites were treated with HCl, HF and HNO_3 followed by bleaching in 3-5% solution of KOH. Heavy liquid (mixture of Potassium iodide and Cadmium iodide) treatment was employed for concentrating the palynomorphs recovered from the clays of Narsapur well No. 2. The slides were made with DPX mountant. Trinocular Research Microscope of Olympus make (CHS-TR-PCD) with semiautomatic photomicrographic system has been used for morphographic study and photography.

Genus —*Surmaspora* Singh & Rao 1984 emended

Type species — *Surmaspora sinuosa* Singh & Rao 1984

Original diagnosis — Miospores triangular to sub-triangular with broadly rounded apices. Trilete, y-rays extend up to 3/4 of the radius, surrounded by a thick labra having globular thickenings at the ray ends. Exine verrucose, verrucae generally sparsely spaced.

Emended diagnosis — Miospores triangular to sub-triangular with broadly rounded apices. Trilete, y-rays extend up to 3/4 of the radius, laesural arms surrounded by a thick, ribbon-like labra, globular thickenings at ends of laesural arms often prominent. Exine verrucate all over. Verrucae sparsely or densely spaced, when densely spaced adjacent verrucae laterally fuse to form pseudoreticulate condition.

Remarks — The spores of *Surmaspora karii* described earlier by Rao and Rajendran (1996) and presently recorded from Godavari and Cauvery Basins show densely verrucate condition all over with the neighbouring verrucae often coalesced to form pseudoreticulate condition. Figure 3 of the type species *S. sinuosa* provided by Singh and Rao (1984) also shows locally densely placed undulating verrucae with occasional coalescence. It is therefore felt that the generic diagnosis of *Surmaspora* should be suitably emended to incorporate this particular aspect.

Surmaspora karii Rao & Rajendran 1996

Pl. 1, figs 1-5

Description — Miospores triangular to sub-triangular with smoothly rounded apices, 42-72 x 72-77 μm, trilete, laesural arms extending up to 3/4 of radius, surrounded by conspicuously thick (5.6-8.0 μm) ribbon-like labra, additional globular thickenings seen often at ends of laesural arms, in some instances such thickenings not prominent. Exine 3-6.5 μm thick, densely verrucate on proximal and distal facets; verrucae thick (2.5 x 4.5 μm) often irregular, undulating, show lateral coalescence to form pseudoreticulate condition. Fused verrucae form wavy or undulating muri.

Remarks — The specimens from Godavari (Pl. 1, figs 1, 2, 4) and Cauvery (Pl. 1, figs 3, 5) Basins are exactly similar to *Surmaspora karii* from the Cannanore district of Kerala and accordingly have been placed in the same species. *Surmaspora sinuosa* from the Surma Group of Meghalaya (Singh & Rao, 1984) shows somewhat sparsely spaced irregular, often wavy verrucae. *Surmaspora verrucata* from Kutch, Gujarat (see Singh & Rao, 1984) does not appear to be a spore type of *Surmaspora* as it lacks thick ribbon-like labra, the most diagnostic feature of this genus.

DISCUSSION

The highly characteristic sporomorph *Surmaspora (S. sinuosa)* was originally recorded from the Lower Miocene Surma Group in Meghalaya (Singh & Rao, 1984; Rao & Singh, 1987). Subsequently *S. karii*, another species of this genus, was recorded from the Miocene outcrops of the Cannanore District in Kerala (Rao & Rajendran, 1996). Spores resembling exactly *S. karii* are now documented from the Miocene sediments (subsurface) of the Godavari Basin in Andhra Pradesh and Cauvery Basin in Tamil Nadu. This clearly indicates that *Surmaspora* is of stratigraphic significance, and may probably constitute a marker spore type for the Miocene strata.

In the Godavari, Cauvery and Kerala Basins, alongwith *Surmaspora karii* spores, *Crassoretitriletes vanraadshooveni* has also been encountered repeatedly and one can notice striking similarity between both these taxa in size, shape and ornamentation. In both of them, the exine all over is of

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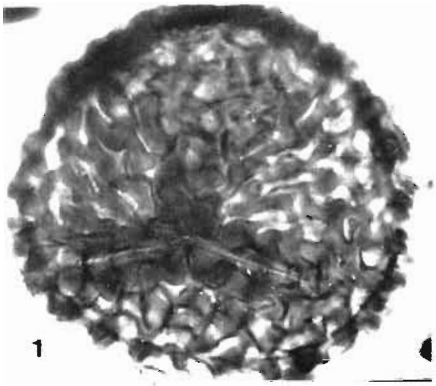
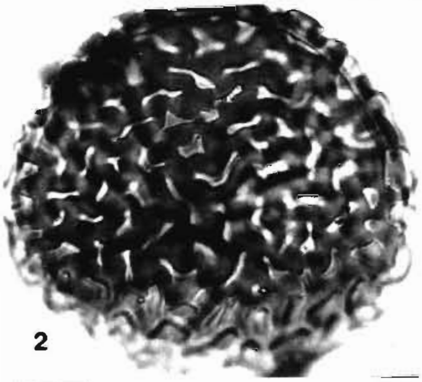
PLATE 1 ⟶

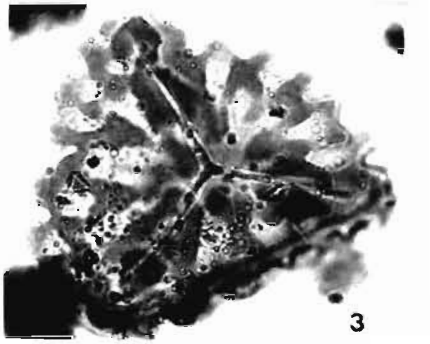
(Unless otherwise mentioned all figs. x 750)

1, 2, 4. *Surmaspora karii* from NSP 2 borewell, Godavari Basin.

3, 5. *Surmaspora karii* from a borewell, 10 km north-east of Jayamkondam in Cauvery Basin (fig. 5 x 500).


1


2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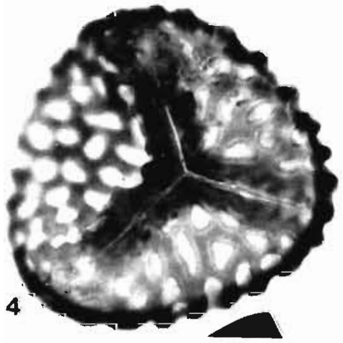
4

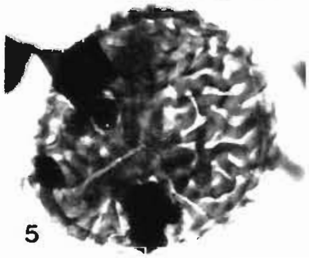
5

PLATE 1

heavily reticulate type with more or less sinuous muri. *Crassoretitriletes* is, however, distinguishable from *Surmaspora* in lacking prominently thick, ribbon-like labra and globular thickenings at the tips of laesural arms.

Comments on botanical affinities—The botanical affinities of *Surmaspora* were considered unknown by the earlier workers (Singh & Rao, 1984; Rao & Rajendran, 1996). However, the overall morphography of the *Surmaspora* spore type clearly indicates that there should be no two opinions regarding its filicinean affiliation. The spores of the modern *Actinopteris australis* of Adiantaceae resemble *Surmaspora* rather strikingly in the possession of thick, ribbon-like labra and dense verrucate sculpture with some of the verrucae coalescing locally (Nayar *et al.*, 1964). The collar-like equatorial ridge (cingulum) in the spores of *A. australis,* however, facilitates easy differentiation of *Actinopteris* from *Surmaspora.*

Similarly, the spores of *Lygodium smithianum* (Nayar *et al.*, 1964) and *L. flexuosum* (Santa Devi, 1977) of Schizaeaceae resemble *Surmaspora* in some important features. Thus *L. smithianum* is comparable to *S. karii* in having conspicuously thick, ribbon-like labra and densely verrucate ornamentation on distal side. The granular proximal surface and the distinct equatorial ridge, however, demarcate the spores of *L. smithianum* from *S. karii.* The spores of *Lygodium flexuosum* resemble *S. karii* in the possession of verrucate sculpture all over, with the neighbouring verrucae coalescing. The thick ribbon-like labra seen in *S. karii,* however, is not seen in *L. flexuosum* spores.

In view of the impressive similarity with *Crassoretitriletes vanraadshooveni,* which is affiliated with *Lygodium microphyllum* (Germeraad *et al.*, 1968), we are of the opinion that *Surmaspora (S. karii)* is also related to *Lygodium,* probably to some extinct species of the Schizaeaceae.

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REFERENCES

Germeraad JR, Hopping CA & Muller J 1968. Palynology of Tertiary sediments from tropical areas. *Rev. Palaeobot. Palynol.* **6**: 189-348.

Nayar BK, Lata P & Tiwari LP 1964. Spore morphology of the ferns of west tropical Africa. *Pollen Spores* **6**: 544-582.

Rao MR & Rajendran CP 1996. Palynological investigation of Tertiary lignite and associated sediments from Cannanore, Kerala, India. *Palaeobotanist* **43**: 63-82.

Rao MR & Singh HP 1987. Palynology of Barail (Oligocene) and Surma (Lower Miocene) sediments exposed along Sonapur-Badarpur Road section, Jaintia Hills, Meghalaya and Cachar (Assam), Part III. Pteridophytic spores. *Palaeobotanist* **35**: 267-280.

Shanta Devi 1997. *Spores of Indian ferns.* Today & Tomorrow's Printers & Publishers, New Delhi.

Singh HP & Rao MR 1984. *Surmaspora,* a new pteridophytic spore genus recovered from the Tertiary sediments of Meghalaya and Assam. *Curr. Sci.* **52**: 803-805.

Palynology of the Late Tertiary sediments (DSDP Site 218) in the Bengal Fan, Indian Ocean

Anil Chandra & Madhav Kumar

Chandra A & Kumar M 1997. Palynology of the Late Tertiary sediments (DSDP Site 218) in the Bengal Fan, Indian Ocean. *Palaeobotanist* **46** (3) : 51-69.

Palynological assemblage from DSDP Site 218 in the Bengal Fan comprises spores, pollen, fungal fruiting bodies and dinoflagellate cysts. The palynofloral composition has minor variation in core no. 27 to 12. The microthyriaceous fungal remains show comparatively higher frequency than other fungal entities. The gymnosperms are represented mostly by the pollen grains of Podocarpaceae and Araucariaceae. Angiosperm pollen are sparsely observed in the assemblage. The pteridophytic spores occur mostly in the bottom and middle cores (core nos. 27-26 and 23-20). Recycled Cretaceous spores have also been found in most of the core samples. This palynoassemblage from Site 218 is comparable to that of the Miocene sediments of north-east India. The environmental relationship of the taxa shows similarity with the modern plants inhabited in the subtropical climate.

Key-words—Palynology, DSDP Site 218, Late Tertiary, Indian Ocean.

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साराँश

हिन्द महासागर में बंगाल फैन के अनंतिम टर्शियरी कालीन अवसादों (डी.एस.डी.पी. 218) का परागाणविक अध्ययन

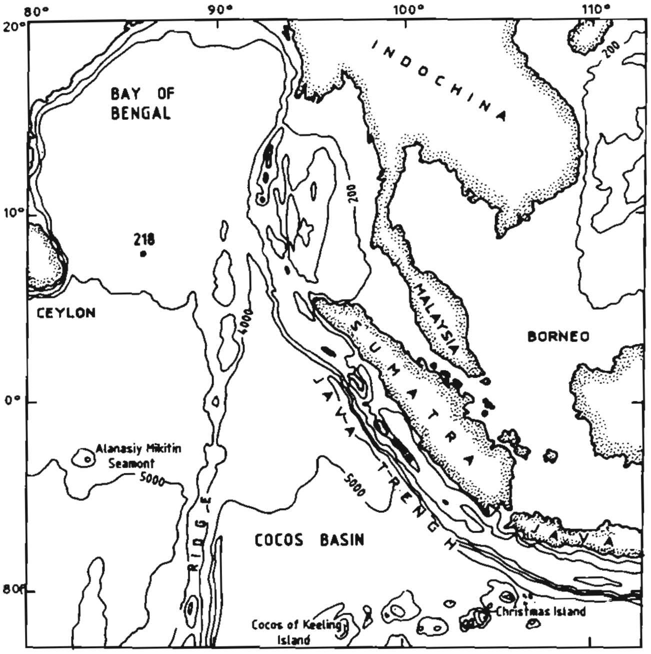
अनिल चन्द्रा एवं माधव कुमार

बंगाल फैन के डी.एस.डी.पी. 218 नामक स्थान से प्राप्त परागाणविक समुच्चय में बीजाणु, परागकण, कवकीय फलन काय एवं घूर्णीकशाभ पुटी विद्यमान है। क्रोड़ संख्या 27 से 12 तक से प्राप्त परागाणविक रूपकों में थोड़ी सी विभिन्नता है। अनावृतबीजीयों में पोडोकार्पेसी एवं अॅराकेरिएसी कुल के परागकण अधिकांशतः मिलते हैं। टेरीडोफाइटी बीजाणु प्रायः तली एवं बीच के क्रोड़ों में ही मिलते हैं। वैसे पुनर्वासित क्रीटेश्यस बीजाणु लगभग सभी क्रोड़ों में प्रेक्षित किये गये हैं। यह समुच्चय उत्तर-पूर्व भारत की मायोसीन कालीन समुच्चयों से तुलनीय है तथा इसमें प्राप्त वर्गक उपोष्ण कटिबन्धीय जलवायु में उगने वाले पौधों से सदृशता वयक्त करते हैं।

PALYNOLOGICAL investigation of Ninetyeast ridge Site 214 and 254 was carried out by Kemp (1978) and Kemp and Harris (1975, 1977). The palynological records from other land masses, bordering the Indian Ocean are from Tertiary of India and Australia. The palynoflora recovered here from the DSDP Site 218, Leg 22 of the Bengal Fan is similar with the Miocene microflora of north-east India and south India (Kar, 1992; Ramanujam, 1982; Rao & Ramanujam, 1982; Ramanujam & Rao, 1993; Jain & Kar, 1979; Jain & Gupta, 1970).

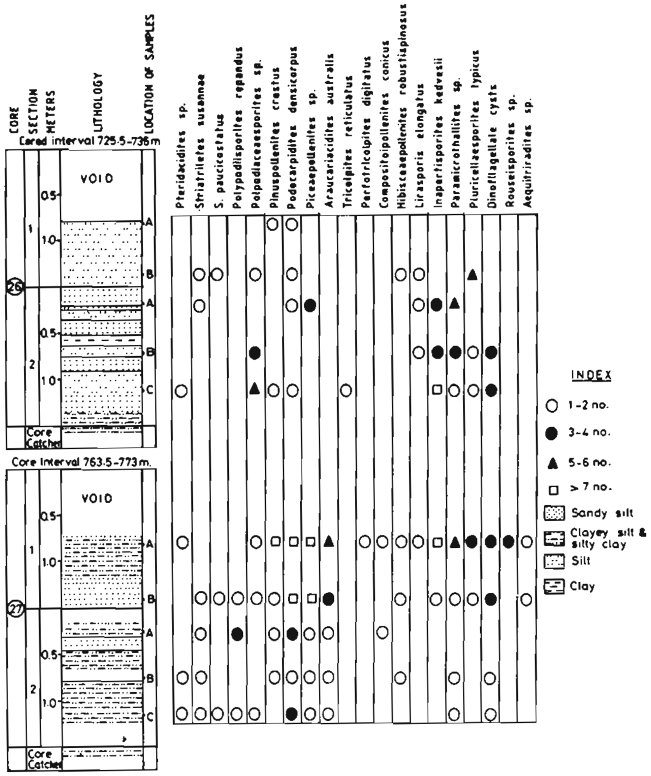
Qualitatively, the palynoassemblage of DSDP Site 218 (Core no. 27-12)is evenly distributed in the vertical sequence with some minor changes, apart from the introduction of marine forms in some sequences. The samples from core no. 11-1 (Pliocene) show poor representation of palynotaxa.

Most of the fossil palynotaxa of the assemblage are attributed with extant botanical affinities. In their brief description we have not used morphologic and superageneric classification; only some important taxa with their limited morphologic descriptions, occurrence and depths have been considered. The palaeoenvironment is drawn on the basis of habitat of modern taxa. The prolific fungal fruiting bodies referred to the family Microthyraceae show limited usefulness in stratigraphic and palaeoclimatic demarcation. The samples of Site 218 contain common

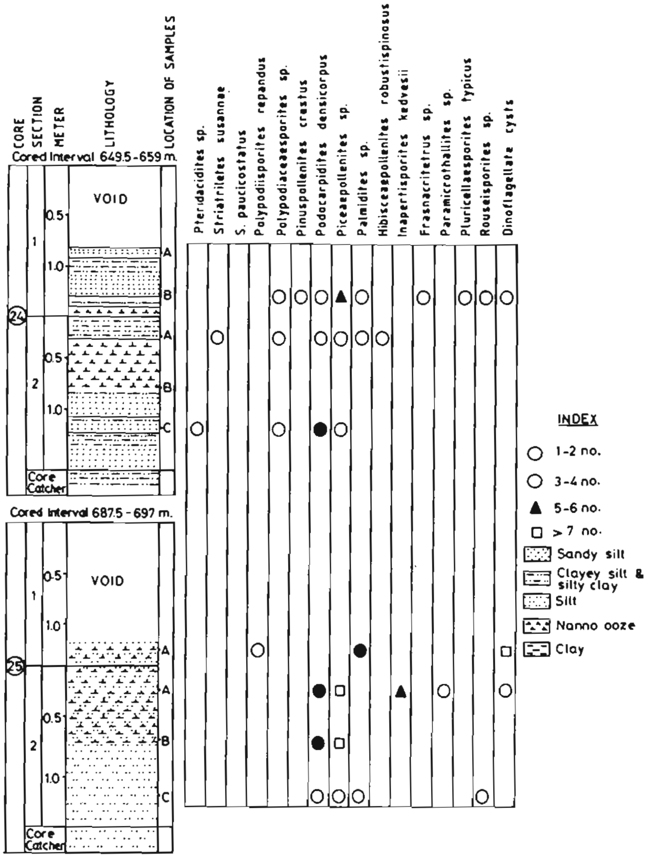


Text-figure 1—Location of DSDP-Site 218, Bengal Fan, Indian Ocean.

Neogene microflora and some recycled Cretaceous spores of *Rouseisporites* and *Aequitriradites* indicate Late Tertiary influence of Cretaceous sediments from other land masses during deposition which may be closer to this island.



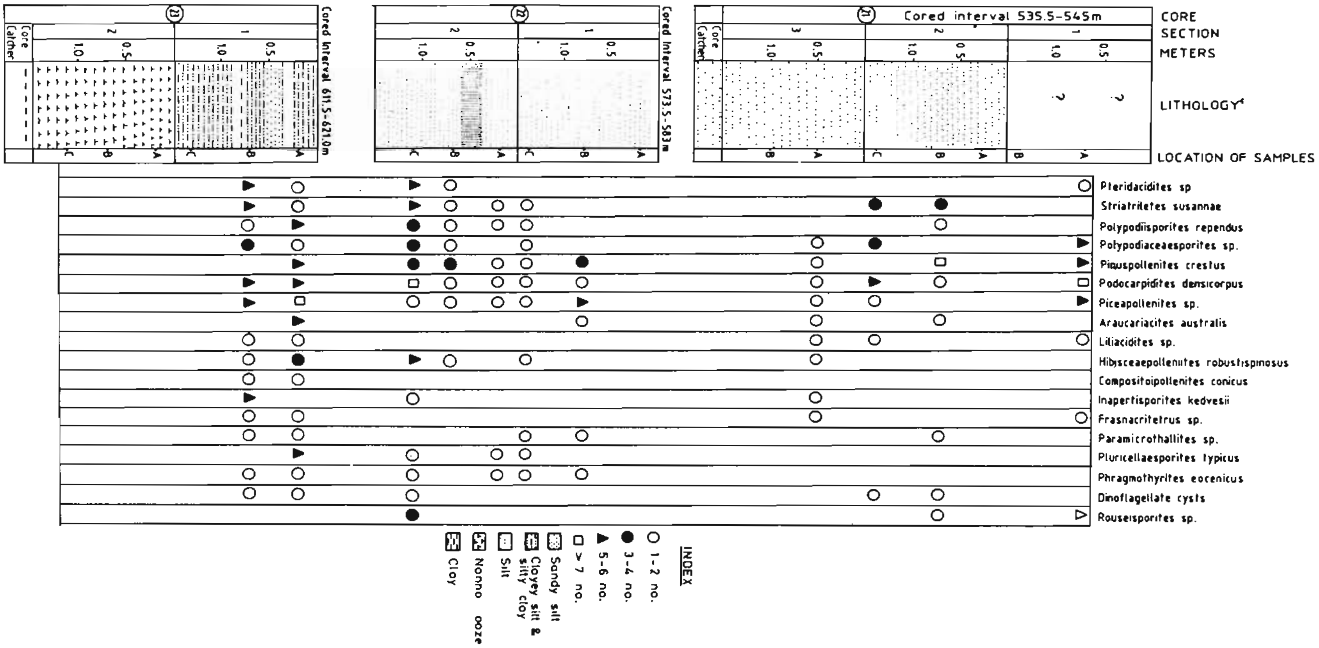
Text-figure 2 — Relative abundance of palynotaxa in DSDP Site 218, core nos. 27-26.



Text-figure 3—Relative abundance of palynotaxa in DSDP Site 218, core nos. 25-24.

MATERIAL AND METHOD

About 5-10 gms of rock samples from various cores (27-12) of the DSDP Site 218 were chemically processed for recovery of palynofossils by using conventional method. The slides were prepared in polyvinyl alcohol and mounted in Canada Balsam. The palynoflora was counted in each sample for quantitative analysis and has been shown in histograms (Text-figures 1-6). The samples from core nos. 11-1 could not be studied due to poor representation of palynofossils. The slides of these palynological preparations have been deposited at the repository of Birbal Sahni Institute of Palaeobotany, Lucknow. Site data, coring summary and lithological summary of Leg 22, Site 218 are from von der Borch *et al* (1974).



Text-figure 4—Relative abundance of palynotaxa in DSDP Site 218, core nos. 23-21.

SITE DATA

Date occupied	-	1 March 1972 (1030)
Date departed	-	4 March 1972 (1030)
Time on site	-	72 hours
Position	-	lat. 08°00: 42'N long. 86°16.97'E
Water depth (to rig floor)	-	3737 m (Echo sounding) 3759 m (Drill pipe)
Penetration	-	773 m
Number of cores	-	27
Total length of the cored section	-	251 m
Total core recovered	-	59.4 m
Acoustic Basement Depth	-	? m
Nature	-	Unknown
Age of the oldest sediments	-	Middle Miocene
Basement	-	Not reached

LIST OF PALYNOTAXA

Bryophytes

Operculosculptites sp.

Pteridophytes

Cyathidites australis Couper 1953

Dictyophillidites sp.

Polypodiisporites repandus Takahashi 1964

Polypodiaceaesporites sp.

Pteridacidites sp.

Schizaeoisporites sp.

Striatriletes susannae van der Hammen 1956

S. paucicostatus Kar 1985

Reworked spores

Aequitriradites sp.

Bicingulispora sp.

Hammulatisporites sp.

Rouseisporites sp.

Gymnosperms

Araucariacites australis Couper 1953

Piceapollenites sp.

Pinuspollenites crestus Kar 1985

Podocarpidites densicorpus Kar 1985

Angiosperms

Liliacidites sp.

Palmidites sp.

Coring Summary (Hole 218)

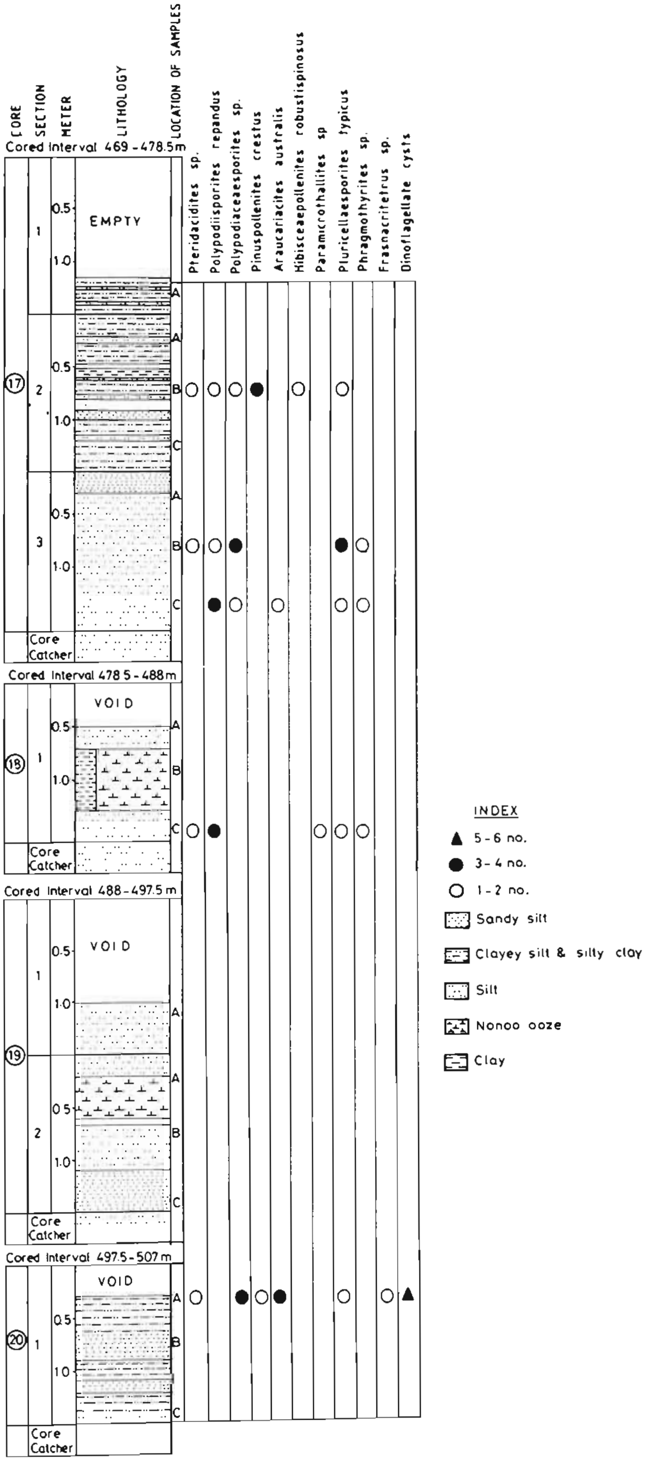
Core	No. of sections (each sec. 1.5 m.)	Date March	Time	Depth from Drill floor (meters)	Depth below Sea floor (meters)	Cored (meter)	Recovered (meters)	Recovery (%)
1.	3	1	1930	3759.0-3763.0	0.0-4.0	4.0	1.5	37
2.	6	1	2040	3763.0-3772.5	4.0-13.5	9.5	8.1	85
3.	2	1	2200	3772.5-3782.0	13.5-23.0	9.5	2.4	25
4.	2	1	2345	3800.5-3810.0	41.5-51.0	9.5	2.3	24
5.	3	2	0140	3829.0-3838.5	70.0-79.5	9.5	4.2	44
6.	2	2	0325	3867.0-3876.5	108.0-117.5	9.5	2.0	21
7.	core catcher	2	0519	3905.0-3914.5	146.0-155.5	9.5	0.1	1
8.	3	2	0726	3943.0-3952.5	184.0-193.5	9.5	4.2	44
9.	1	2	0915	3981.0-3990.5	222.0-231.5	9.5	0.6	6
10.	1	2	1115	4019.0-4028.5	260.0-269.5	9.5	0.9	10
11.	2	2	1314	4057.0-4066.5	298.0-307.5	9.5	1.8	19
12.	1	2	1525	4095.0-4104.5	336.0-345.5	9.5	0.3	3
13.	2	2	1735	4133.0-4142.5	374.0-383.5	9.5	2.4	25
14.	1	2	2005	4171.0-4180.5	412.0-421.5	9.5	0.8	8
15.	1	2	2215	4209.0-4218.5	450.0-459.5	9.5	1.3	14
16.	2	2	2334	4218.5-4228.0	459.5-469.0	9.5	1.8	19
17.	3	3	0106	4228.0-4237.5	469.0-478.5	9.5	3.3	35
18.	1	3	0221	4237.5-4247.0	478.5-488.0	9.5	1.1	12
19.	2	3	0336	4247.0-4256.5	488.0-497.5	9.5	2.0	21
20.	1	3	0446	4256.5-4266.0	497.5-507.0	9.5	1.2	13
21.	2	3	0730	4294.5-4304.0	535.5-545.0	9.5	2.9	30
22.	2	3	1005	4332.5-4342.0	573.5-583.0	9.5	2.9	30
23.	2	3	1235	4370.5-4380.0	611.5-621.0	9.5	3.0	31
24.	2	3	1513	4408.5-4418.0	649.5-659.0	9.5	2.1	22
25.	2	3	1730	4446.5-4456.0	687.5-697.0	9.5	1.7	18
26.	2	3	2230	4484.5-4994.0	725.5-735.0	9.5	2.2	23
27.	2	4	0120	4522.5-4532.0	763.5-773.0	9.5	2.3	24
Totals	53					251.0	59.4	24

Note : Echo sounding depth (to drill floor) = 3737 meters, drill pipe length to bottom = 3759 meters

Lithological Summary

Leg 22, Hole 218

Unit	Depth below Sea floor (m)	Lithology	Age	Cores
1.	0-9	Clay silt-rich nanno ooze with interbeds of silty clay	Quaternary	1, 2
2.	9-70	Silt with interbeds of sand, sandy silt and clayey silt	Quaternary	2, 4
3.	70-225	Nanno-rich clayey silt and silty clay with interbeds of nanno ooze	Quaternary-Pliocene	5-9
4.	225-350	Silts with interbeds of silty sand and clayey silt	Pliocene-Upper Miocene	9-12
5.	350-470	Clayey silt and silty clay with occasional interbeds of nanno-ooze and sandy silt	Upper Miocene	13-16
6.	470-600	Interlaminated clean silt, clayey sandy silt with occasional interbeds of mottled nanno ooze	Upper Miocene	17-22
7.	600-650(?)	Interlaminated clayey silt, silty clay and sandy silt with interbeds of nanno ooze	Upper Miocene	23, 24
8.	650-773	Interlaminated clean silt, sandy silt and clayey silt	Middle Miocene	24-27

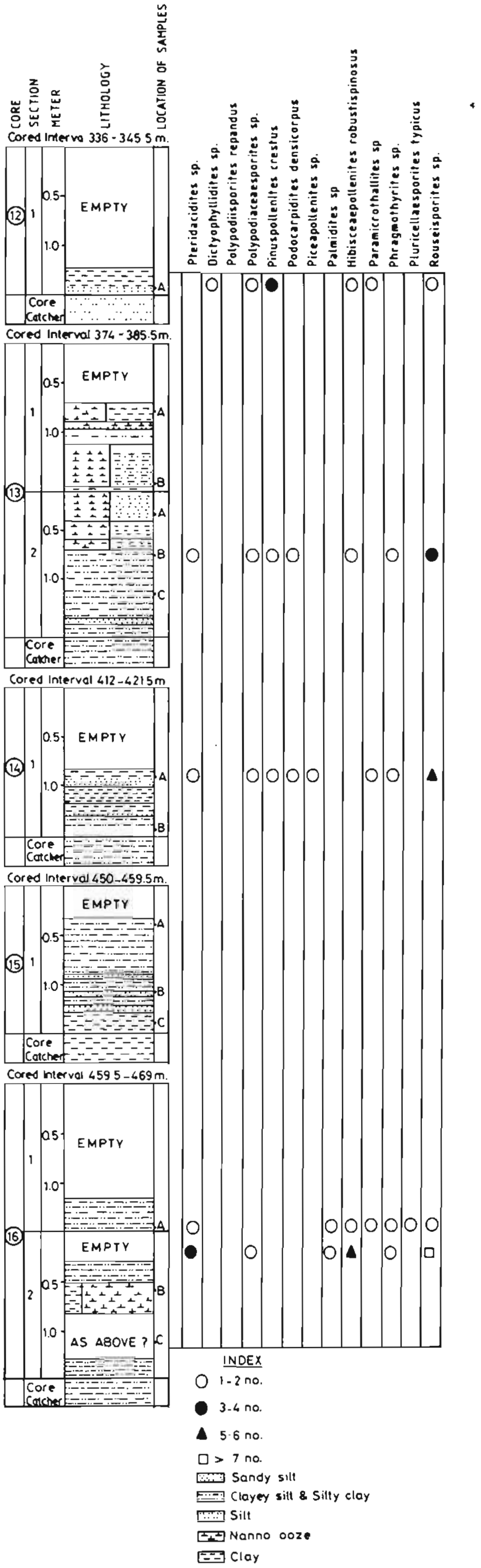


Text-figure 5 — Relative abundance of palynotaxa in DSDP Site 218, core nos. 20-17.

Compositoipollenites conicus Sah 1967

Hibisceaepollenites robustispinosus Kar 1990

Perfotricolpites digitatus Guzman 1967



Text-figure 6 — Relative abundance of palynotaxa in DSDP Site 218, core nos. 19-12.

Polyadopollenites miocenicus Ramanujam 1966
Retipollenites arcotense Ramanujam 1966
Retistephanocolporites sp.

Pollen tetrad Type A

Pollen Type A

Fungi

Diporicellaesporites sp.
Dyadosporonites schwabii Elsik 1968
Dyadosporonites sp.
Inapertisporites variabilis van der Hammen 1954
Frasnacritetrus sp.
Lirasporis elongatus Kar 1990
Meliolinites spinksii Selkirk 1975
Meliolinites sp.
Paramicrothallites sp.
Parmathyrites indicus Jain & Gupta 1970
Phragmothyrites eocenicus (Edwards) Kar & Saxena 1976
Pluricellaesporites typicus van der Hammen 1954
Trichopeltinites kiandrensis Selkirk 1975
Trichothyrites sp.

SYSTEMATIC DESCRIPTION OF SOME SELECTED TAXA

Fungal fruiting bodies

All samples from DSDP Site 218 included in the present paper contain abundant fungal remains, including *Paramicrothallites, Phragmothyrites, Pluricellaesporites, Frasnacritetrus, Trichopeltinites,* etc. These dispersed fungal remains generally can not be identified with living forms. Their diversity and quantity provide little palaeoclimatic information. Most of the fungal fructifications of this assemblage can be referred to the family Microthyraceae. The extant taxa of this family are epiphyllous and host of these fungi are gymnospermic and angiospermic leaves.

Genus—*Paramicrothallites* Jain & Gupta 1970

Type species—*Paramicrothallites spinulatus* (Dilcher) Jain & Gupta 1970.

Paramicrothallites sp.
Pl. 1, fig. 16; Pl. 3, fig. 7

Remarks—These semi-circular microthyraceous flattened ascomata show pseudoparenchymatous cells and have abundant occurrence in the assemblage.

Occurrence—Core length 773.0-687.5 m, 621.0-535.5 m and 488.0-478 m.

Genus—*Phragmothyrites* Edwards 1922

Type species—*Phragmothyrites eocaenica* Edwards 1922.

Phragmothyrites eocenicus Edwards, emend.
Kar & Saxena 1976
Pl. 3, fig. 5

Remarks—This scutate fruiting body lacks an ostiole. The cells are perforated. The extant epiphyllous fruiting fungi generally occur on the leaves of gymnosperms.

PLATE 1

⟶

(All photographs are magnified ca x 500, unless otherwise mentioned)

1. *Dictyophyllidites* sp., Slide no. BSIP 11114 M31
2. *Hammulatisporites* sp., Slide no. BSIP 11084 P25/4
3, 6. *Rouseisporites* sp., Slide nos. BSIP 11103 K14/4, 11097 V30/2
4. *Striatriletes susannae,* Slide no. BSIP 11082 K40/4
5. *Bicingulispora* sp., Slide no. BSIP 11076 X41/2
7. *Meliolinites spinksii,* Slide no. BSIP 11099 Q10
8. *Pluricellaesporites typicus,* Slide no. BSIP 11080 V14/4
9. *Dyadosporonites* sp., Slide no. BSIP 11113 V21/4
10. *Dyadosporonites schwabii* Elsik, Slide no. BSIP 11112 D30
11, 15. *Lirasporis elongatus* Kar, Slide nos. BSIP 11079 L25/2,11069 M45/3
12. Dinoflagellate cyst, Slide no. BSIP 11101 V43
13. *Frasnacritetrus* sp., Slide no. BSIP 11098 R17/4
14. *Dictyosporites* sp., Slide no. BSIP 11102 O40
16. *Paramicrothallites* sp., Slide no. BSIP 11077 J38/2
17. *Parmathyrites indicus* Jain & Gupta, Slide no. BSIP 11105 N35/3
18. *Trichopeltinites* sp. (250x), Slide no. BSIP 11109 D7
19. *Diporicellaesporites* sp., Slide no. BSIP 11090 P36

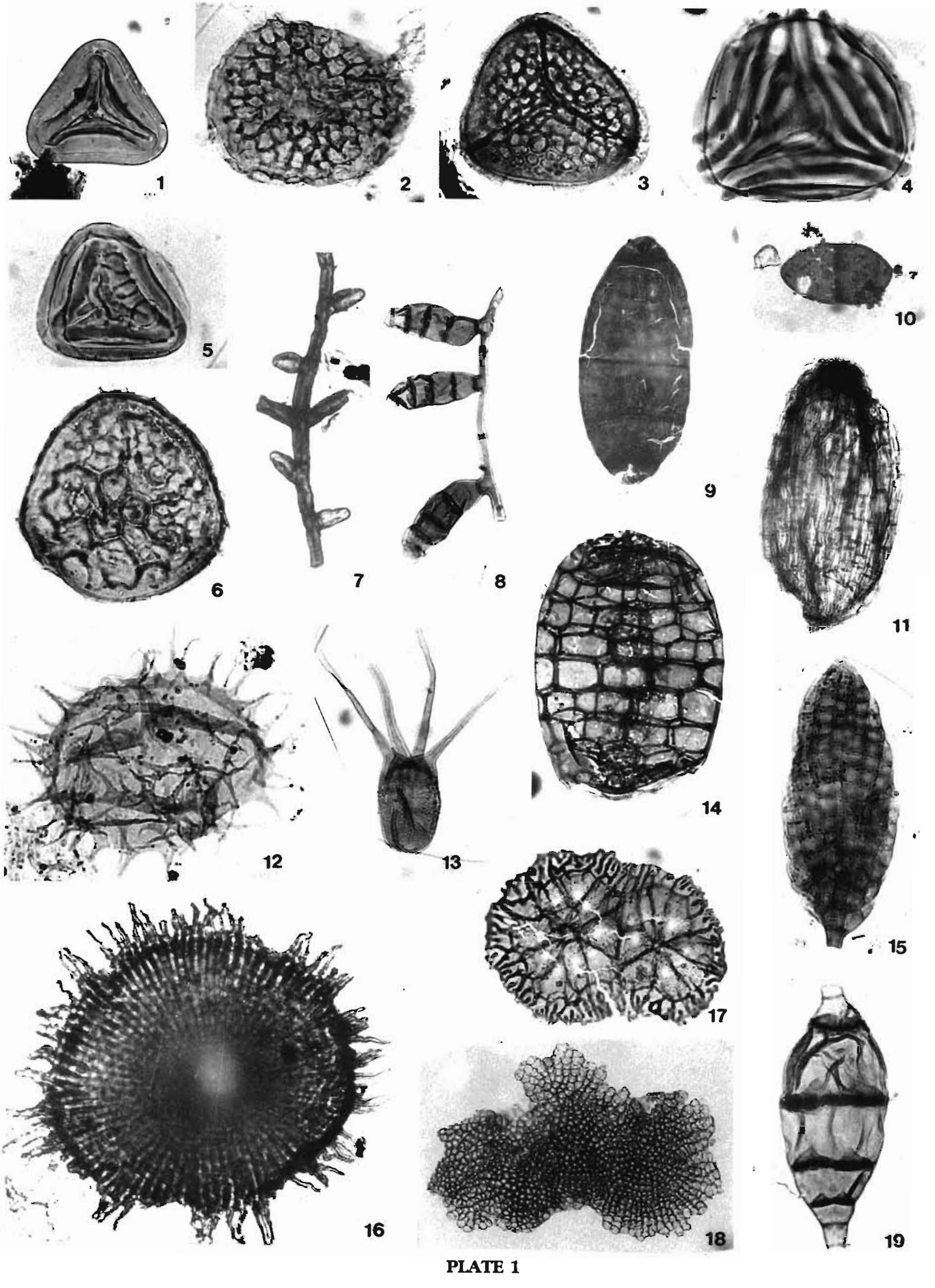
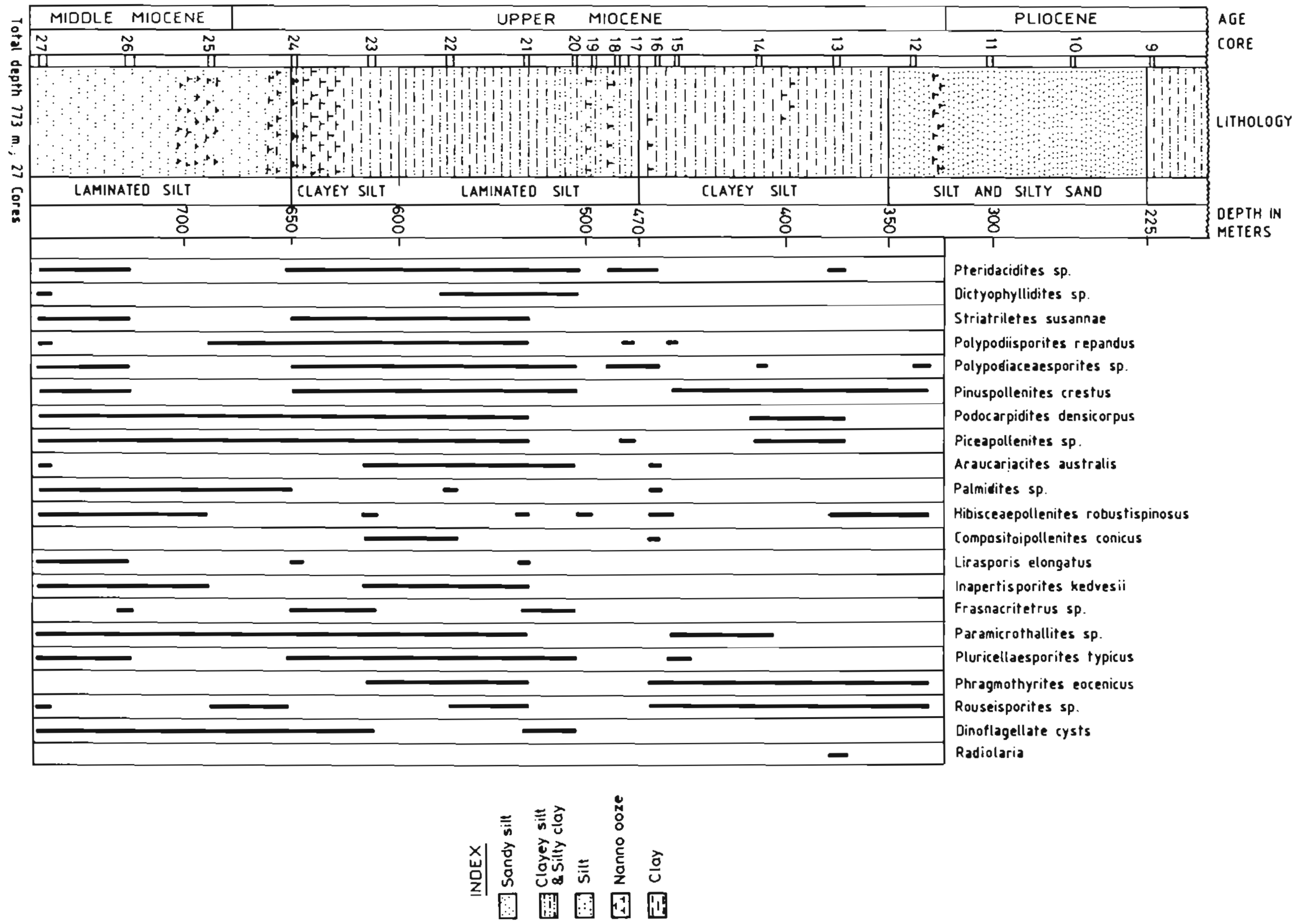


PLATE 1



Text-figure 7— Composite histogram showing representation of palynotaxa from core nos. 27-12 in DSDP Site-218, Bengal Fan, Indian Ocean.

Occurrence—Core length 621.0-611.5m, 583.0-573.5m, 488.0-459.5m, 421.5-412.0 and 383.5-374.0 m.

Genus—*Lirasporis* Potonié & Sah 1960

Type species—*Lirasporis intergranifer* Potonié & Sah 1960 emend. Jain & Kar 1979

Lirasporis elongatus Kar 1990
Pl. 1, figs 11, 15

PLATE 2 ⟶

(All photographs are magnified ca x 500, unless otherwise mentioned)

1. *Pteridacidites* sp., Slide no. BSIP 11100 R35
2. Pollen tetrad Type A, Slide no. BSIP 11085 V41/4
3. *Hibisceaepollenites robustispinosus* Kar, Slide no. BSIP 11093 T17
4. *Perfotricolpites digitatus* Guzman, Slide no. BSIP 11095 G50
5. *Retistephanocolporites* sp., Slide no. BSIP 11095 M41/3
6. *Schizaeoisporites* sp., Slide no. BSIP 11094 L8/1
7. *Rouseisporites* sp., Slide no. BSIP 11092 G6
8. Pollen Type A, Slide no. BSIP 11104 S9/4
9. *Podocarpidites* sp., Slide no. BSIP 11111 V20/2

10, 11. *Compositoipollenites conicus* Sah, Slide no. BSIP 11076 H36

12. Radiolaria Type A, Slide no. BSIP 11109 J19/3
13. Radiolaria Type B, Slide no. BSIP 11109 S25

14, 17. *Retipilonapites arcotense* (1000x) Ramanujam, Slide nos. BSIP 11106 R14/2, 11108 V37/1

15. *Operculosculptites* sp. (1000x), Slide no. BSIP 11115 P44/3
16. *Piceaepollenites* sp., Slide no. BSIP 11095 L40/2
18. *Cyathidites australis* Couper, Slide no. BSIP 11107 Q21
19. *Aequitriradites* sp., Slide no. BSIP 11116 G24

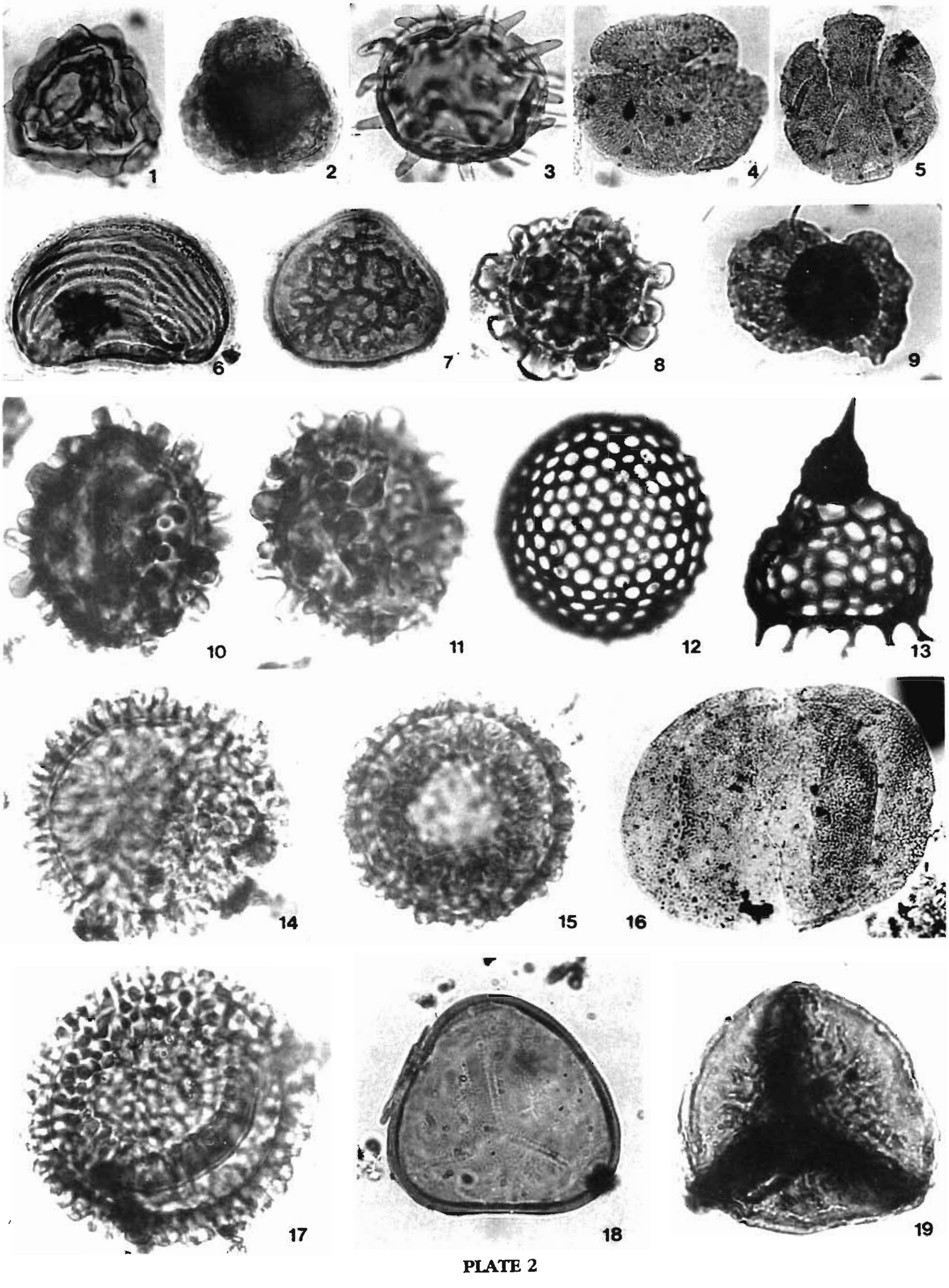


PLATE 2

Remarks—The oval spores segmented in longer axis are common in the core samples from the bottom sediments of the DSDP SITE 218. *Lirasporis elongatus* is also reported from the Miocene sediments of North-East India (Kar, 1990).

Occurrence—Core length 773.0-763.5 m and 7350.0-725.5 m.

Genus—*Meliolinites* Selkirk 1975

Type species—*Meliolinites spinksii* (Dilcher) Selkirk 1975.

Meliolinites spinksii Selkirk 1975
Pl. 1, fig. 7

Remarks—The epiphyllous colony of straight mycelium with hypopodium arranged in alternate fashion on hyphal cells is the characteristic feature of this taxon. The fossil forms resemble modern *Meliola*. The specimens of DSDP SITE 218 match with those recorded from Neyveli lignite (Miocene) of Tamil Nadu (Reddy *et al.*, 1982) and Lower Miocene sediments of Australia (Selkirk, 1975).

Occurrence—Core length 621.0-611.5 m.

Genus—*Frasnacritetrus* Taugourdeau emend. Saxena & Sarkar 1986

Type species—*Frasnacritetrus josettae* Taugourdeau 1968.

Frasnacritetrus sp.
Pl. 1, fig. 13; Pl. 3, fig. 10

Remarks—These quadriseriate fungal conidia (dark coloured) with stiff transversely septate setae show scanty appearance in the assemblage. These specimens resemble *Tetraploa* (Berkeley & Broome, 1850), a modern genus of dematiaceous Hypomycetes (fungi) occuring on dead culms and leaves of grasses.

Occurrence—Core length 773.0-763.5 m, 621.0-611.5 m, 545.0-535.5 m and 507.0-497.5 m.

Genus—*Trichopeltinites* Cookson 1947

Type species—*Trichopeltinites pulcher* Cookson 1947.

Trichopeltinites kiandrensis Selkirk 1975
Pl. 1, fig. 18

Remarks—The epiphyllous mycelium forming radiating prosenchymatous one layered membranous cells without free hyphal outgrowth is the characteristic feature of this species. The thallus is a union of mycelium hyphae. The mycelium shows much similarity with the family Trichopeltaceae which commonly occurs on the leaf cuticle of higher plants.

Occurrence—Core length 583.0-573.5 m.

Genus—*Trichothyrites* Rosendahl 1943

Type species—*Trichothyrites pleistocenica* Rosendahl 1943.

Trichothyrites sp.
Pl. 3, fig. 6

Remarks—This fruiting body with ostiole shows small and thin-walled cells near periphery and around central opening. The central cells are thick-walled, dark brown in colour, while marginal cells are asymmetrical in size and shape.

Occurrence—Core length 773.0-763.5 m.

Genus—*Parmathyrites* Jain & Gupta 1970

PLATE 3

⟶

(All photographs are magnified ca x 500, unless otherwise mentioned)

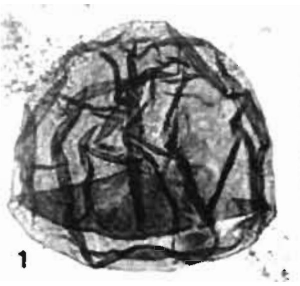
1. *Inapertisporites kedvesii* Elsik, Slide no. BSIP 11086 X24/4
2. *Polypodiisporites repandus* Takahashi, Slide no. BSIP 11081 T43/2
3. *Araucariacites australis* Cookson ex Couper, Slide no. BSIP 11074 O30/2
4. *Polyadopollenites miocenicus* Ramanujam, Slide no. BSIP 11076 T18
5. *Phragmothyrites eocenicus* Edwards, Slide no. BSIP 11078 E31/1
6. *Trichothyrites* sp., Slide no. BSIP 11078 N24/4
7. *Paramicrothallites* sp., Slide no. BSIP 11075 P25/1

8, 9. *Pinuspollenites crestus* Kar, Slide nos. BSIP 11083 M30/4, 11087 L36

10. *Frasnacritetrus* sp., Slide no. BSIP 11077 E49/1

11, 14. *Podocarpites densicarpus* Kar, Slide nos. BSIP 11091 P39, 11087, J49/4, 11089 J30, 11088 P41/1

15. *Pluricellaesporites* sp., Slide no. BSIP 11078 Y25/1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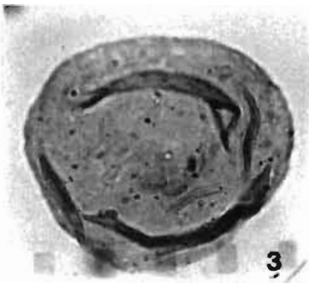
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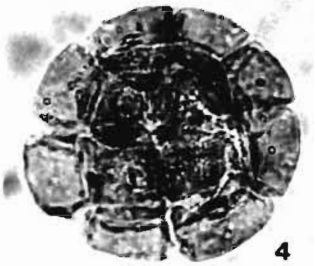
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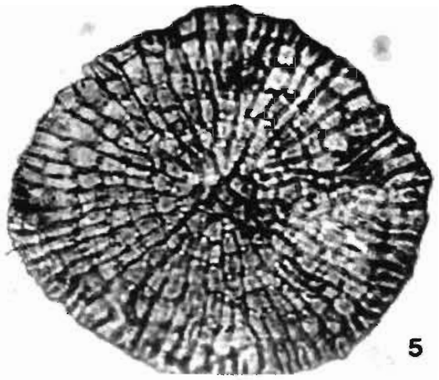
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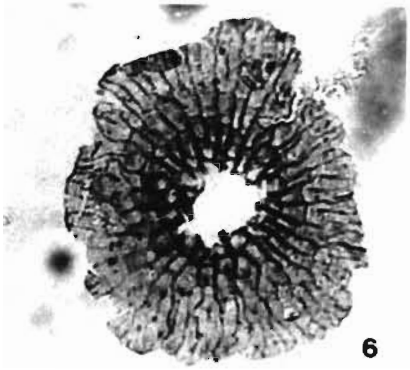
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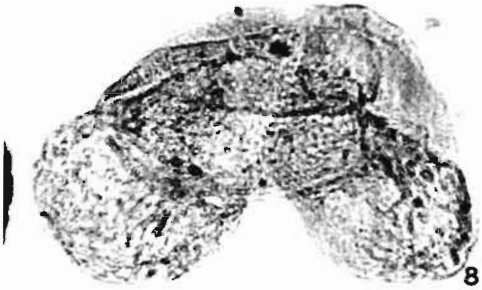
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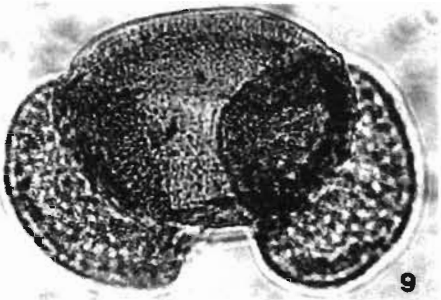
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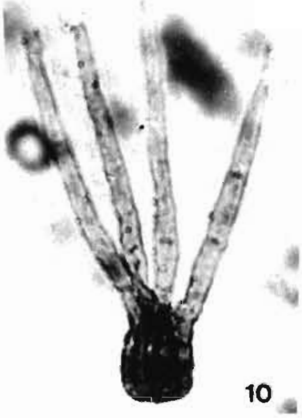
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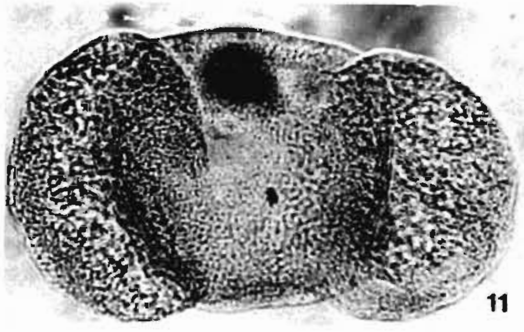
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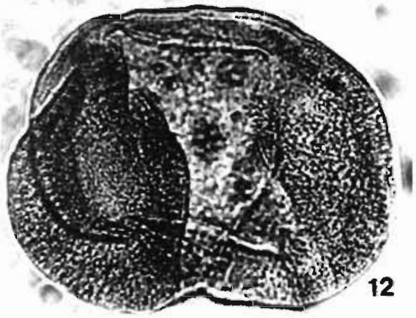
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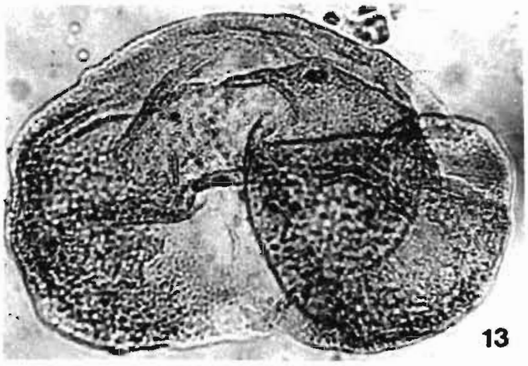
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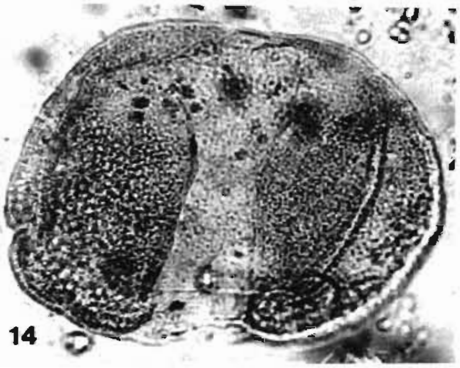
14


15

PLATE 3

Type species—*Parmathyrites indicus* Jain & Gupta 1970.

Parmathyrites indicus Jain & Gupta 1970
Pl. 1, fig. 17

Remarks—Dark brown flattened ascomata show distinct cells with robustly built spines on marginal cells. These specimens show much resemblance with those recorded from Warkali sediments of Kerala (Jain & Kar, 1979; Jain & Gupta, 1970).

Occurrence—Core length 469.0-459.5 m.

Genus—*Pluricellaesporites* van der Hammen emend. Elsik 1968

Type species—*Pluricellaesporites* typicus van der Hammen 1954.

Pluricellaesporites typicus van der Hammen 1954
Pl. 1, fig. 8

Remarks—Spores show thin-walled psilate sculpture with 3-4 transverse septa. These are abundantly found in the DSDP Site 218 assemblage.

Occurrence—Core length 735.0-725.5 m, 659.0-649.5 m, 621.0-611.5 m, 583.0-573.5 m, 507.0-497.5 m.

Genus—*Dyadosporonites* Elsik 1968

Type species—*Dyadosporonites schwabii* Elsik 1968.

Dyadosporonites schwabii Elsik 1968
Pl. 1, fig. 1

Remarks—Uniseptate psilate spores are rare in the assemblage.

Occurrence—Core length 345.5-336.0 m.

Dyadosporonites sp.
Pl. 1, fig. 9

Remarks—Psilate uniseptate fruiting body shows numerous pseudo-septae in both the cells. The spores are comparatively larger than *D. schwabii* (Elsik, 1968).

Occurrence—Core length 269.5-260.0 m.

Genus—*Diporicellaesporites* Elsik 1968

Type species—*Diporicellaesporites stacyi* Elsik 1968.

Diporicellaesporites sp.
Pl. 1, fig. 9

Remarks—Psilate diporate, tetracellate fungal spores with simple pores and unique septal flaps are the characteristic features of this taxon. They are poorly represented in the assemblage.

Occurrence—Core length 697.0-687.5 m.

Genus—*Inapertisporites* van der Hammen emend. Elsik 1968

Type species—*Inapertisporites variabilis* van der Hammen 1954.

Inapertisporites kedvesii Elsik 1968
Pl. 3, fig. 1

Remarks—Dark brown inaperturate fruiting bodies with folded smooth wall are common in the assemblage.

Occurrence—Core length 773.0-763.5 m, 735.0-725.5 m, 697.0-687.5 m, 621.0-611.0 m, 583.0-573.5 m, 545.0-535.5 m.

Bryophytic spores

Genus—*Rouseisporites* Pocock 1962

Type species—*Rouseisporites reticulatus* Pocock 1962.

Rouseisporites sp.
Pl. 1, figs 3, 6; Pl. 2, fig. 7

Remarks—These spores show various types of sculpturing on their proximal surface. The trilete mark sometimes extends up to membranous equatorial zona. Dettmann (1963) proposed resemblance of this genus with those of Ricciaceae and reported several species of *Rouseisporites* from the Mesozoic sediments of South-eastern Australia. The illustrated spores show affinity with *Riccia cavernosa* (Hoffm.) Gupta & Udar 1986. The extant representative of *Rouseisporites* are found in the open habitat.

Occurrence—Core length 773.0-763.5 m, (core no. 27), 697.5-649.5 m (core no. 25-24), 583-535.5 m (core no. 22-21) and 469-336 m (core no. 16-12).

Table—Ecological and geographical distribution of some extant taxa and their affinity with fossil palynotaxa

TAXA	AFFINITY	HABITAT	CLIMATE	GEOGRAPHIC DISTRIBUTION
Pteridophytes				
Cyathidites	Cyatheaceae	Stream side in wet montane forest	Tropical to Temperate	Widely distributed in oceanic islands, forests of tropical mountains
Dictyophyllidites	Gleicheniaceae	Terrestrial,widely creeping in forest open habitat	Tropical to subtropical	Pantropics and sometimes in extratropics
Polypodiisporites repandus	Polypodiaceae	Rain forests	Tropical to boreal	Cosmopolitan
Pteridacidites	Pteridaceae	Forests along rocky stream banks	Tropical	Pantropic but also occur in South Africa, Korea, Japan, New Zealand
Schizaeoisporites	Schizaeaceae	Terrestrial, diverse habitat	Tropical to warm temperate	Mostly Southern Hemisphere
Striatriletes susannae	Parkeriaceae	Terrestrial, usually aquatic, wet habitat	Tropical and subtropical	Tropical America, Africa, Southern and SE Asia, Fiji, etc.
Gymnosperms				
Araucariacites	Araucariaceae	Evergreen Forest	Tropical	South America, Australia, New Guinea, New Caledonia
Piceaepollenites sp.	Pinaceae	Evergreen Forest	Temperate	Widely distributed in the temperate region of Northern Hemisphere, Himalaya and North America, Europe, Siberia, North Asia, etc.
Pinuspollenites crestus	Pinaceae	Evergreen Forest	Subtropical to warm temperate	Europe, North America, Central America, Myanmar, SE Asia, etc.
Podocarpidites densicarpus	Podocarpaceae	Montane Evergreen	Tropical to warm temperate	Europe, North America, Central and Southern Hemisphere
Angiosperms				
Compositoipollenites conicus	Compositae	Widely distributed in lowlands	Tropical to subtropical	Pantropical, America, Madagascar, Asia, Australia, etc.
Hibisceaepollenites robustispinosus	Compositae	Widely distributed in lowlands	Tropical to subtropical	Pantropical, America, Madagascar, Asia, Australia, etc.
Polyadopollenites miocenicus	Mimosoideae	Terrestrial dry land forests	Tropical	Cosmopolitan
Retipilonapites arcotense	Potamogetonaceae	Aquatic (fresh water) or subaquatic	Cosmopolitan	Mostly in Mediterranean and Indo-Pacific region

Genus—*Aequitriradites* Delcourt & Sprumont emend. Cookson & Dettman 1961

Type species—*Aequitriradites dubius* Delcourt & Sprumont emend. Delcourt, Dettmann & Hughes 1963.

Aequitriradites sp.
Pl. 2, fig. 19

Remarks—These Mesozoic recycled forms are triradiate, zonate spores with prominent triradiate scar. The spores have rare occurrence and show affinity with the modern hepatic spores of Sphaerocarpaceae.

Occurrence—*Aequitriradites* sp. occurs only in the samples of core no. 27 (depth 773.0-763.5 m).

Genus—*Operculosculptites* Kar 1990

Type species—*Operculosculptites globatus* Kar 1990.

Operculosculptites sp.
Pl. 2, fig. 15

Remarks—Circular spores with an operculum and dense sculptural elements are rare in the sediments. They resemble the spores of extant mosses. Kar (1990) reported *O. globatus, O. rokhiensis* and *O. baculatus* from the Miocene sediments of north-east India.

Occurrence—Core length 193.5-184.0 m.

Pteridophytic spores

Genus—*Striatriletes* van der Hammen 1956

Type species—*Striatriletes susannae* van der Hammen 1956.

Striatriletes susannae van der Hammen 1956

Pl. 1, fig. 4

Remarks—The trilete spores show equatorial costae which sometimes coalesce at apices. The spores of S. *susannae* and *S. pausicostatus* are present ,in most of the samples. These interesting Neogene spores closely resemble the spores of extant genus *Ceratopteris* of Parkeriaceae, which grows in terrestrial shallow water conditions.

Occurrence—Core length 773.0-763.5m, 735-725.5m, 659.0-649.5m, 621.0- 611.5m, 583.0-573.5m, 545.0-535 m.

Genus—*Dictyophyllidites* Couper 1958

Type species—*Dictyophyllidites harrisii* Couper 1958.

Dictyophyllidites sp.
Pl. 1, fig. 1

Remarks—The laevigate spores with prominent laesurae are common in the Tertiary sediments. These specimens resemble the spores of the family Gleicheniaceae. The members of the family grow in variable habitats of tropical to subtropical region.

Occurrence—Core length 773.0-763.5 m, 583.0-573.5 m, 545.0-535.5 m.

Genus—*Bicingulispora* Frederiksen *et al.* 1983

Type species—*Bicingulispora concentrica* Frederiksen *et al.*, 1983.

Bicingulispora sp.
Pl. 1, fig. 5

Remarks—Spores of *Bicingulispora* show trilete mark with two subequatorial bicingulate structures. Our specimens resemble spores of *Pityrogramma* (Tryon & Tryon, 1982) and *Onychium* (Nayer & Devi, 1967) of family Pteridaceae.

Occurrence—Core length 773.0-763.5 m.

Genus—*Pteridacidites* Sah 1967

Type species—*Pteridacidites africanus* Sah 1967.

Pteridacidites sp.
Pl. 2, fig. 1

Remarks—The spores show single cingulum with verrucose sculptures. Most of the specimens resemble the extant spores of *Pteris* (Pteridaceae) which is widely distributed in subtropical to tropical wet forests.

Occurrence—Core length 773.0-763.5 m, 735.0-725 m, 659.0-649.5 m, 621.0-611.5 m, 583.0-573.5 m, 545.0-535.5 m, 507.0-497.5 m, 488.0-469.0 m.

Genus—*Schizaeoisporites* (Potonié 1951) Potonié 1960

Type species—*Schizaeoisporites eocenicus* Potonié 1956.

Schizaeoisporites sp.
Pl. 2, fig. 6

Remarks—The monolete spores have prominent costae on proximal side and show affinity with those of modern Schizaeaceae. Plants of this family are widely distributed in tropical moist forest of southern hemisphere.

Occurrence—Core length 345.5-336.0 m.

Genus—*Hammulatisporites* Krutzsch 1959

Type species—*Hammulatisporites hamulatus* Krutzsch 1959.

Hammulatisporites sp.
Pl. 1, fig. 2

Remarks—The spores show humulate sculpture with weakly developed flanges on the margin. The laesura is distinct. These specimens resemble extant spores of *Lycopodium*.

Occurrence—Core length 735.0-725.5 m.

Genus—*Polypodiisporites* (Potonié 1931) ex Potonié 1956

Type species—*Polypodiisporites favus* (Potonié 1931) ex Potonié 1956.

Polypodiisporites repandus Takahashi 1964
Pl. 3, fig. 2

Remarks—Monolete spores with verrucate sculptures are abundant in the assemblage. Kar (1990) also recorded this species from Mio-Pliocene sediments of north-east India.

Occurrence—Core length 773.0-763.5 m, 697.0-687.5 m, 621.0-611.5 m, 583.0-573.5 m, 545.0-535.5 m and 488.0-459.5 m.

Genus—*Cyathidites* Couper 1953

Type species—*Cyathidites australis* Couper 1953.

Cyathidites australis Couper 1953
Pl. 2, fig. 18

Remarks—These laevigate trilete spores are rare in the assemblage, which closely resemble the spores of extant Cyatheaceae. This tree fern grows in wet montane forests in subtropical to tropical climate.

Occurrence—Core length 421.5-412 m.

Gymnosperm pollen

Genus—*Araucariacites* Cookson ex Couper 1953

Type species—*Araucariacites australis* Cookson 1947 ex Couper 1953.

Araucariacites australis Couper 1953
Pl. 3, fig. 3

Remarks—Folded thin-walled inaperturate pollen show affinity with modern pollen grains of Araucariaceae, probably with *Araucaria*. The fossil pollen show long and extensive stratigraphic records in the Tertiary sediments.

Occurrence—Core length 773.0-763.5 m, 583.0-573.5 m, 545.0-535.5 m, 507.0- 497.5 m and 478.5-469.0 m.

Genus—*Podocarpidites* Cookson ex Couper 1953

Type species—*Podocarpidites ellipticus* Cookson ex Couper 1953.

Podocarpidites densicarpus Kar 1985
Pl. 3, figs 11-14

Remarks—The bisaccate pollen grains show more or less circular body and intrareticulate bladders with distinct and wide furrow. The specimens are very similar to the extant pollen of *Podocarpus* (Podocarpaceae) which is restricted to the higher elevation, generally in montane forest of high rainfall. Kar (1990) recorded this species from the Mio-Pliocene sediments of northeast India.

Occurrence—Core length 773.0-763.5 m, 735.0-725.5 m, 697.0-687.5 m, 659.0- 649.5 m, 621.0-611.5 m, 583.0-573.5 m, 545.0-535.5 m, 421.5-412.0 m,383.5-374.0 m.

Genus—*Pinuspollenites* Raatz 1938 ex Potonié 1958

Type species—*Pinuspollenites labdacus* Raatz ex Potonie' 1958.

Pinuspollenites crestus Kar 1985
Pl. 3, figs 8, 9

Remarks—These bisaccate pollen grains have circular to oval body with moderately reticulate exine. The bladders are more or less circular to semicircular in shape. *Pinuspollenites crestus* is common in DSDP Site 218 palynoassemblage. Our specimens show affinity with pollen of extant *Pinus* (Pinaceae).

Occurrence—Core length 773.0-763.5 m, 735.0-725.5 m, 659.0-649.5 m, 621.0-611.5 m, 583.0-573.5 m, 545.0-535.5 m, 307.0-497.5 m, 478.5-469.0 m, 421.5-412.5 m, 383.5-374.0 m, 345.5-336.0 m.

Genus—*Piceaepollenites* Potonié 1931

Type species—*Piceaepollenites alatus* Potonié 1931.

Piceaepollenites sp.
Pl. 2, fig. 16

Remarks—The bisaccate pollen grains with laterally elongated body show punctate exine with infrareticulate bladders. These specimens are similar to the pollen of modern *Picea* (Pinaceae). *Picea* is usually found in cooler regions of the northern hemisphere.

Occurrence—Core length 773.0-763.5 m, 735.0-725.5 m, 697.0-687.5 m, 659.0- 649.5 m, 621.5-611.0 m, 583.0-573.5 m, 545.0-535.5 m and 421.5-412.0 m.

Angiosperm pollen

Genus—*Hibisceaepollenites* Kar 1985

Type species—*Hibisceaepollenites splendus* Kar 1985.

Hibisceaepollenites robustispinosus Kar 1990
Pl. 2, fig. 3

Remarks—Subcircular, panporate pollen grains with robustly built spines are common in the assemblage of DSDP Site 218. These pollen grains resemble extant pollen grains of the family Malvaceae.

Occurrence—Core length 773.0-763.5 m, 735.0-725.5 m, 659.0-649.5 m, 621.0- 611.5 m, 583.0-573.5 m, 545.0-535.5 m, 507 478.5-459.5 m, 383.5-374.0 m, 345.5- 336.0 m.

Genus—*Compositoipollenites* Potonié ex Potonié 1960

Type species—*Compositoipollenites rizophorus* (Potonié) Potonié 1960.

Compositoipollenites conicus Sah 1967
Pl. 2, figs 10, 11

Remarks—The panporate pollen grains are ornamented with spines which are bulbous at the base. These specimens having affinity with Compositae pollen have been observed only in the bottom sediments.

Occurrence—Core length 773.0-763.5 m.

Genus—*Retipilonapites* Ramanujam 1966

Type species—*Retipilonapites arcotense* Ramanujam 1966.

Retipilonapites arcotense Ramanujam 1966
Pl. 2, figs 14, 17

Remarks—The retipilate and non-aperturate spheroidal pollen grains are rare in the assemblage. These specimens show similarity with the pollen grains of extant *Potamogeton*.

Occurrence—Core length 469.5-450.0m, 421.5-412.0 m.

Genus—*Polyadopollenites* Pflug & Thomson in Thomson & Pflug 1953

Type species—*Polyadopollenites multipartitus* Thomson & Pflug 1953.

Polyadopollenites miocenicus Ramanujam 1966
Pl. 3, fig. 4

Remarks—The occurrence of the species is rare in the assemblage. These grains are commonly found in Miocene sediments of Neyveli lignite of south India. The polyads are similar to the pollen grains of extant species of *Albizia lucida* (Mimosoideae) .

Occurrence—Core length 773.0-763.5 m.

Genus—*Perfotricolpites* Guzman 1967

Type species—*Perfotricolpites digitatus* Guzman 1967.

Perfotricolpites digitatus Guzman 1967
Pl. 2, fig. 4

Remarks—This subspheroidal tricolpate pollen shows perforate tectum with scabrate sculpture and is rare in DSDP Site 218 palynoassemblage.

Occurrence—Core length 773.0-763.0 m.

Genus—*Retistephanocolporites* van der Hammen & Wijmstra 1964

Typespecies—*Retistephanocolporites quadriporus* van der Hammen & Wijmstra 1964.

Retistephanocolporites sp.
Pl. 2, fig. 5

Remarks—The stephanocolporate pollen with reticulate sculpture has been reported from the Lower Tertiary sediments of India (Kar & Kumar, 1986). However, it is rare in DSDP Site 218 assemblage.

Occurrence—Core length 583.0-573.5 m.

Pollen tetrad Type A
Pl. 2, fig. 2

Remarks—The tetrahedral pollen tetrad is rare in the assemblage. The present specimen resembles the pollen tetrad of Ericaceae.

Occurrence—Core length 735.0-725.5 m.

Pollen Type A
Pl. 2, fig. 8

Remarks—The circular pollen grain ornamented with robustly built gemmae and pila on the exine shows distinct morphological feature. It is rare in the assemblage.

Occurrence—Core length 469.0-459.5 m.

COMPOSITION OF THE ASSEMBLAGE

The palynoassemblage of DSDP Site 218 from Bengal Fan consists of 35 genera and 38 species, in which 7 genera and 8 species belong to pteridophytic spores, 4 genera and 4 species of gymnosperms and 8 genera and 8 species belong to angiospermic pollen. Fungal fruiting bodies are represented by 11 genera and 13 species. Distribution of these taxa in different core samples is shown in Text-figures 1-6. Except for a minor difference in the quantity of pteridophytic spores and angiosperm pollen, the other taxa show uniform distribution in this section. The overall assemblage is dominated by fungal fruiting bodies followed by gymnosperm pollen specially in the bottom cores (no. 27-21: 773 -583 m core length) where *Lirasporis elongatus, Inapertisporites kedvesii, Paramicrothallites* sp., *Pluricellaesporites* sp., *Pinuspollenites crestus, Podocarpidites densicorpus,* and *Piceaepollenites* sp. are quite common. In upper cores (nos. 20-12, core length 497.5-345.5 m) the frequency of these woody gymnosperm pollen decreases.

The pteridophytic spores show good representation in core nos. 27, 23 and 22, where *Striatriletes susannae, Polypodiisporites repandus* and *Polypodiaceaesporites* sp. are dominant taxa, while *Cyathidites* spp., *Dictyophyllidites* sp., *Schizeoisporites* sp. and *Lycopodiumsporites* sp. show comparatively less representation. The spores of *Bicingulispora* sp. was observed only in core no. 27. Some characteristic Cretaceous forms like *Rouseisporites* sp. are represented in several cores like 27, 25, 22, 21 and 14-12, while *Aequitriradites* sp. is observed in core no. 27 only. Perhaps these two spores were recycled from nearby Cretaceous sediments. The *Operculosculptites* sp., probably a bryophytic spore commonly known from subsurface Miocene sediments of north-east India (Kar, 1990), is observed in core no. 8.

The angiosperm pollen, viz., *Palmidites* sp., *Liliacidites* sp., *Hibisceaepollenites robustispinosus, Compositoipollenites conicus* are commonly found in core nos. 27, 26, 23 and 21. They are poorly represented in core nos. 20-12. *Tricolpites reticulatus, Retistephanocolporites* sp., *Perfotricolpites digitatus,* etc. are poorly represented in the assemblage. The dinoflagellate cysts occur in almost all cores except 22 and 19-12. Radiolarians are abundant in core no. 13 (core length 374- 345.5 m) only.

COMPARISON WITH MIOCENE PALYNOASSEMBLAGES OF INDIA

North-east India

The present palynoassemblage is closely comparable with the palynoassemblage recovered from

Surma-Tipam Sandstones (Kar, 1990-91). The taxa, viz., *Polypoditsporites repandus, Polypodiaceaesporites* sp., *Striatriletes susannae, Operculosculptites* sp., *Compositoipollenites* sp., *Hibisceaepollenites robustispinosus, Podocarpidites densicorpus, Pinuspollenites crestus, Phragmothyrites eocenicus, Lirasporis elongatus,* etc. have been found common in DSDP Site 218 palynoassemblage and north-east Indian assemblages.

South India

There are some similarities in the palynoassemblages from DSDP Site 218 and Cuddalore Formation (Miocene) of Neyveli Lignite (Tamil Nadu) and Warkali sediments of Kerala (Ramanujam, 1966; Ramanujam, 1982; Reddy *et al.*, 1982). Several taxa like *Polypoditsporites repandus, Pteridacidites* sp., *Schizaeoisporites* sp., *Polypodiaceaesporites* sp., *Tricolpites reticulatus* also occur in the present palynoassemblage. Some fungal remains, e.g., *Meliolinites, Parmathyrites, Trichopeltinites,* etc. reported by Jain and Gupta (1970) and Reddy *et al.* (1982) from the Neogene of south India also occur in DSDP Site 218 palynoassemblage. Jacob and Jacob (1953) mentioned that fruiting bodies of family Tricopeltaceae occur on the cuticle of leaves of higher plants, which have also been observed in the sample of core no. 22 (depth 583-573.5 m) in DSDP Site 218.

PALAEOECOLOGY

The palynoassemblage of DSDP Site 218 shows a considerable uniformity from samples of core no. 27-13. Most of the taxa which are attributed to extant plants show subtropical distribution and presence of moist evergreen rain forests. The dominance and diversity of fungal fruiting bodies indicate warm and humid climate during the emergence of this site. Presently these microthyriaceous fruiting bodies occur in tropical to subtropical climate.

Rouseisporites, Aequitriradites and *Operculosculptites* occur in core from 773.0 to 345.5 m depth. The pteridophytic spores, viz., *Cyathidites* spp. (Cyatheaceae), *Dictyophyllidites* sp. (Gleicheniaceae), *Pteridacidites* sp. (Pteridaceae), *Bicingulispora* sp., *Lycopodiumsporites* sp., *Schizaeoisporites* sp. (Schizaeaceae) and *Striatriletes* spp. (Parkeriaceae) are common in different cores. The cyatheaceous and parkeriaceous plants show the presence of terrestrial land water transport during sedimentation and are streamside colonisers. The *Pteris*(Pteridaceae) and *Gleichenia* grow mostly in variable habitat in tropical to subtropical regions. These plants are found in terrestrial habitat in stream side forests. In core nos. 27-20, the gymnosperm pollen are represented by *Podocarpidites* (Podocarpaceae) and *Araucariacites*(Araucariaceae). At present woody conifers abundantly occur in montane rainforest of north-east India, Andaman and Nicobar Islands and temperate regions. These plants generally flourish in humid climate with very rich annual precipitation. The occurrence of angiosperm pollen in DSDP Site 218, viz., *Hibisceaepollenites, Compositoipollenites, Tricolpites reticulatus,* etc. represents the flora of low land vegetation. Some dinoflagellate cysts (in depth 773.0-449.0 m) and radiolarians are also recorded at the depth from 383.5-374.0 m, which indicate marine influence in addition to the deposition of local vegetation.

CONCLUSION

The palyno fossil from DSDP Site 218 represent terrestrial deposits during the time of emergence except a few impact of marine infiltrations especially in bottom sediments. The occurrence of low land angiospermous and pteridophytic palynofossils indicates a flat depositional site with scattered hill slopes while montane elements of Podocarpaceae and Araucariaceae of wide range habitat flourished due to seasonal precipitation. The present assemblage is comparable with the Miocene palynoassemblages from north east and south India.

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REFERENCES

Banerjee D 1966. A note on a Tertiary microflora of Andaman Islands, India. *Pollen Spores* **8**: 205-212.

Dallimore W & Jackson AB 1966. *A handbook of Coniferae and Ginkgoaceae* (revised by Harrison SG). Edward Arnold (Publishers) Ltd., London.

Dettmann ME 1963. Upper Mesozoic microflora from south-eastern Australia. *Proc. R. Soc. Vict.* n. ser. **77**: 1-148.

Dilcher DL 1965. Epiphyllous fungi from Eocene deposits in western Tennessee, U.S.A. *Palaeontographica* **B 116** : 1-54.

Ellis MB 1971. Dematiaceous *Hypomycetes*. Commonwealth Mycological Institute, Kew, Surrey, England.

Frederiksen NO, Carr DR, Lowe GD & Wosika EP 1983. Middle Eocene palynomorphs from San Diego, California. *AASP Contr. Ser.* **12**: 1-154.

Good R 1953. *The geography of the flowering plants*. Longman, Green & Co., London.

Gupta A & Udar R 1986. Palynotaxonomy of selected Indian Liverworts. *Bryophytorium Bibliotheca*, **B 29**: 1-141 J. Cramer. Berlin.

Jacob K & Jacob C 1953. Cuticles from the Tertiary lignite of Cuddalore, South Arcot, India. *Proc. 7th Int. bot. Congr.* : 573.

Jain KP & Gupta RC 1970. Some fungal remains from the Tertiaries of Kerala Coast. *Palaeobotanist* **18**(2): 177-182.

Jain KP & Kar RK 1979. Palynology of Neogene sediments around Quilon and Varkala, Kerala Coast, South India - 1. Fungal remains. *Palaeobotanist* **26**(2): 105-118.

Jain KP & Kar RK 1981. Palynology of Neogene sediments around Quilon and Varkala, Kerala Coast, south India - 2. Spores and pollen grains. *Palaeobotanist* **27**(2): 113-131.

Kar RK 1985. The fossil flora of Kachchh-IV. Tertiary palynostratigraphy. *Palaeobotanist* **34**: 1-280.

Kar RK 1990. Two new genera from the Miocene sediments of north-east India. *Geophytology* **20**(1): 1-4.

Kar RK 1990-91. Palynology of Miocene and Mio-Pliocene sediments of North-East India. *J. Palynol. (Silver Jubilee Commem. Vol.)*: 171-217.

Kar RK & Saxena RK 1976. Algal and fungal microfossils from Matanomadh Formation, Kutch, India. *Palaeobotanist* **23**(1) : 1-15.

Kemp EM 1974. Preliminary palynology of sample from Site-254, Ninetyeast Ridge. *In* : Davies TA *et al.* (Editors)—*Initial reports of the Deep Sea Drilling Project,* **26** : 815-823 U.S. Govt. Office Washington.

Kemp EM 1978. Microfossils of fungal origin from Tertiary sediments on the Ninetyeast Ridge, Indian Ocean (compiled by Belford DJ & Sacheibnerova V). *The Crespin volume: Essays in honour of Irene Crespin BMR Bull.* **192** : 73-81.

Kemp EM & Harris WK 1975. The vegetation of Tertiary Islands on the Ninetyeast Ridge. *Nature, London* **258**: 303-307.

Kemp EM & Harris WK 1977. The palynology of Early Tertiary sediments Ninetyeast Ridge, Indian Ocean. *Special paper in Paleontology* **19** : 1-69. The Palaeontological Association, London.

Nayar BK & Devi S 1967. Spore morphology of the Pteridaceae II. The gymnogrammoid ferns. *Grana* **7**: 568-600.

Pocock SAJ 1962. Microfloral analysis and age determination of strata at the Jurassic Cretaceous boundary in the western Canada plains. *Palaeontographica* **B 144**: 1-95.

Ramanujam CGK 1966. Palynology of the Miocene lignite from South Arcot District, Madras. *Pollen Spores* **8** (1): 149-203.

Ramanujam CGK 1982. Tertiary palynology and palynostratigraphy of southern India. *Palaeontol. Soc. India Spl. Publ.* **1**: 57-64.

Ramanujam CGK & Rao KP 1973. On some microthyriaceous fungi from Tertiary lignite of south India. *Palaeobotanist* **20**: 203-209.

Reddy PR, Ramanujam CGK & Srisailam K 1982. Fungal fructification from Neyveli Lignite, Tamil Nadu, their stratigraphic and palaeoclimatic significance. *Rec. geol. Surv. India* **114**(5): 112-122.

Silkirk DR 1975. Tertiary fossil fungi from Kiandra, New South Wales. *Proc. Linn. Soc., N.S.W.* **100**: 70-94.

Truswell EM, Sluiter IR & Harris WK 1984. Palynology of the Oligocene-Miocene sequence in the Oakwale - 1 Core hole, Western Murray Basin, South Australia. *B.M.R. Jl* **9**(4):267-296.

Tryon RM & Tryon AF 1982. *Ferns and allied plants with special reference to tropical America*. Springer-Verlag, Berlin.

Von der Borch CC, Selater JG *et. al.* 1974. *Initial reports of the Deep Sea Drilling Project* **22** : 1-890. U.S. Govt. Office Washington.

Dangripites, a new palynomorph from the Tikak Parbat Formation (Oligocene) of Dangri Kumari Colliery, Upper Assam

B.D. Mandaokar

Mandaokar BD 1997. *Dangripites*, a new palynomorph from the Tikak Parbat Formation (Oligocene) of Dangri Kumari Colliery, Upper Assam. *Palaeobotanist* **46** (3): 70-72.

A new palynomorph, *Dangripites*, has been recorded from the Tikak Parbat Formation (Oligocene) of Dangri Kumari Colliery in Dibrugarh District, Assam. This palynomorph is spherical to elliptical, inaperturate and ornamented with baculae, clavae, verrucae, gemmae and tubercles. A probable bryophytic affinity is suggested for this palynomorph.

Key-words—Palynology, *Dangripites*, Tikak Parbat Formation, Oligocene, Assam, India.

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साराँश

उपरि असम में डाँगरी कुमारी कोयला खान के टिकाक पर्वत शैल-समूह (ओलिगोसीन) से एक नया परागाणुवर्गक—डाँगरीपाइटिस

भगवानदास दोमाजी मंडावकर

असम में डिब्रूगढ़ जनपद में डाँगरी कुमारी कोयला खान के टिकाक पर्वत शैल-समूह (ओलिगोसीन) से *डाँगरीपाइटिस* नामक एक नये परागाणुवर्गक का इस शोध-पत्र में वर्णन किया गया है। नये-नये लक्षण प्रदर्शित करने वाला यह परागाणुवर्गक ब्रायोफाइटी सजातीयता व्यक्त करता है।

THE Tikak Parbat Formation (Oligocene) is exposed at Dangri Kumari Colliery (Lat.27°08'N: Long. 95°22'E) about 20 km south of Dilli Colliery in Dibrugarh District, Assam. This formation consists of light grey to brownish, fine to medium grained, well bedded sandstone, mudstone, shale, siltstone, carbonaceous shale, clay and coal seams. Earlier, Mandaokar (1993) recorded a rich palynofossil assemblage from these sediments which contains a new palynomorph *Dangripites* which is being described here.

The slides of the new taxon are stored in the repository of the Birbal Sahni Institute of Palaeobotany, Lucknow.

DESCRIPTION

Genus—*Dangripites* gen. nov.

Type species—*Dangripites tuberculatus* gen. *et* sp. nov.

Diagnosis—Palynomorphs spherical, oval or elliptical, inaperturate. Wall more or less uniformly

PLATE 1

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(All photomicrographs are magnified x ca. 1000. Coordinates of specimens in slides refer to the stage of Olympus Microscope no. BHS. 235846).

1-10. *Dangripites tuberculatus* sp. nov.

1-2, 9. Slide no. BSIP 11290 (137 x 28, G 26/1)

3. Slide no. BSIP 11294 (150.5 x 22, N 39/1)

4. Slide no. BSIP 11292 (148.5 x 12.5, X 37/2)

5. Slide no. BSIP 11292 (149 x 13.5, V 38/2)

6. Slide no. BSIP 11291 (155 x 25.5, K 44/2)

7. Slide no. BSIP 11294 (156.5 x 18, R 46/3)

8. Slide no. BSIP 11292 (136 x 14.5, V 24/2)

10. Slide no. BSIP 11293 (144 x 23.5, L 33/4)


1


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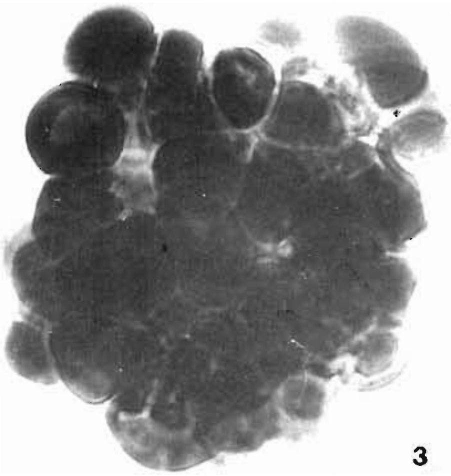
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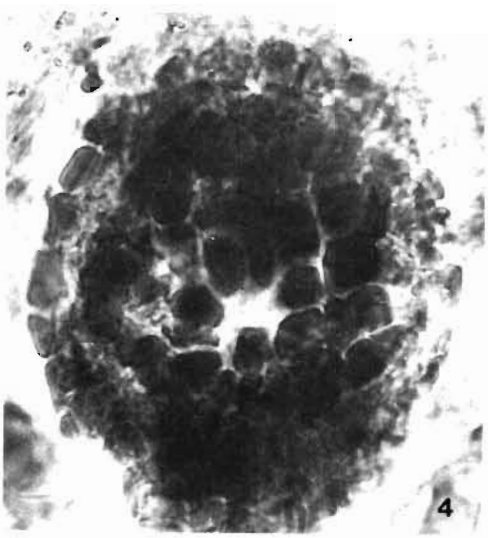
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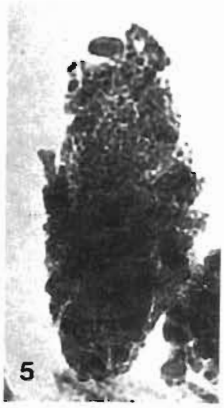
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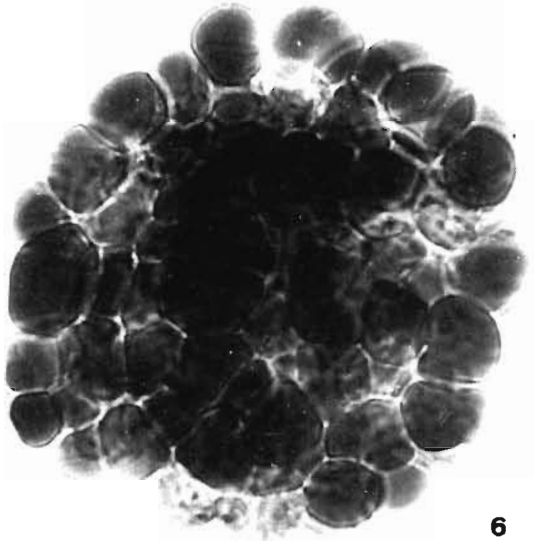
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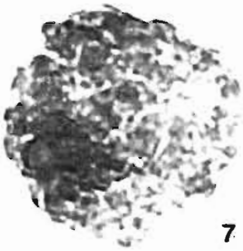
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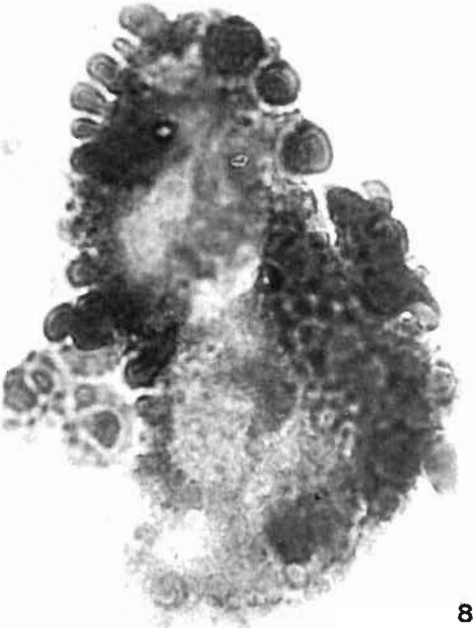
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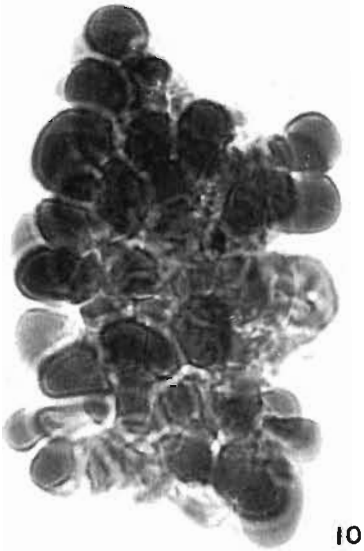
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PLATE 1

covered with coarse baculae, clavae, verrucae, gemmae and tubercles.

Comparison—*Verrualetes* Singh & Saxena 1984 is comparable to the present genus in being inaperturate and having verrucate sculpture. However, *Dangripites* can be differentiated by its coarse and densely placed sculptural elements like verrucae, gemmae, tubercles, clavae, etc. *Reyrea* Herngreen 1974 is similar to *Dangripites* in its inaperturate nature and tuberculate sculpture but can be distinguished by its sculptural elements arranged in longitudinal rows. *Assamiapollenites* Singh emend. Singh & Saxena 1984 is different in having pilate-baculate exine. *Meyeripollis* Baksi & Venkatachala 1970 also resembles the present genus in its sculpture pattern but can be differentiated by being trisyncolporate.

Dangripites tuberculatus sp. nov.

Pl. 1, figs 1-10

Holotype—Pl. 1, fig. 6; size 40 x 15.2 mm (including tubercles), slide no. BSIP 11291 (155 x 25.5).

Type locality, horizon and age—Dangri Kumari Colliery, Upper Assam, Tikak Parbat Formation (Oligocene).

Description—Palynomorph circular to subcircular in outline, size range 57-63 x 35-38 mm; inaperturate. Within the same specimen baculae, gemmae, clavae, verrucae and tubercles can be observed. Sculptural elements densely and irregularly arranged, usually 3-5 mm in diameter, evenly distributed all over the body, surface between the sculptural elements scabrate.

Comments—The morphology of the present taxon suggests its bryophytic affinity.

REFERENCES

Baksi SK & Venkatachala BS 1970. *Meyeripollis*, a new genus from the Tertiary sediments of Assam. *J. geol. Soc. India* **11**(1): 81-83.

Herngreen GFW 1974. Palynology of Albian-Cenomanian strata of Bore-hole 1 -Qs-1 MA, state of Marahuao, Brazil. *Pollen Spores* **15**(3-4): 515-555.

Mandaokar BD 1993. A palynological investigation of the Tikak Parbat Formation (Oligocene) of Dangri Kumari Colliery, Dibrugarh District, Assam, India. *Tertiary Res.* **14**(4): 127-139.

Singh HP & Saxena RK 1984. Palynology of the Neogene sediments of Jorajan Well-3, Upper Assam. *In* : Sharma AK *et al.* (Editors)—*Proceedings of the Symposium on Evolutionary Botany and Biostratigraphy, Calcutta 1979. A.K. Ghosh Commemoration Volume* : 613-631.

Singh RY 1975. Morphological study of the *Retialetes* complex from Indian Tertiaries. *Geophytology* **5**(1): 98-104.

On a fossil wood from the Garu Formation (Permian) of Arunachal Pradesh, India

Usha Bajpai & Trilochan Singh

Bajpai Usha & Singh T 1997. On a fossil wood from the Garu Formation (Permian) of Arunachal Pradesh, India. *Palaeobotanist* **46**(3) : 73-78.

The paper records for the first time a silicified fossil wood from the Garu Formation (Early Permian) exposed in Arunachal Pradesh. The wood is characterised by the presence of distinct growth zones, endarch primary xylem and a single, large, circular to oval, irregularly oriented pit in the cross-field; these features are diagnostic of the genus *Megaporoxylon*. As the wood does not match with any of the known species of the genus, it is given a new name, *Megaporoxylon maheshwarii* sp. nov.

Key-words — *Megaporoxylon*, Wood anatomy, Garu Formation, Permian, Arunachal Pradesh, India.

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सारांश

अरुणाचल प्रदेश (भारत) के गारु शैल-समूह से एक अश्मित काष्ठ

ऊषा बाजपेयी एवं त्रिलोचन सिंह

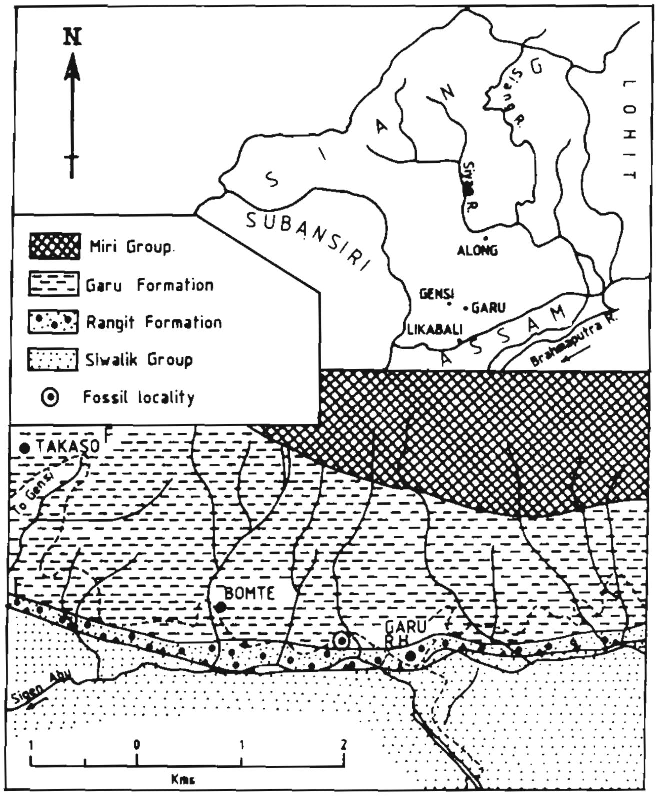
इस शोध-पत्र में अरुणाचल प्रदेश के गारु शैल-समूह (प्रारम्भिक परमियन) से प्राप्त एक सिलिकाभूत काष्ठ का पहली बार वर्णन किया गया है। इस काष्ठ में स्पष्ट वृद्धि मंडलों, मध्यादिदारुक, आदिदारु तथा क्रासित क्षेत्र में एक बड़ा गोलाकार से अंडाकार अनियमित रूप से वितरित गर्त्त विद्यमान है जो कि *मैगापोरॉक्सीलॉन* प्रजाति के नैदानिक लक्षण हैं। चूँकि यह काष्ठ अभी तक वर्णित किसी भी अश्मित काष्ठ से नहीं मिलती अतःएव इसे *मैगापोरॉक्सीलॉन माहेश्वराई* नव जाति से नामाँकित किया गया है।

THOUGH a large number of fossil woods have been reported from the Permian Gondwana sediments of the Indian peninsula, yet there is hardly any record of a fossil wood from the Gondwana equivalent sedimentaries of the Himalayan regions. We record here, for the first time, a fossil wood, collected by one of us (TS), from an exposure of the Garu Formation about 1.25 kilometre from PWD Inspection Bungalow at Garu on Garu-Gensi Road, just crossing the Garu Nala, in Siang District, Arunachal Pradesh (Map 1).

Permian sediments exposed in the region of Arunachal Himalaya comprise three distinct litho-units, namely, Rangit, Garu and Bhareli Formations, in ascending order (Singh, 1993). The plant fossil record comprises palynofossils from Rangit and Garu Formations (Singh, 1979) and leaf-impressions and axes from Bhareli Formation (Singh & Bajpai, 1990).

The Garu Formation is represented mainly by black carbonaceous shale and brown ferruginous shale with thin bands of fine-grained sandstone. Thin lenses of coal and a few tuffaceous beds also occur in this formation. A number of concretionary nodules, many of which contain fossils, occur in the black shale unit. These concretions are believed to be faunal coal balls by Prakash, Singh and Srivastava (1988). Palynofossils have also been recorded from these concretionary nodules (Srivastava, Prakash & Singh, 1987). The fossil wood documented here comes from such a concretionary nodule embedded in the black shale unit.

The specimen and the slides are preserved in the repository of the Wadia Institute of Himalayan Geology, Dehradun, India.



Map 1 — Map of a part of the area showing the location of specimen.

DESCRIPTION

Megaporoxylon maheshwarii sp. nov.

Pl. 1, figs 1-9; Pl. 2, figs 1-8

The specimen (Pl. 1, fig. 1) is a small piece of silicified fossil wood with partially preserved pith and primary xylem, surrounded by a crushed secondary wood. In cross-section the wood is broadly oval in shape and measures 4.3 x 3 cm. The wood and the pith most probably were circular in outline in the living state, and became oval only during diagenesis due to the overlying sediments. The growth zones are usually distinct (Pl. 1, figs 2-3) but at places become obscure due to distortion (Pl. 1, fig. 4). In cross-section the autumn wood zone is 3-6 cells wide; the cells are rectangular with narrow lumen, 14-20 µm in radial diameter. The spring wood zone is 16-35 cells wide, the tracheids are thick-walled, oblong-polygonal in cross-section, and measure 25 x 45 µm in radial diameter. The tangential diameter of tracheids is 25 x 42 µm.

The pith is not well-preserved. It is irregularly oval in shape, large in size, measures 2.5 x 1.3 cm. The pith tissue is parenchymatous, homogeneous. Portions of the pith illustrated here (Pl. 1, figs 5-6) show homogeneous, thin-walled, more or less isodiametric cells, measuring 45.5-180.8 µm in transverse sections becoming comparatively smaller near the periphery of pith. Radially the pith cells are at places irregularly arranged. These cells are almost rectangular in shape, arranged in longitudinal sections and tend to be in end-to-end longitudinal series. They measure 135-540 µm in length.

Primary xylem is distinct in transverse section, forms wedges into the pith, giving a lobed appearance to the latter. In the longitudinal section the elements of the primary xylem are very clear and demonstrate its endarch nature. The primary xylem shows annular thickenings towards the pith (Pl. 1, fig. 7). The tracheids with annular thickenings are followed by those with spiral (Pl. 1, fig. 8), scalariform (Pl. 1, fig. 9; Pl. 2, fig. 1) and reticulate thickenings (Pl. 2, fig. 2), and subsequently passing into tracheids of the secondary xylem.

About seven distinct growth rings are seen in the cross-section. The growth rings are apparently 3-5 mm wide. In longitudinal section the ends of the

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PLATE 1 ⟶

1. Cross-section of the fossil wood, showing a large ovoid pith, and a partly crushed secondary wood with apparent growth rings. Slide no. WIMF/A4, x 2.

2-3. Cross-section of the fossil wood enlarged to show growth rings. Note a false growth ring in the lower half of figure 2.Slide no. WIMF/A4, x 100.

4. Cross-section of the fossil wood showing crumpled tracheids of the secondary wood. Slide no. WIMF/A4, x 100.

5-6. Primary xylem wedged in cross-section, and a part of the homogeneous pith. Slide no. WIMF/A4, x 100.

7. Longitudinal radial section near the periphery of the pith showing elements of primary xylem with annular thickenings. Slide no. WIMF/A2, x 100.

8. Spiral thickenings on the elements of primary xylem. Slide no. WIMF/A3, x 100.

9. Spiral to scalariform thickenings on primary xylem elements. Slide no. WIMF/A3, x 100.

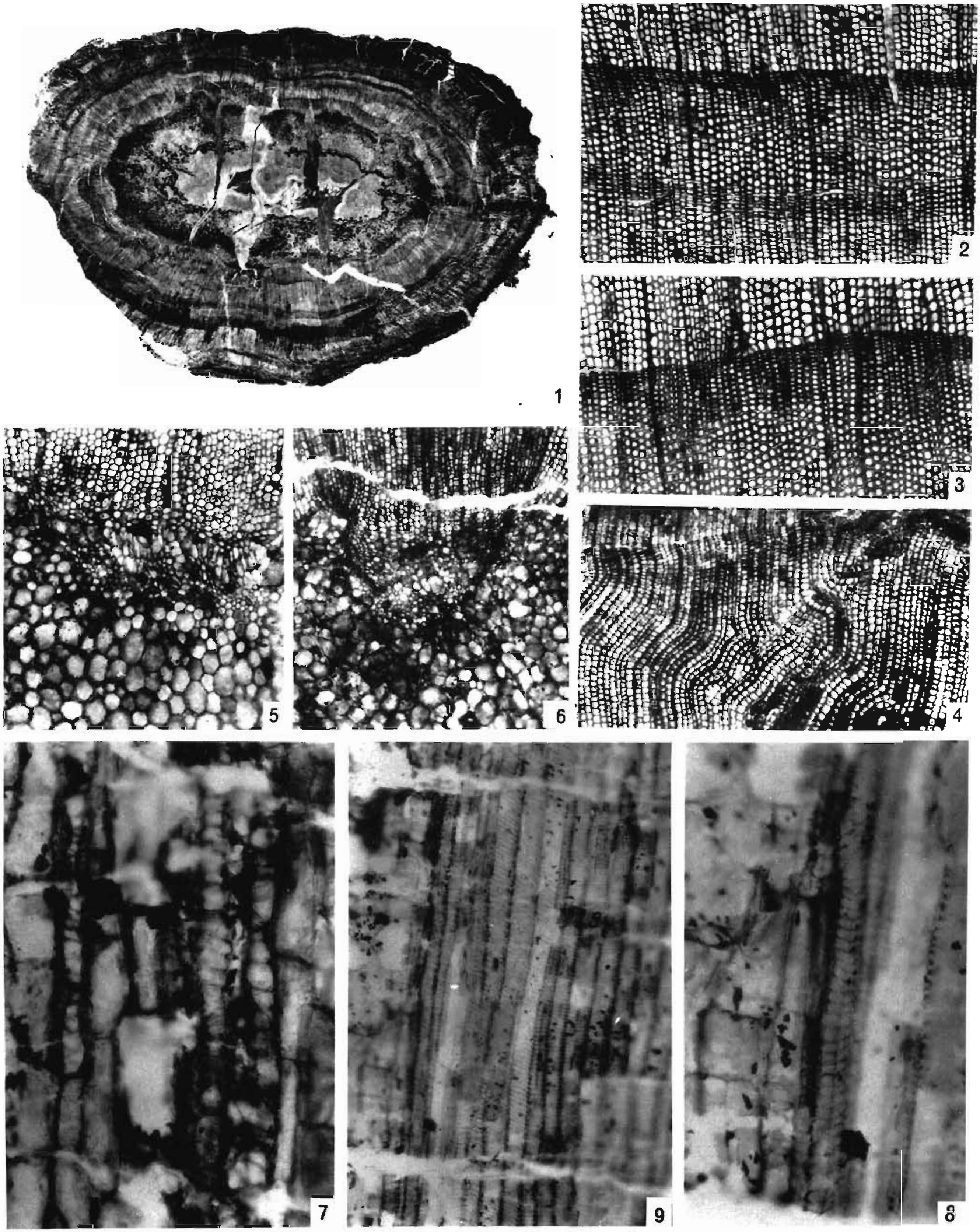

PLATE 1

Table 1 — Comparative account of diagnostic features of different species of the genus *Megaporoxylon*

SPECIES	PITH XYLEM	PRIMARY RAYS	XYLEM PITTING	RADIAL PITS	CROSS-FIELD RINGS	ANNUAL
M. antarcticum Maheshwari 1972	oval and large; cells in T.S. isodiametric, thin-walled, homogeneous	wedge-shaped bundle, endarch	uniseriate, 2-7 cells high	1-3(4) seriate, araucarioid	one, large, oval or elliptical, oblique in orientation	distinct
M. canalosum Maheshwari 1972	1.8 cm in diameter, heterogeneous with secretory cells	wedge-shaped bundle, endarch	uniseriate, 1-8 cells high	1-2(3) seriate, bordered, alternate, contiguous and hexagonal, pit pore centric and circular to broad oval	single, oval, or elliptical, oblique in orientation	distinct
M. kaokense Kräusel 1956	1 cm in diameter, cells rounded in T.S., rectangular in L.S.	endarch	uniseriate, 1-14 cells high	uniseriate, pits bordered, circular-oval	one or two large, simple pit	distinct
M. scherzi Kräusel 1956	large 2x3 cm	endarch	uniseriate, 1-25 cells high	uniseriate, sometimes biseriate	1 large, rarely 2, oval, oblique	distinct
M. zeilleri Kräusel 1956	lobed, 1.4 cm	endarch	uniseriate, 1-12 cells, rarely 18 cells high	1-3 seriate, araucarioid	one round-squarish	distinct
M. maheshwarii sp. nov.	very large, oval, cells in T.S. isodiametric, placed end to end in L.S., heterogeneous	endarch, wedge-shaped	uniseriate, 1-12 cells high	1-2 seriate, pits bordered alternate, contiguous and hexagonal	simple, single pit almost circular to oval	distinct

tracheids are either tapering (Pl. 2, fig. 8) or truncated (Pl. 2, fig. 4).

The pits on the radial walls of tracheids are bordered, usually uniseriate (Pl. 2, fig. 3), sometimes biseriate (Pl. 2, fig. 4), very rarely triseriate (Pl. 2, fig. 5). In the last condition, the pitting simulates that of the araucarioid-types, the pits being alternate, contiguous and hexagonal. The pit pore where seen is almost circular in outline.

In the cross-field, a large simple pit fills up the entire field. The pit is circular (Pl. 2, fig. 6) to oval (Pl. 2, fig. 7) in shape, and irregularly oriented. The circular pits are up to 26 μm in diameter but oval pits measure 14-26 μm in length and 6-10 μm in width.

The xylem rays are homogeneous, uniseriate, 1-12 cells high. The ray cells in tangential section are somewhat rounded-oval and measure 18.5-38.5 μm in longer axis and 14-28 μm in width.

COMPARISON

The most characteristic feature of the present wood is the presence of a single, large, simple pit in the cross-field, a diagnostic feature of certain Permian woods from the Gondwana Supercontinent placed under the genus *Megaporoxylon* Kräusel 1956. So far, five species of the genus are on record from Antarctica (Maheshwari, 1972), India (Maheshwari, 1966) and South Africa (Kräusel, 1956a, 1956b). A comparison of these fossil woods with the present wood is tabulated in Table 1. Due to differences in the nature of the pith,

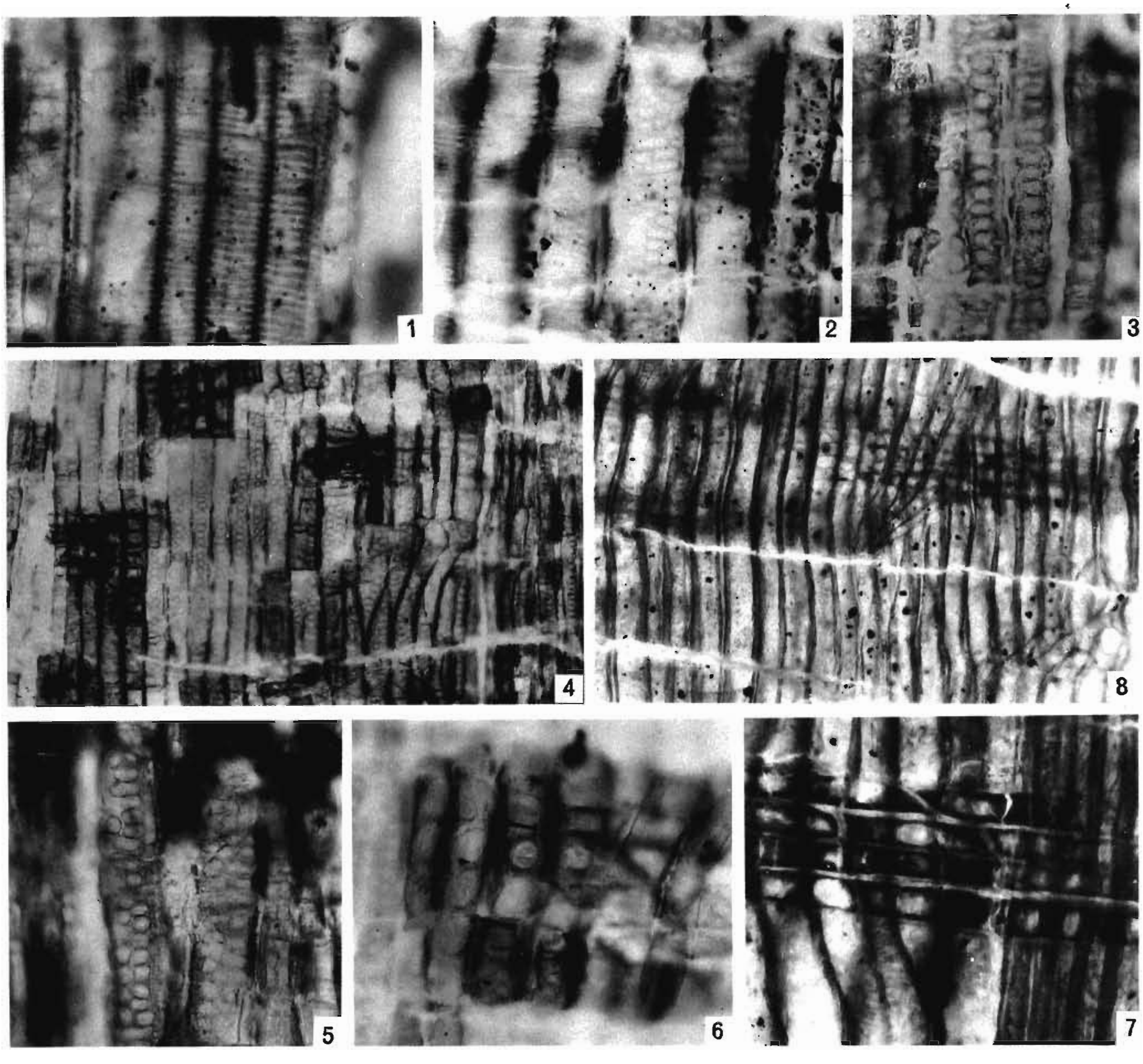

PLATE 2

1-2. Scalariform to reticulate thickenings on the primary xylem elements. 1, Slide no. WIMF/A1, x 250; 2, Slide no. WIMF/A3, x 250.

3. Uniseriate, bordered pits on the radial walls of secondary wood tracheids. Slide no. WIMF/A1, x 250.

4. Uni- to bi-seriate bordered pits on the radial walls of tracheids. Note truncated ends of some of the tracheids. Slide no. WIMF/A3, x 100.

5. Bi- to tri-seriate radial wall pits. Slide no. WIMF/A1, x 250.

6-7. Pits in the cross-field. Slide no. WIMF/A3, x 250.

8. Radial longitudinal section showing tracheids with tapering ends. Slide no. WIMF/A3, x 100.

the primary xylem and the orientation of the cross-field pits, the Garu specimen is assigned to a new species. The wood is named after Dr H.K. Maheshwari who has made notable contributions to the knowledge of the genus.

Specific Diagnosis—Wood with growth rings distinct; pith homogeneous, apparently lobed; primary xylem endarch, having elements with annular, spiral, scalariform and reticulate thickenings; secondary wood tracheids generally showing radial walls with uniseriate bordered pits; cross-field pits circular to oval in shape, irregular in orientation.

Holotype— Specimen no. WIF/A 100, Slide nos. WIMF/A1-9, Wadia Institute of Himalayan Geology, Dehradun, India; Garu Formation, Early Permian; about 1.25 kilometre from PWD Inspection Bungalow at Garu on Garu-Gensi Road, Siang District, Arunachal Pradesh.

ACKNOWLEDGEMENT

This report is an outcome of the collaborative research between Birbal Sahni Institute of Palaeobotany, Lucknow and Wadia Institute of Himalayan Geology, Dehradun. The authors thank the Directors of the two institutions for their constant encouragement and providing necessary facilities. The authors also thank Dr H.K. Maheshwari, Deputy Director, BSIP for kindly going through the manuscript and for generous help with literature.

REFERENCES

Kräusel R 1956a. Der "Versteinerte Wald" im Kaokoveld, Südwest-Afrika. *Senckenberg. leth.* **37**:411-445.

Kräusel R 1956b. Hölzer aus dem südlichen Gebiet der Karru-Schichten Südwest-Afrikas. *Senckenberg. leth.* **37**:447-453.

Maheshwari HK 1966. Studies in the Glossopteris Flora of India - 28. On some fossil woods from the Raniganj Stage of the Raniganj Coalfield, Bengal. *Palaeobotanist* **15**:243-257.

Maheshwari HK 1972. Permian wood from Antarctica and revision of some Lower Gondwana wood taxa. *Palaeontographica* **B138**:1-43.

Prakash A, Singh T & Srivastava SC 1988. Occurrence of faunal coal balls in Gondwana sediments (Permian) of Arunachal Himalaya, India. *Int. J. Coal Geol.* **9**:305-314.

Singh T 1979. Palynostratigraphy of Permian rocks of Siang District, Arunachal Pradesh. *In* : Verma PK (Editor) — *Metamorphic rock sequences of the eastern Himalaya* : 100-113. Bagchi & Company, Calcutta.

Singh T 1993. Gondwana sediments (Permian) of Arunachal Himalaya: stratigraphic status and depositional environment. *In : Gondwana Eight*: 345-355. A.A. Balkema, Rotterdam.

Singh T & Bajpai U 1990. On some plant fossils from Gondwana equivalent sediments of eastern Himalaya. *Palaeobotanist* **37**:284-291.

Srivastava SC, Prakash A & Singh T 1988. Permian palynofossils from the eastern Himalaya and their genetic relationship. *Palaeobotanist* **36**:326-338.

Palynostratigraphy and palynofacies analysis of subsurface Permian sediments in Talcher Coalfield, Orissa

Archana Tripathi

Tripathi Archana 1997. Palynostratigraphy and palynofacies analysis of subsurface Permian sediments in Talcher Coalfield, Orissa. *Palaeobotanist* **46**(3) : 79-88.

Palynological analysis of subsurface sediments in bore-hole TCC-19 near Chhendipada, Talcher Coalfield, Orissa reveals the presence of a Permian palynoflora both below and above the key marker horizon — a conglomeratic pebble bed. The presence of acritarchs in the assemblage suggests brackish water conditions; the palynofacies analysis indicates low energy lacustrine conditions during the deposition of these sediments.

Key-words—Palynology, Palynostratigraphy, Palynofacies, Palaeoenvironment, Early Permian, India.

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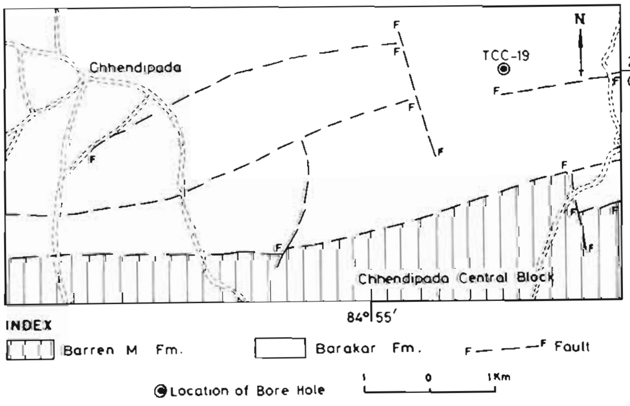
साराँश

उड़ीसा के तलचीर कोयला-क्षेत्र में उपसतही परमियन अवसादों का परागाणुस्तरविन्यास एवं परागाणविक विश्लेषण

अर्चना त्रिपाठी

उड़ीसा के तलचीर कोयला-क्षेत्र में उपसतही परमियन अवसादों के परागाणुस्तरविन्यास एवं परागाणु संलक्षणी विश्लेषण से व्यक्त होता है कि मुख्य संस्तर के नीचे और ऊपर परमियन कालीन परागाणुवनस्पतिजात विद्यमान है। इस समुच्चय में एक्रीटार्कों की उपस्थिति से खारे जल वाली परिस्थितियों का होना इंगित होता है जबकि परागाणु संलक्षणी विश्लेषण से इन अवसादों के निक्षेपण के समय कम शक्ति वाली सरोवरी परिस्थतियों का होना व्यक्त होता है।

RECENT palynological studies in the Talcher Coalfield have revealed the presence of a Late Permian palynoassemblage in coal-bearing sediments cropping out in Madalia River near Patrapara (Tiwari *et al.*, 1991). In an attempt to understand the palynostratigraphy of these Gondwana sediments core samples from bore-hole TCC-19 were studied. This 318 m deep bore-hole was drilled by the Geological Survey of India near Chhendipada (Map 1) and intersected about five metres of conglomeratic pebble bed, sandwitched between the Lower Gondwana coal horizon pertaining to Barakar Formation.



Map 1 — Showing location of bore-hole TCC-19 in the Talcher Coalfield, Orissa.

OBSERVATIONS

Seventeen samples were palynologically analysed (Table 1), all but one (greenish shale, 318 m depth) represented coal beds. Most of the samples were rich in organic matter, including spore-pollen, acritarch, wood, cuticle; three samples had a high spore-pollen content. These were used for detailed palynological analysis. The richness of organic material in most of

Table 1—List of samples in bore-hole TCC-19, Chhendipada Block, Talcher Coalfield, Orissa

Depth	Lithology	Remarks
10.75 - 27.85	Coal	full of wood pieces, spore-pollen rare
47.41 - 60.47	Coal	rich in other plant tissues, spore-pollen and wood pieces comparatively less
about 5 m thick conglomeratic bed ———		
65.60 - 67.21	Coal	rich in spore-pollen and plant tissues, wood pieces comparatively less
70.86 - 79.12	Coal	full of wood pieces, spore-pollen rare
80.50 - 87.83	Coal	full of wood pieces, spore-pollen rare
91.81 - 92.51	Coal	full of wood pieces, spore-pollen rare
103.30 - 104.05	Coal	full of wood pieces, spore-pollen absent
113.60 - 115.30	Coal	full of wood pieces, spore-pollen rare
117.60 - 118.35	Coal	full of wood pieces, spore-pollen comparatively less
132.43 - 133.15	Coal	full of wood pieces, spore-pollen comparatively less
154.37 - 155.42	Coal	full of wood pieces, spore-pollen rare and broken
159.91 - 162.52	Coal	full of wood pieces, spore-pollen rare
167.29 - 167.81	Coal	full of wood pieces, spore-pollen rare
168.28 - 169.22	Coal	full of wood pieces, spore-pollen comparatively less
170.96 - 172.11	Coal	rich in wood pieces and other plant tissues, spore-pollen comparatively less and broken
177.04 - 177.24	Coal	full of wood pieces, spore-pollen comparatively less
318.00	Greenish shale	spore-pollen poor

the samples allowed palynofacies analysis. In the present study the palynofacies analysis was used for palaeoenvironmental interpretation. The palynological slides have been deposited in the Museum of Birbal Sahni Institute of Palaeobotany, Lucknow.

PALYNOSTRATIGRAPHICAL ANALYSIS

Following taxa are present in the palynoflora of bore-hole TCC-19.

Cyclogranisporites gondwanensis Bharadwaj & Salujha 1964

Cyclogranisporites optimus Bharadwaj & Salujha 1965

Cyclobaculisporites indicus Bharadwaj & Salujha 1964

Cyclobaculisporites minutus Bharadwaj & Salujha 1964

Brevitriletes communis Bharadwaj & Srivastava emend. Tiwari & Singh 1981

Brevitriletes unicus Bharadwaj & Srivastava emend. Tiwari & Singh 1981

Microfoveolatispora foveolata Tiwari emend. Tiwari & Singh 1981

Microbaculispora tentula Tiwari 1965

Microbaculispora barakarensis Tiwari 1965

Callumispora gretensis (Balme & Hennelly) Bharadwaj & Srivastava emend. Tiwari *et al.* 1989

Lacinitriletes badamensis Venkatachala & Kar 1965

Lacinitriletes minutus Venkatachala & Kar 1968

Leiotriletes sp.

Indotriradites sparsus Tiwari 1965

Horriditriletes novus Tiwari 1965

Verrucosisporites sp.

Faunipollenites varius Bharadwaj emend. Tiwari *et al.*1989

Faunipollenites perexiguus Bharadwaj emend. Tiwari, *et al.*1989

Striatopodocarpites decorus Bharadwaj & Salujha 1964

Striatopodocarpites multistriatus Tiwari 1965

Crescentipollenites fuscus (Bharadwaj) Bharadwaj *et al.*1989

Verticipollenites secretus Bharadwaj 1962

Striatites altus Venkatachala & Kar 1968

Striatites solitus Bharadwaj & Salujha 1964

Striatites communis Bharadwaj & Salujha 1964

Lahirites incertus Bharadwaj & Salujha 1964

Rhizomaspora indica Tiwari 1965

Primuspollenites levis Tiwari 1965

Primuspollenites obscurus Tiwari 1965

Primuspollenites dicavus Tiwari 1965

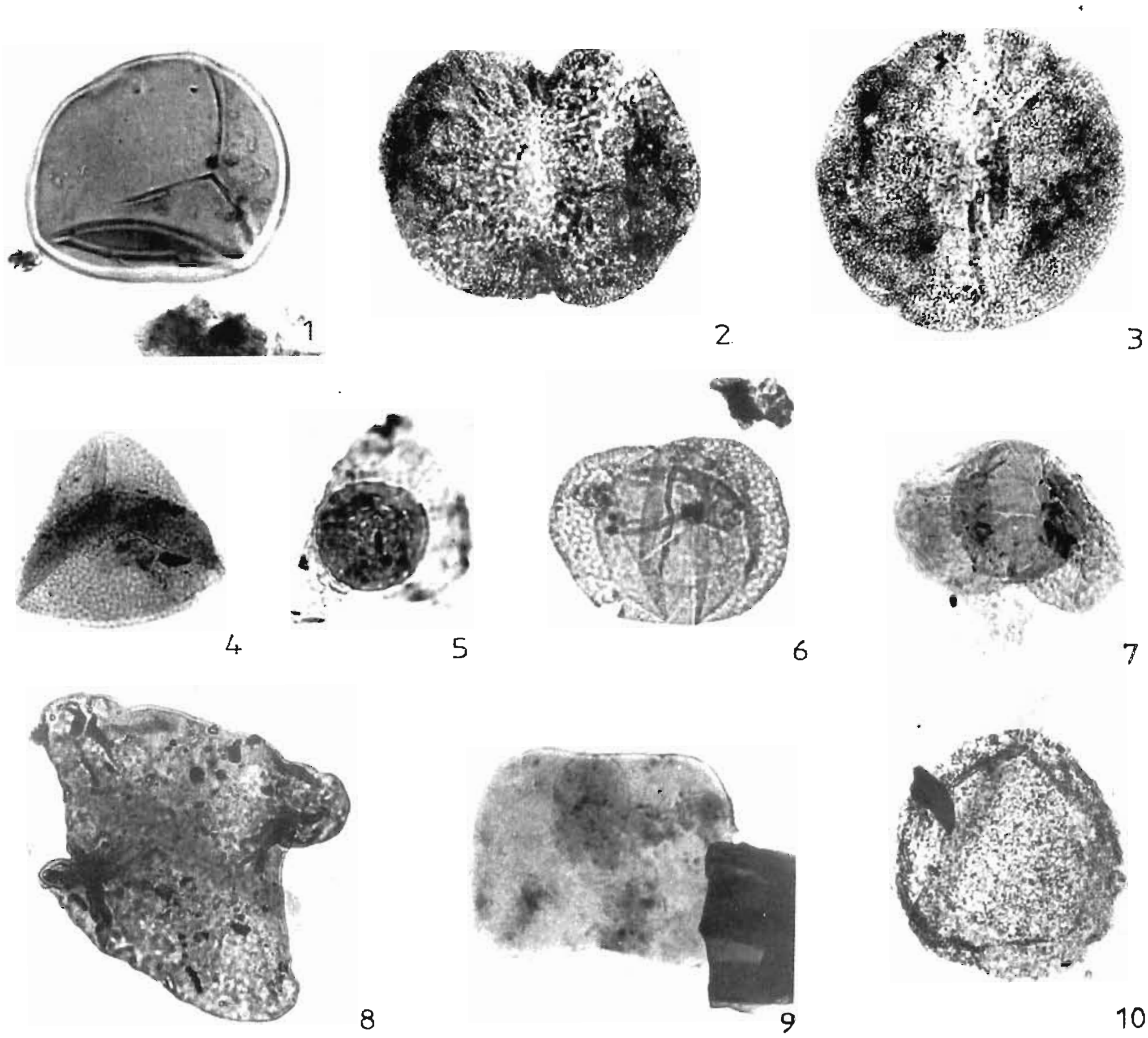


PLATE 1

(All photomicrographs are X 500)

1. *Callumispora*, Slide no. BSIP 11394
2. *Primuspollenites*, Slide no. BSIP 11392
3. *Scheuringipollenites*, Slide no. BSIP 11392
4. *Microbaculispora*, Slide no. BSIP 11394
5. *Maculatasporites*, Slide no. BSIP 11394
6. *Crescentipollenites*, Slide no. BSIP 11394
7. *Sahnites*, Slide no. BSIP 11394
8. *Tetraporina*, Slide no. BSIP 11391
9. *Balmeella*, Slide no. BSIP 11394
10. *Lophosphaeridium*, Slide no. BSIP 11392

Vestigisporites disectus Hart emend. Tiwari & Singh 1984

Vestigisporites diffusus Maithy 1965

Sahnites thomasi Pant emend. Tiwari & Singh 1984

Sahnites barrelis (Tiwari) Tiwari & Singh 1984

Sahnites methoris (Hart) Tiwari & Singh 1984

Sahnites elongatus (Lele & Karim) Tiwari & Singh 1984

Scheuringipollenites tentulus (Tiwari) Tiwari 1973

Scheuringipollenites barakarensis (Tiwari) Tiwari 1973

Scheuringipollenites maximus (Hart) Tiwari 1973

Ginkgocycadophytes sp.

Tiwariasporis gondwanensis (Tiwari) Maheshwari & Kar 1967

Parasaccites korbaensis Bharadwaj & Tiwari 1964

Parasaccites obscurus Tiwari 1965

Table 2—Relative percentage of spores and pollen in samples from bore-hole TCC-19. Presence of palynomorphs is marked with + in samples where quantitative analysis could not be done; (+) less than 5; (++) more than 5 and less than 15; (+++) more than 15. Details of Groups : I - Acritarchs; II - Striate bisaccate; III - Bisaccate with imperfect striations; IV - Nonstriate bisaccate; V - Radial monosaccate; VI - Trilete and zonate spore; VII - Others

Group		Depth in meters								
	Genera	10.75-27.85	47.41-60.47	65.60-67.21	117.60-118.35	132.40-133.15	154.37-155.42 & 159.52-162.52	168.24-169.22	170.96-172.11	177.04-177.24
I	*Balmeella*	-	1	4	-	-	-	+	-	-
	Leiosphaeridia	+	5	1	-	-	-	-	-	-
	Tetraporina	-	1	-	-	-	-	-	-	-
	Lophosphaeridium	-	1	1	-	-	-	-	-	-
II	*Crescentipollenites*	+	1	-	+	+	-	-	+	2
	Faunipollenites	+	38	6	++	+	+	+	+	6
	Striatopodocarpites	+	9	5	+	+	-	+	+	7
	Striatites	-	3	4	-	-	-	-	-	-
	Verticipollenites	-	1	-	-	-	-	-	-	-
III	*Primuspollenites*	-	1	5	-	+	-	-	-	-
	Rhizomaspora	-	1	2	-	-	-	-	-	-
IV	*Platysaccus*	-	2	1	-	-	-	-	-	-
	Paravesicaspora	-	-	1	-	-	-	-	+	-
	Scheuringipollenites	-	32	68	+++	++	+	++	+	8
	Vestigisporites	-	-	-	+	-	+	+	+	3
	Sahnites	+	-	-	-	+	+	++	+	6
V	*Parasaccites*	+	4	2	+	+	+	+	++	8
	Plicatipollenites	-	-	-	-	-	-	-	-	1
VI	*Microfoveolatispora*	-	-	-	-	-	-	-	-	1
	Brevitriletes	-	-	-	++	++	-	+	+++	10
	Microbaculispora	-	-	-	+	+	-	+	++	33
	Lacinitriletes	-	-	-	-	-	-	-	+	4
	Horriditriletes	-	-	-	-	-	-	-	-	1
	Cyclogranisporites	-	-	-	-	-	-	-	+	6
	Indotriradites	-	-	-	+	-	-	++	+	2
VII	*Callumispora*	-	-	-	-	+	-	+	+	1
	Tiwariasporis	-	-	-	-	+	-	-	-	1
	Quadrisporites	-	-	1	-	-	-	-	-	-

Parasaccites bilateralis Tiwari 1965

Cahenisaccites indicus Lele 1964

Potonieisporites lelei Maheshwari 1967

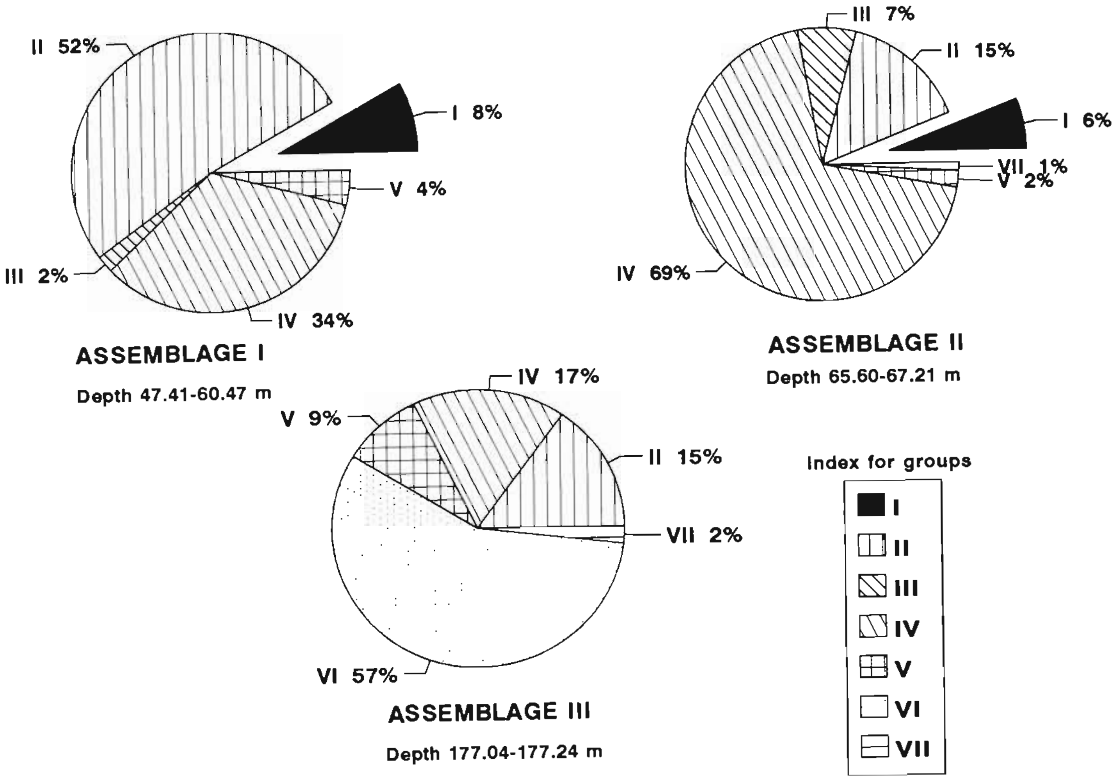
Besides the above mentioned palynomorphs, acritarch taxa, viz., *Leiosphaeridia* Downie & Sarjeant 1965, *Lophosphaeridium* Timofeev ex. Downie 1963, *Balmeella* Pant & Mehra 1963, *Tetraporina* Naumova ex. Naumova emend. Kar & Bose 1976, and *Maculatasporites* Tiwari 1965 are also recorded. The quantitative analysis of spore-pollen and acritarch population (Pl. 1, figs 1-10) has been differentiated in seven groups as detailed in Table 2. Their distribution pattern reveals the presence of three assemblages (Table 2; Text-figure 1). The ordinal scale categories used for representation of the palynomorphs are : above 25% = abundant, 25% - 10% = common; and less than 10% = rare.

Assemblage I

This assemblage is recorded from the lowermost coal horizon (170.96-177.24 m depth) of the sequence. The palynoflora is dominated by the trilete spore *Microbaculispora* together with *Brevitriletes, Lacinitriletes* and *Cyclogranisporites*. The nonstriate bisaccates (*Scheuringipollenites* + *Sahnites* + *Vestigisporites*) attain the second position numerically followed by the striate bisaccates (*Faunipollenites* + *Striatopodocarpites*). Radial monosaccates are common.

Assemblage II

This assemblage is also recorded from the coal-bearing horizon (65.60-169.22 m depth) below marker conglomeratic pebbly bed. The dominance



Text-figure 1 — Relative frequency of palynomorph groups I-VII recorded in various assemblages identified in samples from bore-hole TCC-19. The frequency plotted here is the sum of percentage of various palynotaxa of a particular Group as given in Table 2.

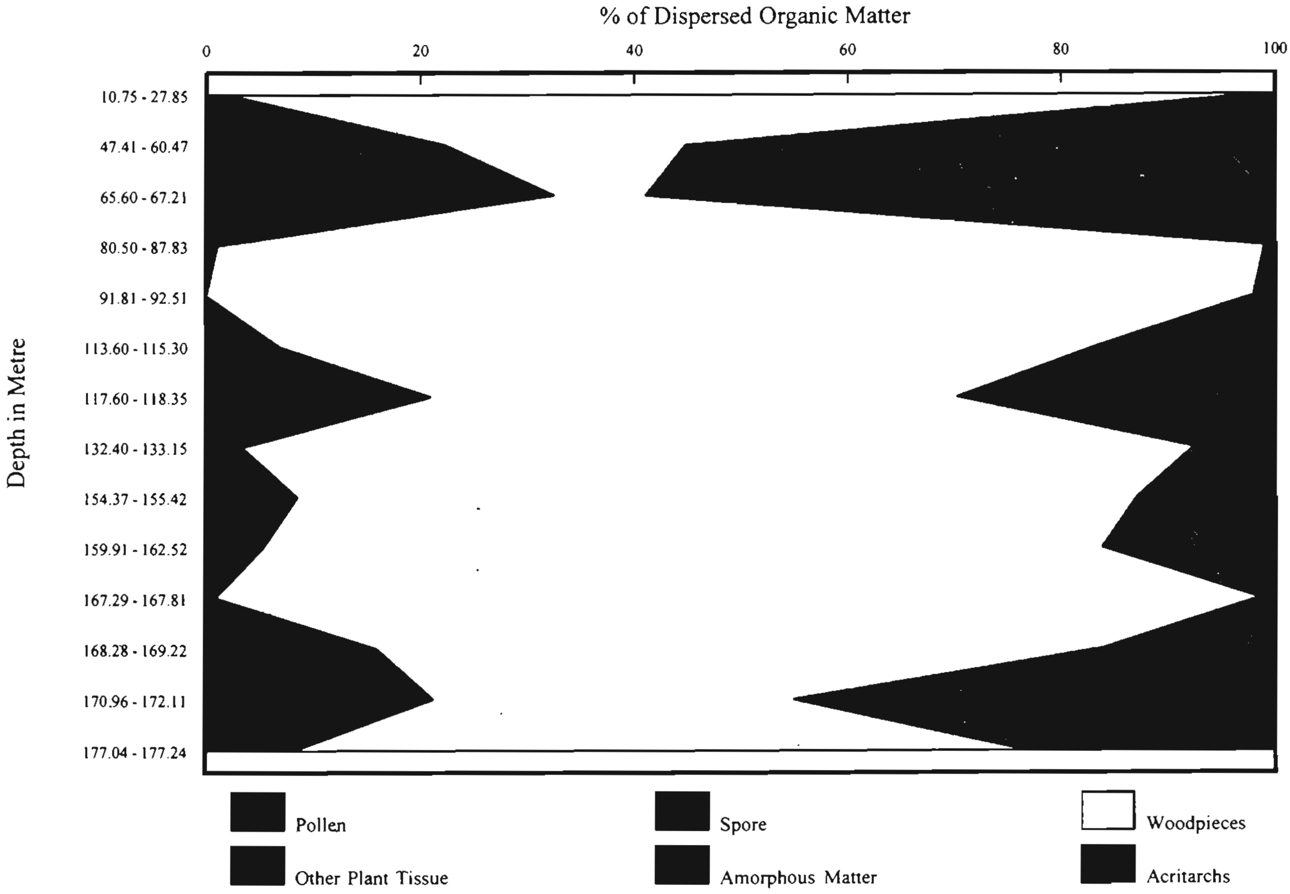
of trilete spores of Assemblage I is replaced by nonstriate bisaccate *Scheuringipollenites* and *Primuspollenites*. Common representation of trilete spores reveals continuity of the flora from Assemblage I, where they are abundant, to Assemblage II. The radial monosaccates show a declining trend. The presence of acritarchs *Balmeella*, *Leiosphaeridia* and *Lophosphaeridium* at 65.60-67.21 m depth, although rare, is noteworthy.

Assemblage III

This assemblage is recorded from the coal-bearing horizon (10.75-60.47 m depth) above the conglomeratic pebbly bed. It has a distinct palynoflora which is dominated by striate bisaccates (*Faunipollenites* + *Striatopodocarpites*) and the nonstriate bisaccates attain second place numerically. The trilete spores are rare. The assemblage shows presence of acritarchs *Leiosphaeridia*, *Lophosphaeridium* and *Balmeella*. At 47.41-60.47 m depth just above the conglomeratic bed all the three forms are present where as at 10.75-27.85 m depth only *Leiosphaeridia* is recorded.

PALYNOFACIES ANALYSIS

The palynofacies analysis included the study of complete acid resistant organic residue, divisible into — (i) terrestrial material (spores, pollen, fresh water algae, wood and cuticle), (ii) marine algae, microforam tests, and (iii) structureless organic



Text-figure 2 — Composite diagram showing the lithocolumn of bore-hole TCC-19 along with palynological characteristics of various assemblages and palynofacies units with remarks on palaeoenvironment.

PLATE 2

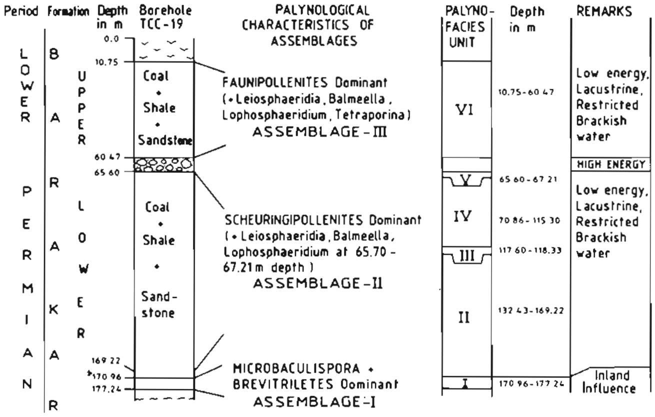
1. Spore-pollen rich contents with some structure-less brownish black wood pieces, Slide no. BSIP 11394.
2. Palynodebris rich in splintery (SW), blade shape (BW) and some equidimensional (EW), brownish black structure-less wood pieces with few palynomorphs, Slide no. BSIP 11393.
3. Structureless brownish black woody material (W) along with pollen (P) and acritarch (A), Slide no. BSIP 11391.
4. Structureless brownish black woody material along with other plant tissue (PT), Slide no. BSIP 11391.

matter-bacterially reworked biomass of laminar or granular appearance. All these entities are now termed as "Palynodebris" which was coined by Manum (1976, in Boulter, 1994). In the present study the palynodebris are identified according to the classification proposed by van Bergen *et al.* (1990).

The palynofacies analysis for acid resistant organic matter (Pl. 2, figs 1-4) was carried out for all the coal samples. They were subjected to nitric acid and mild alkali treatment for oxidation and release of the organic matter. Thereafter passed through 400 mesh sieve. This resulted in the removal of very fine matter (± 15 µm). Relative occurrences of various components were observed in at least three slides, under a 20 x 40 mm coverglass, of each sample. Text-figure 2 illustrates the distribution pattern of organic matter in the samples considered for palynofacies analysis. In general, the composition shows that most samples have dominance of woody material except at depths 170.96-172.11 m and 47.41 to 67.21 m, where other plant tissues contribute as dominant group. In none of the samples spores and pollen show dominance. On the basis of relative frequencies of various groups the sequence may be subdivided into the following palynofacies units from bottom to top (Text-figure 3).

Unit I

This is recorded in two samples. The sample at 177.04-177.24 m depth is rich in splintery, blade-shaped wood remains, and the spore-pollen are comparatively less. The sample at 170.96-172:11 m is rich in golden-yellow spore-pollen with other plant tissues. Detritus is attached to the debris. Most of the gymnospermous pollen are broken.



Text-figure 3 — Distribution pattern of dispersed organic matter in the samples from bore-hole TCC-19, Talcher Coalfield, Orissa, India.

Unit II

It is recorded in five samples from 132.43 -169.22 m depth. The samples are rich in woody material and spore-pollen are less and broken. The wood pieces are splintery as well as equidimensional varying in colour from golden brown to dark brown and black. Few cuticle pieces are also present. Only one specimen of smooth-walled acritarch is found.

Unit III

The sample from 117.60-118.35 m depth is rich in spore-pollen and cuticle, in which the pollen are broken. Wood pieces dominant, equidimensional, brown and black in colour.

Unit IV

This unit is recorded in six samples at 70.86 - 115.30 m depth. In this unit the spore-pollen are poorly represented and the samples are rich in woody material. The wood pieces are mostly splintery and some are equidimensional, dark brown to black in colour.

Unit V

The sample (65.60-67.21 m depth) is rich in spore-pollen. Wood pieces and other plant tissues are few and big, equidimensional and dark brown in colour. The acritarch are also present, though in small numbers.

Unit VI

This unit is represented in two samples at 10.75-60.47 m depth. These are full of golden yellow to blackish brown equidimensional but not splintery wood pieces. Spore-pollen are few, mostly degraded, yellow but not hyaline and difficult to identify at species level. The acritarchs are also recorded in this unit having better representation at 47.41-60.47 m depth with dominance of other plant tissues.

DISCUSSION

Assemblages I-III in bore-hole TCC-19 can closely be identified with the palynoflora of Barakar age (Tiwari & Tripathi, 1988). Assemblage I and II show difference in the dominant and subdominant taxa but the palynofloral change is gradual, and not abrupt. These two assemblages are compositionally similar to the Lower Barakar palynoflora (Tiwari, 1974; Srivastava, 1984). Assemblage III reveals a compositional change due to dominance of striate-bisaccates and is correlatable with the Upper Barakar assemblages (Bharadwaj & Srivastava, 1969; Tiwari, 1974; Srivastava, 1984; Tripathi, 1993). The palynoflora is continuous and does not indicate any sharp break inspite of the presence of conglomeratic pebble bed. The palynoflora clearly indicates the intraformational nature, well within Barakar rather than at the base of Barakar, of this marker bed.

The occurrence of acritarchs in Assemblage II at 65.70-67.21 m depth, which also continues in Assemblage III at 47.41-60.47 m depth is significant. The acritarchs are also recorded below and above the conglomeratic pebble bed (56.60-180.70 m depth) in the bore-hole NCTB-288 (Srivastava, 1984). The presence of acritarchs indicates brackish water condition (Tappan, 1980) which evidently started before the deposition of conglomeratic pebble bed and existed even after its deposition in this coalfield. The acritarchs are also on record from the Barakar assemblage of bore-hole TCW-25 in north-western part of the Talcher Coalfield (Tripathi, 1993). Acritarchs have been reported from early Late Barakar assemblages from areas of Damodar, Son-Mahanadi, Krishna-Godavari and Rajmahal Basins (Tiwari *et al.*, 1995; Prasad *et al.*, 1996).

The oval-shaped pebbles suggest their transportation over a long distance (Roy, 1963). Their unsorted nature in the bed suggests high energy conditions. The area of provenance might be from Antarctica, as during Permian the Eastern Antarctica have shown palaeodrainage system towards north through Son-Mahanadi Graben of India (Casshyap & Tewari, 1984; Webb & Fielding, 1993).

The palynofacies analysis reveals good preservation of organic matter, except in Units I and VI where black specks are attached to the matter which could not be separated through chemical treatments by HCl. The spore and pollen are yellow but not hyaline. However, the structureless amorphous organic matter is comparatively less. The sequence is characteristic in having abundance of blade-shaped splintery wood pieces and relatively low frequency of palynomorphs except at 170.96-172.11 m and 47.41-67.21 m depths where the woody material is replaced by high incidence of other plant tissue. This indicates low to medium energy conditions and fluvial environment. The amorphous organic matter is present in very low percentage throughout. This together with high incidence of woody material and other plant tissue is suggestive of the lacustrine environment (Boulter, 1994). The high incidence of plant tissues at depth levels 170.96-172.11 m and 47.41-67.21 m is interpreted as indicative of a near shore environment (Pocock *et al.*, 1988; Traverse, 1988). The presence of smooth-walled acritarchs suggests restricted brackish water condition. The high influx of pteridophytic spore content within the coal at 168.28-172.11 m depth indicates the influence of inland flora growing in and around the basin and in the provenance area as undergrowth. The high frequency of the splintery and blade-shaped black wood pieces in the coal samples suggests terrigenous input and fluvial conditions (Boulter & Riddick, 1986; van Bergen & Kerp, 1990). The brownish black to black colour of the wood components may be the result of oxidation during transportation (Pocock *et al.*, 1988).

From the present state of observation it is clear that the coal bed sequence studied in this paper was deposited in low energy conditions with a short spell of high energy during deposition of the conglomeratic pebble bed and fluvial lacustrine palaeoenvironment with restricted brackish water conditions.

CONCLUSION

1. Palynological Assemblages I and II from the coal horizon below the conglomeratic pebblebed are comparable to the Early Barakar

palynoflora while the Assemblage III is comparable to Late Barakar palynoflora of Damodar Valley coalfields.

2. The presence of acritarch indicates a brackish water depositional environment.
3. The palynofacies analysis reveals that low energy, lacustrine conditions with a short spell of high energy prevailed during the deposition of these sedimentaries.

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REFERENCES

Bharadwaj DC & Srivastava SC 1969. Palynological correlation of coal seams in Talcher Coalfield, Orissa, India. *Palaeobotanist* **17**(2) : 152-156.

Boulter MC 1994. An approach to a standard terminology for palynodebris. *In* : Traverse Alfred (Editor)—*Sedimentation of organic particles* : 199-216. Cambridge University Press.

Boulter MC & Riddick A 1986. Classification and analysis of palynodebris from the Palaeocene sediments of the Forties Field. *Sedimentology* **33** : 871-886.

Casshyap SM & Tewari RC 1984. Fluvial models of the Lower Permian coal measures of Son-Mahanadi and Koel-Damodar Valley Basins, India. *In* : Rahmani RA & Flores RM (Editors)—*Sedimentology of coal and coal-bearing sequences - Spec. Publs. Int. Assoc. Sedimentol.* **7** : 121-147. Blackwell Scientific Publications.

Combaz A 1964. Les palynofacies. *Rev. Micropaleont.* **7**(3) : 205-218.

Hart GF, Pasley MA & Gregory WA 1994. Particulate organic matter, maceral facies models, and applications to sequence stratigraphy. *In:* Traverse Alfred (Editor)—*Sedimentation of organic particles* : 337-390. Cambridge University Press.

Pocock SAJ, Vasanthy G & Venkatachala BS 1988. Introduction to the study of particulate organic materials and ecological perspectives. *J. Palynol.* **23-24** : 167-188.

Prasad B, Jain AK & Mathur YK 1996. A standard palynozonation scheme for the Cretaceous and pre-Cretaceous subsurface sediments of Krishna-Godavari Basin, India. *Geosci. J.* **16**(2) : 155-232.

Roy RK 1963. On the occurrence of the Barakar pebble bed in the Talcher Coalfield, Orissa. *Q. Jl geol. Min. metall. Soc. India* **35**(2) : 155-157.

Srivastava SC 1984. Palynological succession in a bore hole, Talcher Coalfield, Orissa, India. *In* : Tiwari RS, Awasthi N, Srivastava SC, Singh HP & Sharma BB (Editors)—*Proc. V Indian Geophytol. Conf., Lucknow* : 110-128. The Palaeobotanical Society, Lucknow.

Tappan H 1980. *The paleobiology of plant protists.* Freeman, Oxford.

Tiwari RS 1974. Inter-relationships of palynofloras in the Barakar Stage (Lower Gondwana), India. *Geophytology* **4**(2) : 111-129.

Tiwari RS & Tripathi A 1988. Palynological zones and their climatic inference in the coal-bearing Gondwana of peninsular India. *Palaeobotanist* **36** : 87-101.

Tiwari RS, Tripathi A & Jana BN 1991. Palynological evidence for Upper Permian Raniganj coals in western part of Talcher Coalfield, Orissa, India. *Curr. Sci.* **61**(6) : 407-410.

Tiwari RS, Tripathi A & Vijaya 1995. Organic-walled microfossils of doubtful origin in Permian and Triassic sequences on peninsular India. *Palaeobotanist* **43**(1) : 1-38.

Tripathi A 1993. Palynosequence in subsurface Permian sediments in Talcher Coalfield, Orissa, India. *Geophytology* **23**(1) : 99-106.

van Bergen PF, Janssen NMM, Alfernik M & Kerp JHF 1990. Recognition of organic matter types in standard palynological slides. *Meded. Rijks Geol. Dienst* **45** : 9-22.

van Bergen PF & Kerp JHF 1990. Palynofacies and sedimentary environments of a Triassic section in southern Germany. *Meded. Rijks. Geol. Dienst* **45** : 23-38.

Webb JA & Fielding CR 1993. Late Permian-Early Triassic stratigraphy and basin evolution of the Lambert Graben, Northern Prince Charles Mountains, Antarctica. *In* : Findlay RH, Unrug R, Banks MR & Veevers JJ (Editors)—*Proc. 8th Int. Gondwana Symp., Tasmania, Australia* : 357-369. A.A. Balkema Roterdam.

Fossil dicotyledonous liana *Anamirta pfeifferi* sp. nov. (Menispermaceae) from the Deccan Intertrappean beds of India

S.D. Bonde

Bonde SD 1997. Fossil dicotyledonous liana *Anamirta pfeifferi* sp. nov. (Menispermaceae) from the Deccan Intertrappean beds of India. *Palaeobotanist* **46** (3) : 89-94.

A fossil dicotyledonous woody liana, *Anamirta pfeifferi* sp. nov., showing anomalous secondary growth has been described from the Deccan Intertrappean beds of Nawargaon-Maragsur area, district Wardha, Maharashtra, India. The wood exhibits pluriseriate secondary growth with alternate concentric rings of xylem and phloem, vascular bundles in a ring separated by broad primary xylem rays, differentiated pith and endarch primary xylem. Pluriseriate type of anomalous secondary growth in a fossil dicotyledonous wood has been described here for the first time.

Key-words— Xylotomy, *Anamirta*, Menispermaceae, Deccan Intertrappean beds, Uppermost Cretaceous, India.

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साराँश

भारत की दक्खन अन्तर्ट्रेपी संस्तरों से अश्मित द्विबीजपत्री बन्ध-लता–*एनामिर्टा फिफेराई* नवजाति

सुरेश डी० बोंडे

महाराष्ट्र में वर्धा जनपद में नवरगाँव-मारगसूर क्षेत्र के दक्खन अन्तर्ट्रेपी संस्तरों से द्वितीयक वृद्धि युक्त एक अश्मित द्विबीज पत्री बन्ध-लता—*एनामिर्टा फिफेराई* नव जाति का वर्णन किया गया है। इस अश्मित काष्ठ में दारु एवं पोषवाह के एक के बाद एक वलयों से युक्त अनेक पंक्तिक द्वितीयक वृद्धि, चौड़ी दारु किरणों से पृथक्कृत एक वलय में विन्यस्त वाही बंडल, मज्जा तथा अन्तःमुखी आदि दारु विद्यमान हैं। अश्मित काष्ठों में इस प्रकार की अनेक-पंक्तिक द्वितीयक वृद्धि का यह पहला अभिलेख है।

THE Deccan Intertrappean beds exposed in Nawargaon-Maragsur area ($21^{0}01'$, North & $78^{0}35'$, East), district Wardha, Maharashtra are rich in angiospermic remains. Of them, *Aristolochioxylon prakashii* Kulkarni & Patil 1977, *Ardisioxylon indicum* Shete & Kulkarni, *Heterophragmoxylon indicum* Shete & Kulkarni, *Aeschynomenoxylon nawargaoensis* Shete & Kulkarni, *Evodinium intertrappeum* Shete & Kulkarni 1982, *E. indicum* Bande & Prakash, *Amooroxylon deccanensis* Bande & Prakash 1984, *Sonneratioxylon preapetalum* Awasthi (=*S. caeseolarioides* Shete & Kulkarni 1982; =*S. nawargaoensis* Bande & Prakash 1984 emend. Mehrotra 1988), *Gmelina tertiara* Bande 1986 and *Paraphyllanthoxylon palaeoemblica* Prakash *et al.* 1986 are the dicotyledonous woods and *Unonaspermum corneri* Bonde 1993, an anonaceous seed, described from these beds. In addition to these, number of monocotyledonous plants have been reported from these beds (Bonde, 1995).

SYSTEMATIC DESCRIPTION

Family—Menispermaceae

Genus—*Anamirta* (L.) W.&A.

Anamirta pfeifferi sp. nov.

Pl. 1, figs 1-10

Material—The present species is based on a small piece of permineralized wood consisting of a central pith surrounded by a ring of primary xylem and secondary wood collected from Nawargaon-Maragsur area. The wood is 6.5 cm long and 1.0 x 1.7 cm in diameter. The axis shows spirally twisted ribs and furrows (Pl. 1, fig. 1).

Diagnosis—Axis spirally twisted with ribs and furrows; *primary xylem* poles sixteen, placed in a ring around the pith; each pole consisting of 1-4 protoxylem and 6-10 metaxylem elements. *Pith* small, compressed, 1.0 x 1.3 mm, differentiated; central parenchymatous cells large with intercellular spaces; peripheral compact cells small, polygonal. *Secondary wood* pluriseriate with alternate concentric rings of xylem and phloem. Vascular bundles in a ring separated by broad primary rays. *Vessels* small to large, solitary, round. Small vessels 45 x 106 µm (average 75 x 75 µm), large vessels 166-257x150-300 µm (average 225 x 195 µm), 252-468 µm (340 µm) long with truncate ends; perforation simple, intervessel pitpairs contiguous, polygonal. *Parenchyma* (i) conjunctive-broad bands forming concentric rings capping phloem from cortical side, stone cells present; (ii) apotracheal diffuse in short tangential lines, one cell wide, 2-4 cells per strand, longitudinally elongated. *Interfascicular xylem rays* broad and long, not continuous radially from one ring of bundles to the next, 8-16 cells wide; cells procumbent, squarish, homogeneous. Fascicular rays occasional, narrow, homogeneous with upright cells, 1-2 cells wide and 1-10 cells tall. *Fibres* libriform in radial rows, 6.8-17.0 x 8.5-22.0 µm (average 14x12 µm), 119-238 µm long; interfibre pits bordered in rows, pits 5.1 µm. *Phloem* tangentially elongated bands forming concentric rings alternate to xylem rings.

Holotype—N80, Botany Unit, Plant Science Division, Agharkar Research Institute, Pune.

Locality—Nawargaon-Maragsur, Wardha District, Maharashtra, India.

Horizon—Deccan Intertrappean beds.

Age—Uppermost Cretaceous.

Topography—The wood in cross section is pluriseriate (*Corpus lignosum circumvallatum*) having alternate concentric rings of xylem and phloem (Pl. 1, fig. 2). *Primary xylem* having sixteen poles arranged in a ring at the periphery of the pith. Each primary xylem group consists of 1-4 circular, 10.0-27.0 µm long protoxylem elements and 6-10 round to radially elongated metaxylem vessels, t.d. 31.0-48.0 µm and r.d. 41.0-61.0 µm. Pith 1045 x 1382 µm, differentiated into central and peripheral zones. Central zone is much wider with large parenchyma cells, 68x75-85x112 µm with stone cells and small intercellular spaces. Peripheral zone 14-18 cells wide, composed of small polygonal 24x27-48x48 µm cells (Pl. 1, figs 3-4).

Wood diffuse porous. *Growth rings* distinct, consisting of 16 and 24 vascular bundles in the first two rings respectively. Other four rings are incomplete. *Vessels* small to large, nearly all solitary, sometimes filled with dark contents; round to oval in cross section. Small vessels 45 x 106 µm (average 75 x 75 µm); large vessels t.d. 166-257 µm, r.d. 150-300 µm (average 225x195 µm), wall 6.8 µm thick; vessel members 252-468 µm long with truncate ends, perforations simple; intervessel pit pair contiguous, polygonal, pits 6.8x6.8-12.2x13.6 µm in size (Pl. 1, fig. 10). *Parenchyma* apotracheal, diffuse, occasionally in short tangential lines, one cell wide, 2-4 cells per strand. The cells are tubular to rectangular or longitudinally elongated; radial width 10.2-20.4 µm, tangential width 10.2-17.0 µm and length 34.0-51.0 µm; with simple, circular 2.0-4.0 µm pits. *Conjunctive parenchyma* present between successive ph-

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PLATE 1

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Anamirta pfeifferi gen. et sp. nov.

1. Fossil wood showing twisted axis x 0.85.
2. Cross section showing central pith, primary xylem and pluriseriate secondary wood with six alternate rings of xylem and phloem x 6.
3. Cross section showing pith and endarch primary xylem x 45.
4. Cross section showing primary xylem groups and first ring of vascular bundles x 60.
5. Cross section showing vascular bundles in a ring separated by broad primary xylem rays x 60.
6. Tangential section showing very broad and long primary xylem rays x 6.
7. The same x 60.
8. Secondary xylem rays x 60.
9. Wood fibres with uniseriate bordered pits x 600.
10. Intervessel pittings x 150.

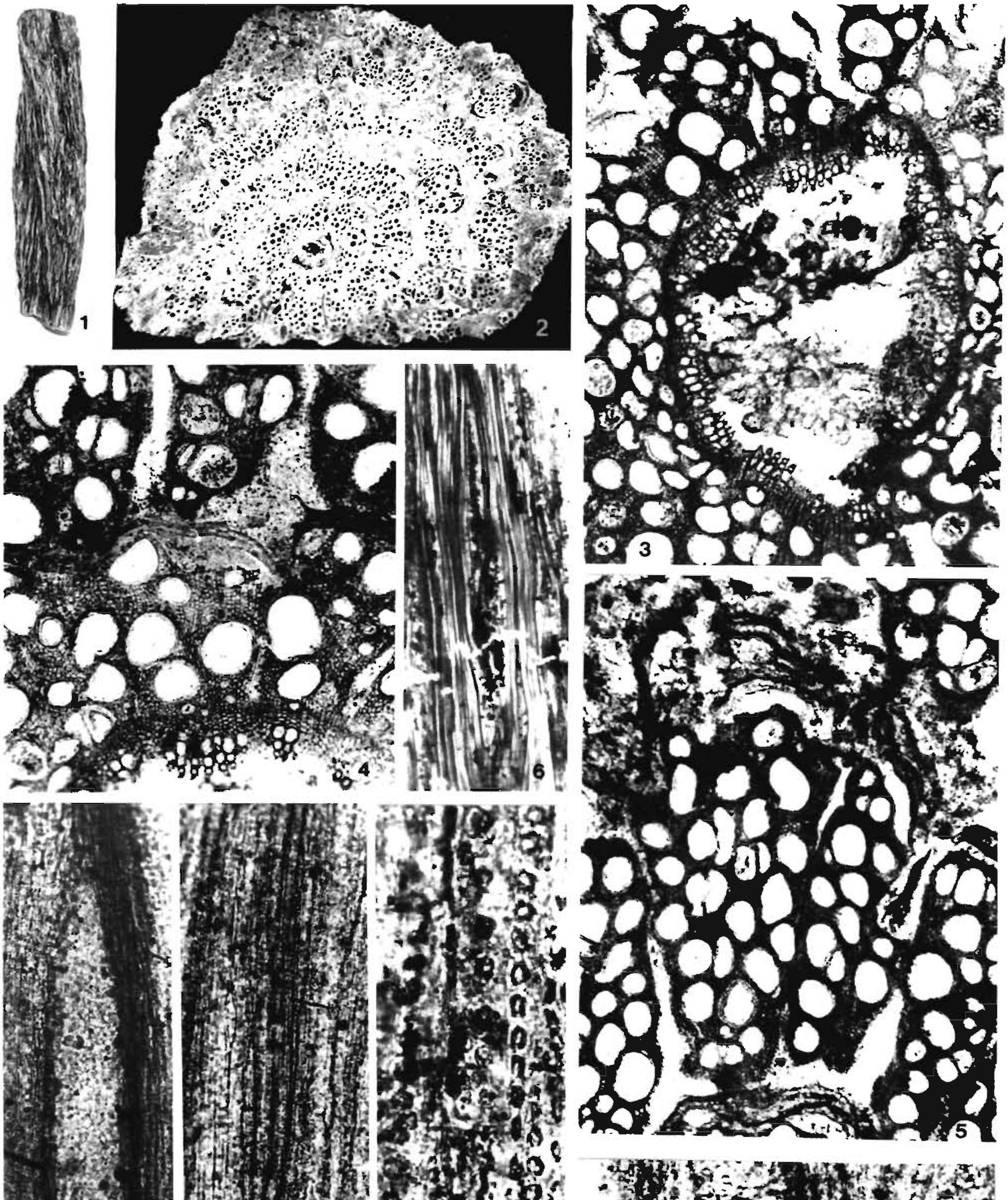

PLATE 1

loem and xylem rings; isodiametric to radially elongated 2-3 layered stone cells present, usually 2-5 cells in a row, sometimes with dark bodies. *Xylem rays* (i) interfascicular very broad and long; not contiguous radially from one ring of bundles to the successive rings, almost homogeneous; 8-16 cells wide, cells procumbent with little distinction between central and marginal cells (Pl. 1, figs 5-7); (ii) fascicular rays very occasional, narrow, 1-2 cells wide and 1-10 cells tall of upright cells only; cells 34.0 x 6.8-82.0 x 10.2 μm (Pl. 1, fig. 8). *Fibres* libriform, aligned in radial rows; t.d. 8.5-22.0 μm, r.d. 6.8-17.0 μm, wall 1-2 μm thick, length 119.0-238.0 μm; interfibre pits distinctly bordered, 5.1 μm in diameter, both on radial and tangential walls (Pl. 1, fig. 9). *Phloem* in tangential concentric bands alternate to the xylem bands.

DISCUSSION

The important features of the present wood are (i) longitudinally twisted ribbed axis, (ii) pluriseriate secondary wood consisting of alternate concentric rings of xylem and phloem, (iii) a ring of conjunctive parenchyma capping the phloem ring from the cortical side; (iv) broad primary xylem rays; (v) vessels small to large, solitary; (vi) fibres with bordered pits in a row, both on radial and tangential walls; (vii) endarch primary xylem, and (viii) differentiated pith. These characters suggest anomalous secondary growth in the present wood. Gaudichaud (1833), Schenk (1893, 1895), Pfeiffer (1926), Radlkofer (1931-34), Chalk and Chattaway (1937) and Obaton (1960) have given the comprehensive survey of anomalous structures in woody plants. Pfeiffer has recognized eight types of anomaly in woody plants depending upon the organization and activity of the cambium.

The present fossil exhibits concentric rings of phloem embedded in the secondary xylem (*Corpus lignosum circumvallatum)*. Such rings are formed because the cambium is short lived and replaced by successive cambia originating in the pericyclic or cortical region and repeating the structure of a young stem. Such type of pluriseriate secondary growth has been recorded in Amaranthaceae, Ampelidaceae, Buxaceae, Capparidaceae, Caryophyllaceae, Chenopodiaceae, Compositae, Connaraceae, Convolvulaceae, Dilleniaceae, Ficoidaceae, Flacourtiaceae, Hippocrateaceae, Leguminosae, Loranthaceae, Menispermaceae, Nyctaginaceae, Phytolaccaceae, Plumbaginaceae, Polygalaceae, Polygonaceae, Rubiaceae, Rutaceae and Umbelliferae of dicotyledons and Gnetaceae of Gymnosperms (Metcalfe, 1983; Metcalfe & Chalk, 1950; Obaton, 1960; Pfeiffer, 1926).

Amaranthaceae, Capparidaceae, Caryophyllaceae, Chenopodiaceae, Compositae, Hippocrateaceae, Loranthaceae, Phytolaccaceae, Plumbaginaceae, Rubiaceae, Rutaceae, Umbelliferae and Verbenaceae differ from the present fossil in having small to very small vessels in radial multiples or in groups and simple pits on their fibres (Loranthaceae and Rubiaceae have bordered pits). Moreover, interfascicular rays in Amaranthaceae are continuous from pith to cortex. Loranthaceae has 1-3 celled wide xylem rays, while Rubiaceae possesses aliform-confluent parenchyma and Caryophyllaceae has scanty inter-fascicular rays. Nyctaginaceae differs in having storied fibres with simple pits; Connaraceae, Convolvulaceae, Ficoidaceae and Polygalaceae differ due to scanty and narrow interfascicular rays in them. Flacourtiaceae and Polygonaceae differ in having vasicentric parenchyma; Dilleniaceae and *Tetrastigma* of Ampelidaceae possess storied parenchyma; Leguminosae varies in having aliform-confluent parenchyma whereas in Buxaceae wood parenchyma is lacking. *Gnetum* of Gymnospermae resembles the fossil wood in general but the vessels endplate in *Gnetum* have a row of perforations. Moreover, *Gnetum* does not show distinct primary xylem groups (Maheshwari & Vasil, 1961; Rao & Keng, 1975).

In Menispermaceae, *Cocculus, Arcangelisia, Tiliacora, Menispermum* and *Abuta* show near resemblance with the present fossil wood. However, the wood of *Cocculus* differs from the fossil in having very small to moderate-sized vessels. *Arcangelisia* differs in having very small to large vessels, while *Tilicora* differs in having vessels in tangential rows. *Menispermum* differs due to thick walled vessels with pitted tyloses. Whereas, *Abuta* differs in having irregular fibres with large lumina, adjoining the vessels. The present fossil resembles closely the wood of *Anamirta* Colebr. On examination of the published literature (Santos, 1931; Zamora, 1966) as well as the thin sections of *A. cocculus* (L.) W. & A. show a close resemblance with the fossil in having (i) pluriseriate secondary growth with alternate concentric rings of xylem and phloem, (ii) a ring of conjunctive parenchyma capping the phloem ring from cortical side, (iii) broad interfascicular xylem rays and occasional narrow fascicular rays, (iv) small to large solitary vessels, (v) endarch primary xylem in groups, and (vi) differentiated pith.

Aristolochioxylon prakashii Kulkarni & Patil 1977 is the only fossil dicotyledonous liana described so far. It differs from the present wood in having a single ring of vascular bundles and vasicentric parenchyma. Moreover, fascicular rays are absent in *A. prakashii* .

Anamirta is a monotypic genus with a single species, *A. cocculus* (L.) W. & A. (syn. *A. paniculata* Colebr.). It is a large climbing shrub at low and medium altitudes distributed in the Indo-Malayan region (Forman, 1978). It occurs in Oudh in Bangladesh, Myanmar, Khasia Hills, Assam, Orissa and in the Deccan in Cuddapah and Mysore, Western Ghats, Cochin and Travancore (Hooker, 1875; Gamble, 1922, 1935).

As far as the author is aware, this is the first record of a fossil dicotyledonous liana with pluriseriate type of secondary growth. It has been named as *Anamirta pfeifferi* sp. nov. The specific epithet is after Dr H. Pfeiffer who has done extensive work on anatomy of woody lianas.

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REFERENCES

Bande MB. 1986. Fossil wood of *Gmelina* Linn. (Verbenaceae) from the Deccan Intertrappean beds of Nawargaon with comments on nomenclature of Tertiary woods. *Palaeobotanist* **35** (2): 165-170.

Bande MB & Prakash U 1984. Occurrence of *Evodia, Ammora* and *Sonneratia* from the Palaeogene of India. *In*: AK Sharma *et al*, (Editors)—*Evolutionary Botany Biostratigraphy (A.K. Ghosh Comm. Vol.)* :97-114. New Delhi.

Bonde SD 1993. *Unonaspermum corneri* gen. *et* sp. nov., an annonaceous seed from the Deccan Intertrappean beds of India. *J. Indian bot. Soc.* **72** : 251-253.

Bonde SD 1995. *Arecoideostrobus moorei* gen. *et* sp. nov., a palm rachilla from the Deccan Intertrappean beds of India. *Palaeobotanist* **43** (3) : 102-109.

Chalk L & Chattaway MM 1937. Identification of woods with included phloem. *Tropical woods* **50 :** 1-31.

Forman LL 1978. A revision of the tribe Coscinieae Hook. f. & Thoms. (Menispermaceae). The Menispermaceae of Malesia and adjacent areas: IX. *Kew Bull.* **32** (2) : 323-338.

Gamble JS 1922. *A manual of Indian timbers.* Sampson Low, Morston & Co., London.

Gamble JS 1935. *Flora of the Presidency of Madras*, Vol. **I.** Reprinted by Botanical Survey of India, Calcutta.

Gaudichaud BC 1833. Observations sur quelques points de physiologie et d'anatomie comparee's des vegetaux et special ment sur l'accroissement des tiges. *Arch. de Bot.* **2** : 481-500.

Hooker JD 1875. *The flora of British India*- Vol. **I.** L. Reeve & Co., London.

Kulkarni AR & Patil KS 1977. *Aristolochioxylon prakashii* from the Deccan Intertrappean beds of Wardha District, Maharashtra. *Geophytology* **7**(1) : 44-49.

Maheshwari P & Vasil V 1961. *Gnetum. Botanical monograph No.1* C.S.I.R., New Delhi.

Mehrotra RC 1988. Fossil wood of *Sonneratia* from the Deccan Intertrappean beds of Mandla District, Madhya Pradesh. *Geophytology* **18** (2) : 129-134.

Metcalfe CR 1983. Anomalous structure. *In: Anatomy of the dicotyledons.* Vol. II. (Metcalfe CR & Chalk L: Editors). Second Edn. Clarendon Press, Oxford.

Metcalfe CR & Chalk L 1950. *Anatomy of the dicotyledons* . Vols. **I** & **II.** Clarendon Press, Oxford.

Obaton M 1960. Les lianas ligneuses a structure anomale des forets denses d'Afrique occidentale. *Ann. des Sci. nat. bot. Ser* . 12. **1** : 1-220.

Pfeiffer H 1926. Das abnorme *Dickenwachstum. Handbuch der Pflanzenanatomie* Vol. 9.2 Berlin.

Prakash U, Bande MB & Lalitha V 1986. The genus *Phyllanthus* from the Tertiary of India with critical remarks on the nomenclature of fossil woods of Euphorbiaceae. *Palaeobotanist* **35** (1) : 106-114.

Radlkofer L 1931-34. Sapindaceae. In Engler's *Das Pflanzenreich* **IV:** 165.

Rao AN & Keng H 1975. Anomalous secondary growth in *Gnetum gnemon*. *Ann . Bot.* **39**: 973-974.

Santo JK 1931. Anomalous stem structure in *Archangelisia flava* and *Anamirta cocculus* from the Philippines. *Philippines J. Sci. (Bot.)* **44**: 385-407.

Schenk H 1893. Beitrage zur Anatomie der Lianen. Schimper'sf bot. *Mitth. aus den Tropen* **5:** 1-291.

Schenk H 1895. Ueber die Zerkluftungsvorgange in anomalen Lianenstammen. *Jb. Wiss. Bot.* **27**: 580-612.

Shete RH & Kulkarni AR 1982. Contributions to the dicotyledonous woods of the Deccan Intertrappean (Early Tertiary) beds of Wardha District, Maharashtra, India. *Palaeontographica* 183 **B:** 57-81.

Solereder H 1908. *Systematic anatomy of the dicotyledons* . Vols. **I** & **II**, Clarendon Press, Oxford.

Zamora 1966. *Philipp. Agricult.* **50** : 437-444.

Angiospermous fossil leaves from the Siwalik sediments (Middle Miocene) of Darjeeling District, West Bengal

J.S. Antal & M. Prasad

Antal JS & Prasad M 1997. Angiospermous fossil leaves from the Siwalik sediments (Middle Miocene) of Darjeeling District, West Bengal. *Palaeobotanist* 46(3) : 95-104.

In the present paper some more angiospermous leaf-impressions recovered from Ghish River, Lish River and Sevok Road section in Darjeeling District, West Bengal have been described. These are—*Flacourtia tertiara* Prasad & Awasthi 1996, *Alsodeia palaeoracemosa* sp. nov. (Flacourtiaceae), *Shorea bengalensis* sp. nov. (Dipterocarpaceae), *Zizyphus palaeoapetala* sp. nov., *Ventilago tistaensis* sp. nov. (Rhamnaceae), *Syzygium palaeocuminii* Prasad & Awasthi 1996 (Myrtaceae) and *Homonoia mioriparia* sp. nov. (Euphorbiaceae). Out of these seven taxa, five are new records to the Siwalik flora. The dominance of evergreen and moist deciduous elements in the assemblage further confirms the prevalence of warm and humid climate during the deposition of the Himalayan foreland sediments.

Key-words—Angiosperms, Leaf-impressions, *Flacourtia, Alsodeia, Shorea, Zizyphus, Ventilago, Syzygium, Homonoia,* Middle Miocene, West Bengal (India).

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सारांश

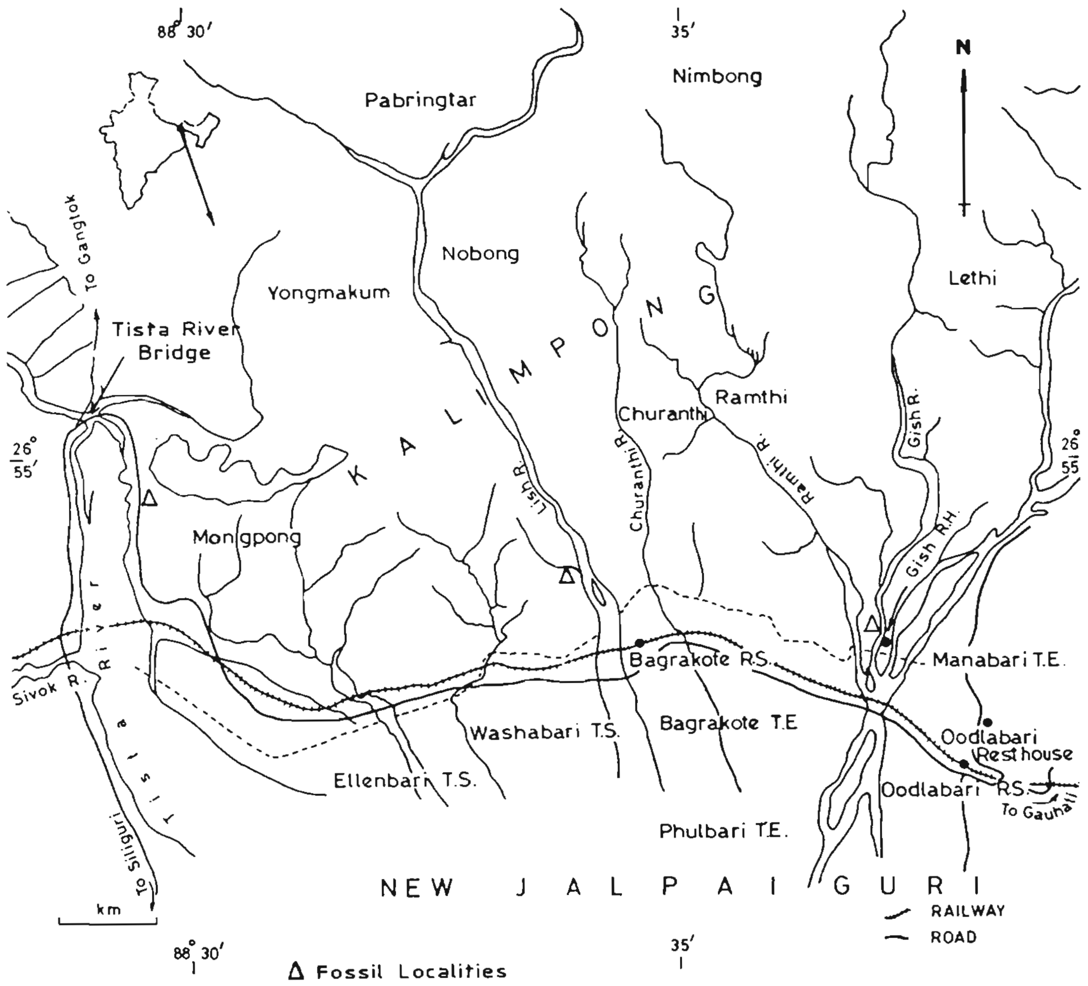
पश्चिम बंगाल में दार्जिलिंग जनपद के शिवालिक अवसादों से प्राप्त आवृत्तबीजी अश्मित पत्तियाँ

जसवन्तसिंह अन्तल एवं महेश प्रसाद

इस शोध-पत्र में पश्चिम बंगाल में दार्जिलिंग जनपद में घिश नदी, लिश नदी एवं सिवक रोड खंड से उपलब्ध कुछ और आवृत्तबीजी पर्ण-छापों का वर्णन किया गया है। ये अश्मित पत्तियाँ पाँच कुलों के सात वर्गकों *फ्लेकोर्शिया टर्शियेरा* प्रसाद व अवस्थी 1996, *आल्सोडिआ पेलियोरेसीमोसा* नव जाति (फ्लेकोर्शिएसी), *शौरिया बंगालेन्सिस* नव जाति (डिप्टेरोकार्पेसी), *जिजीफ़स पेलियोएपेटेला* नव जाति, *वेन्टीलागो तिस्तायेन्सिस* नव जाति (रहमनेसी), *सिजीजियम पेलियोक्युमिनाई* प्रसाद व अवस्थी 1996 (मिर्टेसी) एवं *होमोनोइया मायोराइपेरिया* नव जाति (यूफोर्बिएसी) से सम्बद्ध हैं। इन सात वर्गकों में से पाँच वर्गक शिवालिक वनस्पतिजात के लिये नये हैं। इस समुच्च्य में सदाहरित एवं नम पर्णपाती अवयवों की बाहुल्यता से हिमालयी गिरि-पादों के अवसादों के निक्षेपण के समय इस क्षेत्र में उष्ण और आर्द जलवायु होने की पुष्टी होती है।

THE Siwalik sequence of West Bengal has been broadly subdivided into three units—(i) upper pebbly sandstone and conglomerate unit, (ii) middle sandstone unit, and (iii) lower claystone unit (Acharyya, 1972, 1975). The lower claystone unit is best exposed in Ramthi River, Ghish River and along Tista River on the Sevok Road. They consist of claystone, siltstone and fine-grained sandstone. The middle sandstone unit is well exposed in Lish and Ghish Rivers and also in some tributaries of Tista River

The material for the present investigation was collected from both lower and middle units exposed in Ghish River, Lish River and Sevok Road section about 2 km from Tista River Bridge towards Oodlabari (Map 1). Earlier a number of leaf-impressions, some fruits and fossil woods have been described from this area (Antal & Awasthi, 1993; Antal & Prasad, 1995, 1996a, 1996b, 1996c; Antal *et al.*, 1996). Recently, a large number of well preserved impressions of leaves, fruits and seeds were collected from these sections. The study on these impressions reveals the presence of some more new taxa which have been described and discussed in this paper. For description of these leaf-impressions the terminology given by Hickey (1973) and Dilcher (1974) has been followed.



Map 1 — Showing the fossil localities in the area.

All the figured specimens have been deposited in the Museum of Birbal Sahni Institute of Palaeobotany, Lucknow.

SYSTEMATIC DESCRIPTION

Family—Flacourtiaceae

Genus—*Flacourtia* Comm. ex L'Herit

Flacourtia tertiara Prasad & Awasthi 1996
Pl. 1, fig. 1

Material—One specimen with counterpart.

Description—Leaf simple, symmetrical, elliptic, preserved size 9.0 x 3.8 cm; apex slightly broken; base acute, normal; margin serrate, serration con-

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PLATE 1 ⟶

(All specimens are in Natural size)

1. *Flacourtia tertiara* Prasad & Awasthi 1996, fossil leaf showing shape, size, venation pattern and serrate margin; Specimen no. BSIP 38020.
2. *Alsodeia palaeoracemosa* sp. nov., fossil leaves showing shape, size and venation pattern; Specimen no. BSIP 38021.
3. *Alsodeia palaeoracemosa* sp. nov., another fossil leaf showing details of venation; Specimen no. BSIP 38022.
4. *Shorea bengalensis* sp. nov., fossil leaf showing shape, size and venation pattern; Specimen no. BSIP 38023.
5. *Shorea bengalensis* sp. nov., apical part of the fossil leaf showing nature of apex; Specimen no. BSIP 38024.

6, 7. *Shorea bengalensis* sp. nov., another fossil leaves showing some variation; Specimen nos. BSIP 38025 and 38026.


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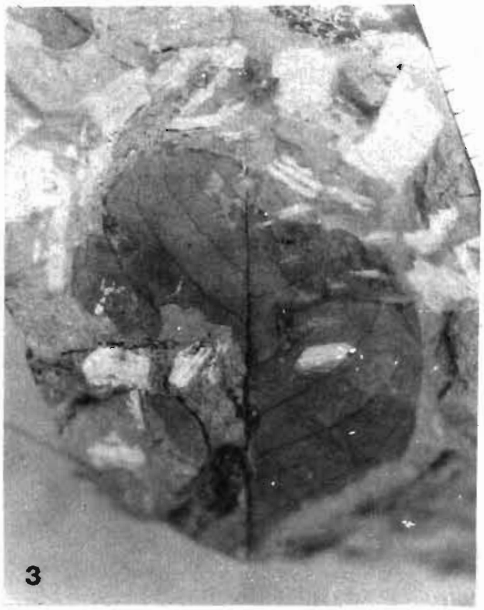
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7

PLATE 1

vex from basal as well as apical side; texture thick, chartaceous; petiole broken; venation pinnate, simple craspedodromous; primary vein (1°) single, prominent, almost straight, stout; secondary veins (2°) five pairs preserved, alternate to subopposite, distance between secondary veins 1.3 to 3.0 cm, curving up toward margin and run toward apex to a greater length before terminating at the margin, angle of divergence about 50°, acute, sometimes branched; tertiary veins (3°) fine, angle of origin R-R, percurrent, branched, almost straight and right angle in relation to midvein, close; further details not clearly visible.

Specimen — No. BSIP 38020.

Locality—Sevok Road section about 2 km from Tista River Bridge towards Oodlabari, Darjeeling District, West Bengal.

Horizon & age—Lower Siwalik, Middle Miocene.

Comparison—The important distinguishing characters of the fossil leaf are elliptic shape, acute base, serrate margin, simple craspedodromous venation and percurrent tertiaries with right angle in relation to midvein. Besides, the secondary veins arising from midvein run towards apex up to a greater length. These features indubitably indicate that the fossil leaf belongs to the family Flacourtiaceae. Among this family nearly resembling modern genera *Scolopia, Xylosmia, Maesa* and *Flacourtia* were studied in detail in order to identify this fossil leaf and found that the genus *Flacourtia* shows closest resemblance with the fossil. To identify it up to specific level, a number of herbarium sheets of various species of this genus were consulted and observed that the leaves of extant *Flacourtia inermis* Roxb. comes closest with the fossil leaf.

So far only two fossil leaves resembling the genus *Flacourtia* have been recorded under *F. nepalensis* Awasthi & Prasad 1990 and *F. tertiara* Prasad & Awasthi 1996 from The Siwalik sediments of Surai Khola, western Nepal. On comparison of the present fossil leaf with those already known fossil leaves of *Flacourtia*, it has been observed that *F. tertiara* which has also been compared with *F. inermis* Roxb., shows closest similarity in all morphological features. Therefore, it has been described under *F. tertiara* Prasad & Awasthi 1996; though it is the first record from India.

The genus *Flacourtia* Comm. ex'L'Herit consists of about 15 species of trees and shrubs distributed in tropical Asia and Africa. The extant taxon *F. inermis* Roxb. is an evergreen tree and native of Malayan Archepelago. It is also cultivated in India on account of its edible fruits (Brandis, 1971).

Genus—*Alsodeia* Thours

Alsodeia palaeoracemosa sp. nov.

Pl. 1, figs 2, 3

Material—This species is based on three specimens.

Description—Leaf simple, symmetrical, wide ovate, preserved size 7.5 x 5.0 cm; apex seemingly bluntly acute; base narrow acute, normal; margin entire; texture chartaceous; venation pinnate, eucamptodromous; primary vein (1°) single, prominent, thicker at the basal region, massive; secondary veins (2°) 5 to 6 pairs preserved, less than 1.00 to 2.5 cm apart, alternate to subopposite, angle of divergence 45°, seemingly unbranched, intersecondary veins present, simple; tertiary veins (3°) very fine, angle of origin usually RR, percurrent, sometime branched, predominantly alternate, right angle in relation to midvein, close to slightly distantly placed; quaternary veins (4°) still fine with angle of origin RR, branched forming orthogonal to polygonal meshes.

Holotype—Specimen no. BSIP 38021.

Paratype—Specimen no. BSIP 38022.

Locality—Sevok Road section about 2 km from Tista River Bridge towards Oodlabari, Darjeeling District, West Bengal.

Horizon & age—Lower Siwalik, Middle Miocene.

Comparison—The distinguishing features of the fossil leaves such as wide ovate shape, acute base and apex, entire margin, chartaceous texture, eucamptodromous venation and percurrent tertiary with RR angle of origin and closely to distantly placed tertiary veins collectively indicate their resemblance with the modern leaves of *Alsodeia racemosa* H.f. & Th. (CN Herbarium Sheet no. 32274) of the family Flacourtiaceae.

As far as we are aware there is only one record of the fossil leaves of *Alsodeia palaeozeylanica* Antal & Awasthi 1993 described from Ghish River Section near Oodlabari, Darjeeling District, West Bengal. This fossil leaf was compared with another modern species—*Alsodeia zeylanica* Thw. and thus obviously differs from the present specimens in being small size and possessing very closely placed percurrent fine tertiary veins. Therefore the present fossil leaves have been assigned to a new species-*Alsodeia palaeoracemosa*.

Genus *Alsodeia* Thours. includes 50 species distri- buted in the tropics of both hemispheres. The comparable extant species *A. racemosa* H.f. & Th. is a small tree of the tropical forests and upper mixed forest of Martaban and Tenasserim up to 500 m. In India, it is also distributed in Assam (Gamble, 1972; Brandis, 1971).

Family—Dipterocarpaceae

Genus—*Shorea* Roxb.

Shorea bengalensis sp. nov.
Pl. 1, figs 4-7

Material—There are 12 specimens in the collection.

Description—Leaf simple, symmetrical, ovate to elliptic, preserved size 9.0 x 6.0 cm, 11.0 x 6.0 cm, 9.0 x 6.0 cm; apex acute; base cordate to rounded, normal; margin entire; texture coriaceous; petiole present, 0.5 cm preserved, normal; venation pinnate, simple craspedodromous to eucamptodromous; primary vein (1°) single, prominent, almost straight, sometime slightly curved, thicker at the basal region; secondary vein (2°) about 10 pairs visible, 0.5 to 1.2 cm apart, curved up, angle of divergence acute to nearly right angle (65°-85°), usually alternate; tertiary veins (3°) fine, angle of origin usually RR, percurrent, sometime branched, straight, oblique in relation to midvein, predominantly alternate and close, further details could not be seen.

Holotype—Specimen no. BSIP 38023.

Paratype—Specimen nos. BSIP 38024, 38025 and 38026.

Locality—Sevok Road section about 2 km from Tista River Bridge towards Oodlabari, Darjeeling District, West Bengal.

Horizon & age—Lower Siwalik, Middle Miocene.

Comparison—The characteristic features of the present fossil leaves are ovate to elliptic shape, cordate to rounded base, entire margin, usually eucamptodromous venation, arrangement of lowest pair of secondary veins and percurrent tertiaries having right angle origin. These features indicate that the fossil leaves belong to the genus *Shorea* Roxb. of the family Dipterocarpaceae. In order to find out its nearest comparable species a large number of available Herbarium sheets of different species of *Shorea* were consulted. After critically examination it has been found that the fossil leaves show closest affinity with the extant species *Shorea roxburghii* (*S. talura* Roxb.) (CN Herbarium Sheet no. 82236).

The fossil leaves resembling the genus *Shorea* are known both from India and abroad (Merill, 1923; Seward, 1935; Antal & Prasad, 1996c, p. 76). Of them, three fossil species have been reported from the Siwalik sediments of India. These are *Shorea siwalica* Antal & Awasthi 1993 from Lower Siwalik sediments, Ramthi River, Darjeeling District, West Bengal; *S. neoassamica* Prasad 1994 from the Lower Siwalik sediments of Kathgodam, Uttar Pradesh, India and *S. miocenica* Antal & Prasad 1996c from the Middle Siwalik sediments of Ghish River Section near Oodlabari, Darjeeling District, West Bengal. The comparison of present fossil leaves with those already known fossil leaves of *Shorea* was done and found that none of them is comparable to the present leaves. Thus they have been described as a new species *Shorea bengalensis*.

The genus *Shorea* Roxb. consists of about 167 species distributed all over the world. Out of these, nearly 100 species of trees grow throughout the tropical parts of Indo-Malayan region (Pearson & Brown, 1932). The extant taxon *Shorea roxburghii*, with which the fossils show closest resemblance, is a large handsome tree found in the evergreen forests of North Kanara southwards and the hills of southern Deccan. It is also found in the Malayan Peninsula (Desch, 1957; Brandis, 1971).

Family—Rhamnaceae

Genus—*Zizyphus* Juss.

Zizyphus palaeoapetala sp. nov.

Pl. 2, figs 1, 2

Material—This species is represented by four specimens.

Description—Leaf simple, slightly asymmetrical at base, narrow elliptic, preserved size 11.0 x 4.0 cm and 7.0 x 4.2 cm; apex acute; base acute, oblique; margin almost entire; texture thick chartaceous; petiole not preserved; venation acrodromous, basal, perfect; primary veins (1°) three, one midvein and two strongly developed secondary veins; secondary veins (2°) 4-5 pairs arising from mid-primary vein, up to 10 secondary veins radiating towards margin, distance between secondaries at mid-primary 2.5 to 3.5 cm and at lateral primary about 1.00 cm, alternate, angle of divergence acute, about 35°, curved up running towards apex up to a greater length joining to their supradjacent secondaries; tertiary veins (3°) fine, angle of origin AR to RO, percurrent, straight as well as retroflex, angle in relation to midvein almost right angle, predominantly alternate and close, further details not clearly visible.

Holotype—Specimen no. BSIP 38027.

Paratype—Specimen no. BSIP 38028.

Locality—Lish River, near Bagrakot and Sevok Road Section about 2 km from Tista River Bridge towards Oodlabari, Darjeeling District, West Bengal.

Horizon & age—Lower Siwalik, Middle Miocene.

Comparison—The narrow elliptic shape with slightly asymmetrical acute base, acute apex, almost entire margin, basal perfect acrodromous venation, prominent secondaries arising both from mid- and lateral primary veins and straight to retroflexed tertiaries with almost right angle in relation to mid-primary vein indubitably indicate their resemblance with the genus *Zizyphus* Juss. of the family Rhamnaceae. In order to identify them up to specific level the herbarium sheets of a number of species of this genus have been examined and observed that the present fossil specimens closely resemble the leaf of *Zizyphus apetala* Hook.f. (CN Herbarium Sheet no. 80636) in shape, size and venation pattern.

As far as we are aware there are about 16 fossil records of *Zizyphus* leaves from India and abroad (Prasad, 1994, p. 134). Of them, six fossil leaves have been reported from the Siwalik sediments. They are : *Z. siwalicus* Lakhanpal (1965, 1966) from Jawalamukhi, Himachal Pradesh; *Z. indicus* Singh & Prakash 1980 from Arunachal Pradesh; *Z. champaran* Lakhanpal & Awasthi 1984 from Bhikhnathoree, Bihar; *Z.* cf. *Z. rugosa* Prasad 1994a from Haridwar, Uttar Pradesh and *Z. miocenica* Prasad 1994b from Kathgodam, Uttar Pradesh and Koilabas, western Nepal.

All the known fossil leaves were critically compared with the present fossil leaves and found that these are entirely different from them either in size or nature and arrangement of secondary and tertiary veins. Thus they have been described as *Zizyphus palaeoapetala* sp. nov.

The genus *Zizyphus* Juss. consists of about 40 species of shrubs or trees, mostly Indo-Malayan. The extant species *Z. apetala* Hook.f., with which our fossil leaves resemble, is a large struggling shrub or small tree distributed in Sikkim (Brandis, 1971).

Genus—*Ventilago* Gaertn.

Ventilago tistaensis sp. nov.

Pl. 2, fig. 3

Material—Three specimens, one with counterpart, are in the collection.

Description—Leaf simple, almost symmetrical, narrow ovate, preserved size 9.6 x 4.6 cm; apex seemingly acute; base nearly obtuse, somewhat

PLATE 2

⟶

(All specimens are in Natural size)

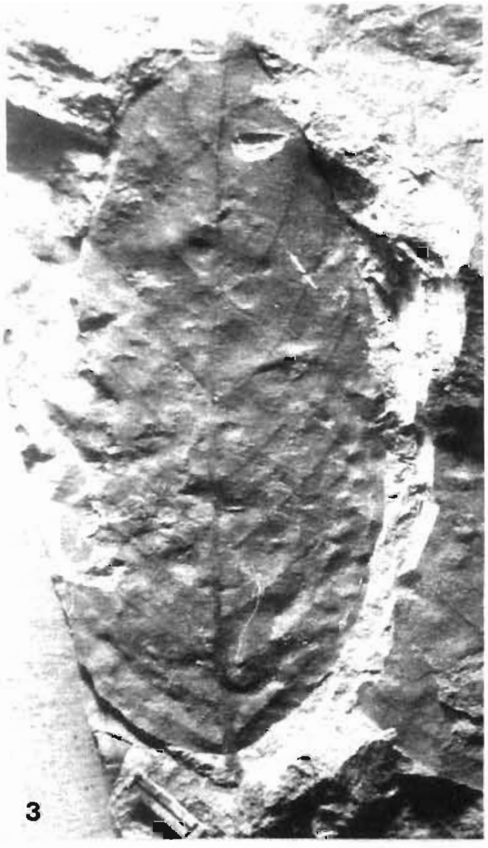
1. *Zizyphus palaeoapetala* sp. nov., a fossil leaf showing shape, size and venation pattern; Specimen no. BSIP 38027.
2. *Zizyphus palaeoapetala* sp. nov., another fossil leaf showing details of venation; Specimen no. BSIP 38028.
3. *Ventilago tistaensis* sp. nov., a fossil leaf showing shape, size and venation pattern; Specimen no. BSIP 38029.
4. *Syzygium palaeocuminii* Prasad & Awasthi 1996, a fossil leaf showing shape, size and venation pattern; Specimen no. BSIP 38030.
5. *Homonoia mioriparia* sp. nov., a fossil leaf showing shape, size and venation pattern; Specimen no. BSIP 38031.
6. *H. mioriparia* sp. nov., another fossil leaf variation in size; Specimen no. BSIP 38032.


1


4


6


2


3


5

PLATE 2

oblique; margin entire; texture chartaceous; petiole 0.4 cm preserved, normal; venation pinnate, craspedodromous to eucamptodromous; primary vein (1°) single, prominent, stout, thicker at basal half part, almost straight; secondary veins (2°) about 9 pairs visible, 0.6 to 1.5 cm apart, alternate to subopposite, angle of divergence acute, about 55°, uniformly curved up, unbranched; tertiary veins (3°) very fine, angle of origin usually RR, percurrent, branched, almost straight, oblique to right angle in relation to midvein, alternate to opposite, close; quaternary veins not visible.

Holotype—Specimen no. BSIP 38029.

Locality—Sevok Road section about 2 km from Tista River Bridge towards Oodlabari, Darjeeling District, West Bengal.

Horizon & age—Lower Siwalik, Middle Miocene.

Comparison—The most characteristic features of the present fossil leaves are narrow ovate shape, nearly oblique obtuse base, entire margin, chartaceous texture, craspedodromous to eucamptodromous venation, very fine and somewhat closely placed percurrent tertiary veins having right angle origin. These features obviously indicate their resemblance with the leaves of genus *Ventilago* Benth. of Rhamnaceae. In order to reach up to specific level the herbarium sheets of all available species of *Ventilago* were examined and observed that the present leaves closely resemble those of *V. calyculata* (CN Herbarium Sheet no. 168) in all morphological features.

As far as the authors are aware, so far there is no fossil record of the genus *Ventilago* and hence this has been described as a new species *Ventilago tistaensis*. The specific name is after Tista River flowing along the road section, from where the Holotype was collected.

The genus *Ventilago* Gaertn. consists of about five species of large climbing shrubs. *V. calyculata*, which closely resembles with the fossil leaves is a very conspicuous forest climber distributed throughout the plains of India, chiefly in the drier forests, also in Myanmar and Sri Lanka (Gamble, 1972).

Family—Myrtaceae

Genus—*Syzygium* Gaertn.

Syzygium palaeocuminii Prasad & Awasthi 1996
Pl. 2, fig. 4

Material—This species is represented by only one specimen.

Description—Leaf simple, symmetrical, wide elliptic, preserved length 7.5 cm and width 2.0 cm (one side of midrib; apex acute; base acute; margin entire; texture chartaceous; petiole not preserved; venation pinnate, eucamptodromous; primary vein (1°) prominent, straight, stout; secondary veins (2°) about 28 pairs visible, alternate to opposite, branched, angle of divergence widely acute, 60°-75°, uniformly curved up, closely placed, joining their supradjacent veins forming intramarginal vein, intersecondary veins frequent, simple, 3-4 intersecondary veins in between secondaries; tertiary veins (3°) fine with angle of origin AO, exmedially ramified, oblique in relation to midvein and close.

Specimen—No. BSIP 38030.

Locality—Sevok Road section about 2 km from Tista River Bridge towards Oodlabari, Darjeeling District, West Bengal.

Horizon & age—Lower Siwalik, Middle Miocene.

Comparison—Wide elliptic shape, acute apex and base, entire margin, eucamptodromous venation, closely placed secondary veins with wide acute angle of divergence, presence of intramarginal vein and exmedially ramified tertiary veins indubitably indicate its resemblance with the genus *Syzygium* Gaertn. of the family Myrtaceae. After detail examination of the extant species of this genus it has been found that the present fossil leaf closely resembles the leaves of *Syzygium cuminii* Roxb. However, during the examination of leaves of extant species it has been observed that the nature of venation pattern in most of the species looks somewhat similar due to which it becomes practically difficult to distinguish them from one another.

So far, six fossil species of *Syzygium* are known from different parts of world. These are *S. floribundoides* Engelhardt from the Middle Miocene of West Germany (Miller, 1934), *S. chaneyi* Huzioka & Takahashi 1970 from the Eocene of Japan, *S. kachchhense* Lakhanpal & Guleria 1981 from the Eocene of Kachchh, *S. miocenicum* Prasad & Prakash 1984 from the Siwalik sediments of Koilabas, Nepal; *S. palaeobracteatum* Awasthi & Lakhanpal 1990 from the Siwalik sediments of Bhikhnathoree, Bihar and *S. palaeocuminii* Prasad & Awasthi 1996 from the Siwalik sediments of Surai Khola, Nepal.

The present fossil leaf was critically compared with all the known species and found that it shows close resemblance with *S. palaeocuminii* Prasad & Awasthi 1996 in all morphological features and thus has been described under it.

The genus *Syzygium* (= *Eugenia*) Gaertn. includes about 650 species distributed in the tropical and subtropical region of Asia, tropical America and few of them in tropical Africa and Australia. About 110 species are found in India and Myanmar. The modern comparable species *S. cuminii* Roxb. is an evergreen tree occurring throughout India, Myanmar and Sri Lanka. It is chiefly found along river banks and in the forests of moist localities (Brandis, 1971; Gamble, 1972).

Family—Euphorbiaceae

Genus—*Homonoia* Lour.

Homonoia mioriparia sp. nov.
Pl. 2, figs 5, 6

Material—This species is represented by two specimens, one specimen with counterpart.

Description—Leaf simple, symmetrical, narrow elliptic, preserved size 8.0 x 2.1 cm; apex seemingly acute; base seemingly acute, normal; margin entire to slightly wavy; texture thick, chartaceous; petiole not visible; venation pinnate, eucamptodromous; primary vein (1°) single, prominent, straight, massive; secondary veins (2°) 6-7 pairs visible, usually alternate, 1.5 to 2.2 cm apart, angle of divergence 50° to 65°, acute, unbranched, uniformly curved up; tertiary veins (3°) fine, poorly visible, angle of origin RR, percurrent, seemingly unbranched, almost straight, predominantly alternate; close; further details not visible.

Holotype—Specimen no. BSIP 38031.

Paratype—Specimen no. BSIP 38032.

Locality—Sevok Road section about 2 km from Tista River Bridge towards Oodlabari, Darjeeling District, West Bengal.

Horizon & age—Lower Siwalik, Middle Miocene.

Comparison—The distinguishing features of the present fossil leaf are narrow elliptic shape, seemingly acute apex and base, slightly wavy margin, eucamptodromous venation, distantly placed secondary veins with acute angle of divergence having characteristic curvature which collectively indicate its resemblance with extant taxon *Homonoia riparia* Lour. of the family Euphorbiaceae (CN Herbarium Sheet no. 417075).

As far as we are aware there is only one record of the fossil leaf resembling *H. riparia* from the Siwalik sediments of Haridwar, Uttar Pradesh. This specimen was described as *Homonoia* cf. *H. riparia* Lour. by Prasad (1994, p. 90) without establishing a form species. Since this leaf as well as the present fossil leaf both possess same morphological characters and also have been compared with the same extant species, these are being named as *Homonoia mioriparia* sp. nov.

Genus *Homonoia* Lour.consists of about 3 or 4 Indo-Malayan species. *Homonoia riparia* Lour., with which the present fossil species closely resembles, is an evergreen shrub distributed in Myanmar, Sri Lanka, Malaya Peninsula, China and throughout India, except in the north-west (Brandis, 1971; Gamble, 1972).

DISCUSSION

The investigation of the present plant megafossils recovered from Ghish River near Oodlabari, Lish River near Bagrakot and Sevok Road Section near

Tista River Bridge in Darjeeling District, West Bengal reveals the presence of some more elements belonging to five dicotyledonous families and seven taxa. Of them, *Ventilago tistaensis, Zizyphus palaeoapetala, Alsodeia palaeoracemosa, Shorea bengalensis* and *Homonoia mioriparia* are new to the angiospermous fossil leaf records from the Tertiary sediments of Indian Subcontinent . The remaining two taxa, viz., *Sygygium palaeocuminii* and *Flacourtia tertiara* are already known from the Siwalik sediments of Surai Khola, western Nepal. It is interesting that the present assemblage represents trees, shrubs and climbers distributed mostly in evergreen forests either in north east India, Myanmar or Malayan region. The habit and habitat as well as physiognomic characters of the fossil floral assemblage infer that an evergreen forest was flourishing under tropical climate with excessive rainfall in and around the area.

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REFERENCES

Acharyya SK 1972. Geology of the Darjeeling Coalfield with a reference to its intrusives. *Rec. geol. Surv. India* **99**(2) : 75-101.

Acharyya SK 1975. Structure and stratigraphy of the Darjeeling frontal zone, eastern Himalaya. *Rec. geol. studies in Himalaya, geol. Surv. India Misc. publ.* **24**(1) : 71-90.

Antal JS & Awasthi N 1993. Fossil flora from the Himalayan foot-hills of Darjeeling District, West Bengal and its palaeoecological and phytogeographical significance. *Palaeobotanist* **42**(1) : 14-60.

Antal JS & Prasad M 1995. Fossil leaf of *Clinogyne* Salisb. from the Siwalik sediments of Darjeeling District, West Bengal. *Geophytology* **24**(2) : 241-243.

Antal JS & Prasad M 1996a. Some more leaf-impressions from the Himalayan foot-hills of Darjeeling District, West Bengal, India. *Palaeobotanist* **43**(2) : 1-9.

Antal JS & Prasad M 1996b. Leaf-impressions of *Polyalthia* Bl. in the Siwalik sediments of Darjeeling District, West Bengal. *Geophytology* **26**(1) : 125-127.

Antal JS & Prasad M 1996c. Dipterocarpaceous fossil leaves from Ghish River section in Himalayan foot-hills near Oodlabari, Darjeeling District, West Bengal. *Palaeobotanist* **43**(3) : 73-77.

Antal JS, Prasad M & Khare EG 1996. Fossil woods from the Siwalik sediments of Darjeeling District, West Bengal, India. *Palaeobonist* **43**(2) : 98-105.

Awasthi N & Lakhanpal RN 1990. Additions to the Neogene florule from near Bhikhnathoree, West Champaran District, Bihar. *Palaeobotanist* **37** : 278-283.

Awasthi N & Prasad M 1990. Siwalik plant fossils from Surai Khola area, western Nepal. *Palaeobotanist* **38** : 298-318.

Brandis D 1971. *Indian trees.* Bishen Singh Mahendra Pal Singh, Dehradun.

Desch HE 1957. Manual of Malayan timbers. *Malaya For. Rec.* **15** : 1-328.

Dilcher DL 1974. Approaches to the identification of angiosperm leaf remains. *Bot. Rev.* **40**(1) : 1-157.

Gamble JS 1972. *A manual of Indian timbers.* Bishen Singh Mahendra Pal Singh, Dehradun.

Hickey LJ 1973. Classification of the architecture of dicotyledonous leaves. *Am. J. Bot.* **60** : 17-33.

Huzioka K & Takahashi E 1970. The Eocene flora of the Ube Coalfield, southwest Honshu, Japan. *J. Min. Coll. Akita Univ.*, ser. A **4**(5) : 1-88.

Lakhanpal RN 1965. Occurrence of *Zizyphus* in the Lower Siwalik beds near Jawalamukhi. *Curr. Sci.* **34**(23) : 666-667.

Lakhanpal RN 1966. Fossil Rhamnaceae from the Lower Siwalik beds near Jawalamukhi (Himachal Pradesh). *Publ. Centre Adv. Study Geol. Punjab Univ.* **3** : 23-26.

Lakhanpal RN & Guleria JS 1981. Leaf-impressions from the Eocene of Kachchh, western India. *Palaeobotanist* **28-29** : 353-373.

Lakhanpal RN & Awasthi N 1984. A Late Tertiary florule from near Bhikhnathoree in West Champaran District, Bihar. *Proc. Symp. Evol. Bot. Biostratigr., Calcutta 1979 (A.K. Ghosh Comm. Vol.)* **10** : 587-596.

Merill ED 1923. Distribution of the Dipterocarpaceae. *Philipp. J. Sci.* **23** : 1-32.

Muller WR 1934. Die Pflanzen des Neozoikums. *Oberre in Fossil Katalog* **3**(10) : 1-153.

Pearson RS & Brown HP 1932. *Commercial timbers of India* **-1 & 2.** Manager of Publications, Calcutta.

Prasad M 1994a. Investigation on the Siwalik (Middle Miocene) leaf-impressions from the foot-hills of the Himalaya, India. *Tertiary Res.* **15**(2) : 53-90.

Prasad M 1994b. Plant megafossils from the Siwalik sediments of Koilabas, central Himalaya, Nepal and their impact on palaeoenvironment. *Palaeobotanist* **42**(2) : 126-156.

Prasad M & Awasthi N 1996. Contribution to the Siwalik flora from Surai Khola sequence, western Nepal and its palaeoecological and phytogeographical implications. *Palaeobotanist* **43**(3) : 1-42.

Prasad M & Prakash U 1984. Leaf-impressions from the Lower Siwalik beds of Koilabas, Nepal. *Proc. V Indian geophytol. Conf. (1983), Spl. publ.* : 246-256.

Seward AC 1935. Leaves of dicotyledons from the Nubian sandstone of Egypt. *Min. of Finance Surv. Dept., Egypt* : 1-21.

Singh T & Prakash U 1980. Leaf-impressions from the Siwalik sediments of Arunachal Pradesh, India. *Geophytology* **10**(1) : 104-107.

The plants of glossopterids : a reappraisal and review

Divya Darshan Pant

Pant DD 1997. The plants of glossopterids: a reappraisal and review. *Palaeobotanist* **46** (3) : 105-110.

New information about the structural features of the plants of *Glossopteris* and related genera is reviewed in the light of advances made on the basis of permineralized fossils of the group mainly those which have been lately discovered in Antarctica. It is pointed out that the permineralized remains have merely confirmed, although far more vividly, the presence of anatomical features which had been inferred earlier by the study of impression and compression (incrustation) fossils of the glossopterids. The author concludes that the study of impression, compression (incrustation) fossils is as important as that of permineralized remains and many a time the former furnish details which are difficult to observe in permineralized remains.

Key- words — Glossopterids, Anatomy, Permineralized fossils, Impressions, Compressions (incrustations).

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साराँश

ग्लॉसॉप्टेरिडी पौधे : एक पुनर्व्याख्या एवं समालोचना

दिव्य दर्शन पन्त

ग्लॉसॉप्टेरिडी तथा सम्बद्ध प्रजातियों के पौधों के संरचनात्मक लक्षणों के बारे में अभी हाल में अंटार्कटिका से एकत्रित इसी समूह के पारखनिजीकृत पादपाश्मों के अध्ययन से उपलब्ध नई जानकारी की समीक्षा की गई है। यह प्रदर्शित किया गया है कि पारखनिजीकृत अवशेषों से केवल शारीरीय लक्षणों की उपस्थिति की ही पुष्टी होती है जैसा कि पहले ग्लॉसॉप्टेरिडी पौधों की छापों एवं संपीडनाश्मों के आधार पर अनुमान लगाया गया था। समीक्षा के आधार पर यह निष्कर्ष निकाला गया है कि छापों एवं संपीडनाश्मों का अध्ययन भी उतना ही महत्वपूर्ण है जितना कि पारखनिजीकृत अवशेषों का बहुधा छापों एवं संपीडनाश्मों से ऐसी विस्तृत जानकारी मिल जाती है जो कि पारखनिजीकृत अवशेषों से बहुत ही मुश्किल से मिल पाती है।

NEARLY twenty years ago I published an account of "The plant of *Glossopteris*" (Pant, 1977) wherein I tried to present a reconstruction of the plant based on studies of impressions and compressions of the different fragments of its vegetative and reproductive organs. A recent article by Pigg and Trevitt (1994) has now triggered the necessary stimulus in me to review my earlier account of the plant which is duly cited by the above authors in their references but, unfortunately, without mentioning that my associates and I had arrived at practically the same conclusions much earlier about the structural features besides additional details of the various organs of the *Glossopteris* plant on the basis of our studies of its different organs in the compressed state. Unfortunately, two papers by Pant and Nautiyal (1965, 1984b) on the compressed seed bearing, fructifications whose permineralized remains are mentioned as "megasporophylls" by Pigg and Trevitt (1994), seem to have been missed in being cited by them. However, their references to Pant (1982, 1987) imply that these authors may have been aware of the work.

IMPRESSIONS AND COMPRESSIONS VERSUS PERMINERALISATIONS

At the outset it is important to say that careful studies of compressed fossils preserved as incrustations, based on observations of parts and counterparts, are often as informative as permineralizations (Whittington & Morris, 1985; Gould, 1991). Organs which became naturally macerated by the plant substance becoming preserved in various states of degradation, during fossilization, are often rendered more or less translucent and they show various details of internal structure under the microscope, particularly when these are pulled out in cellulose acetate and mounted in Canada balsam. When plant parts of sizeable thickness are compressed in rock matrix, e.g., bunches of sporangia which lie in slightly differing planes, above or below the plane of fracture of a hand specimen, they can be carefully excavated out of the matrix or they can be extracted out by carefully dissolving the rock piece in HF, if silicified, or HCl if calcified. Observations of compressions in oil can reveal the presence of hairs or other similarly protruding structures (Pant, 1958). Harris (1938) was able to show that the highly controversial fossils of *Naiadita*, belonged to a bryophyte by studying them in oil.

In fact, sectional views of permineralized remains are often inadequate for a clear understanding of the form and, therefore, some crustaceans (Scourfield, 1926) and cyanobacteria (Croft & George, 1959) had to be observed directly in broken chips of rock by putting them in oil and observing them under an oil immersion objective but without sectioning as is usually the practice for observing permineralized remains. Compressed fossils have often yielded important information about the hidden face of incrustations of compressions by preparing transfers with Walton's transfer technique (Walton, 1923). This was actually done by Pant and Nautiyal (1984) in the case of *Ottokaria*, the female fertiliger of *Glossopteris* where they could observe attached seeds on the usually uneven and therefore firmly rock-attached concave faces of the fructifications.

It is important to mention that even impressions of fossils, when they are well preserved in fine-grained rock matrix, can show features of epidermal cells, stomata, hairs and other superficial structures in the parts and counterparts under oblique lighting or in oil.

Compression or telescoping of an organ in different directions can yield information about its shape in different directions, e.g., the platyspermic and radiospermic character of seeds (Pant, 1958; Pant & Nautiyal, 1960) the form of sporangia and annulus (Pant & Khare, 1960) and about internal structures like presence of fibres and vascular strands and nucellar surface and tissues, pollen chambers, megaspore membranes, gametophytic tissues and archegonia and starch grains inside cells of glossopterid seeds have been described in detail by Pant (1958), Pant and Nautiyal (1960), Pant and Srivastava (1964) and Pant *et al.* (1985).

No doubt permineralized fossils can yield indubitable information about the details of internal structure of plant fossils but, as mentioned above, the details of surface and internal features inferred from compressions are in no way less significant. It is actually important to mention that compressions of fossils of several extinct groups of plants which have not been found preserved in permineralized condition have been vividly deciphered from such remains without having a single permineralized fossil. This is also true of many early vascular plants from the Late Silurian and Devonian, numerous Carboniferous, Permian, Triassic, Jurassic, Cretaceous and Cainozoic fossils like those of many Palaeozoic ferns, pteridosperms, the Caytoniales, Corystospermales, Peltaspermales, Pinophytes and Ginkgophytes. Last but even more important are the Cretaceous and Cainozoic flowers (Friis, 1983, 1985, 1990; Friis *et al.*, 1987) which are not usually found permineralized.

Many of the above mentioned plants are known only in the form of impressions and compressions (incrustations) but their structural details are almost as well known as those of permineralized fossils. As is true for almost all fossils, there are many mute points about their growth habits and reconstructions like what is true about the glossopterids, e.g., the growth habit of one of the best known pteridosperms, *Lyginopteris oldhamia- Sphenopteris hoeninghausii-Calymmatotheca-Lagenostoma,* is largely a matter of conjecture. Indeed that is also true about some of the best known Mesozoic pteridosperms like the Caytoniales or Corystospermales. The stems of these two groups are almost unknown although I would like to think that their foliage and fructifications were borne on sizeable trees or climbing shrubs. At least their disaccate pollen grains would suggest that

Caytonanthus and *Pteruchus* microsporangia may have been held high for the wide scatter of such pollen grains through air currents. Pant (1949, 1987, 1992) has suggested the possibilities of pollen rains in forests of Glossopteris flora.

RELATIVE ADVANTAGES OF COMPRESSION FOSSILS OVER PERMINERALIZATIONS

In fact, compressions can many a time vividly indicate and confirm the unclear details of permineralized fossils which can be studied only in almost repetitive sections and thereafter reconstructed. Compressions reveal the entire external form of fossils which permineralized parts may fail to show. A classic example of such studies is furnished by the observations made by Surange (1952) and Chaloner (1958) on *Bensonites fusiformis*, the magasporangium of *Stauropteris burntislandica*. Surange observed *Bensonites* only in sections of permineralized material and could not ascertain the number and the form of the megaspores inside the megasporangia, whereas Chaloner could find the entire megasporangia in macerations of rock matrix and he could also extract them from their permineralized material. He could thus show that the megasporangium of *Bensonites* contained a tetrahedral tetrad of two large megaspores juxtaposed with two small ones and all of them were enclosed in a membrane which he called *Didymosporites*. It is, therefore, important, nay many a time essential for students of permineralized fossils not to overlook the earlier achievements of those who have studied impressions and compressions and found structural details which are confirmed by their studies of permineralized fossils.

Unfortunately, the article by Pigg and Trevitt (1994) while highlighting the details of internal structure revealed by permineralized fossils gives the impression that many of the structural features of glossopterid gymnosperms were discovered for the first time by studies of permineralized fossils. This is far from being true since earlier observations on impression and compression fossils had already revealed many structural details which have no doubt been confirmed vividly by studies of permineralized fossils. I would particularly like to mention that the presence of epidermal hairs, sunken stomata, stomatal pits, subsidiary cells with overarching papillae, polar and lateral lignin lamellae of guard cells, presence of a hypodermis, palisade and spongy mesophyll cells, fibres in vein meshes and along veins, multiple veined midribs, upwardly curved or almost joined veins at the margins, vein and midrib bundle xylem showing scalariform and pitted elements had been observed by the author (Pant, 1958) and his group of workers (Pant & Gupta, 1971; Pant & Singh, 1971, and others).

It must also be mentioned that the difference between leaves of *Glossopteris* and other glossopterids like *Belemnopteris* (Feistmantel, 1976, 1981; Lacey *et al.*, 1974, 1975; Pant & Chowdhury, 1977). *Sagittop- hyllum* (Pant *et al.*, 1984; Pant & Chauhan, 1996) and others would have been difficult to decipher if only permineralized fossils had been available to us.

Our studies of compressions have in fact helped us also in allaying our own doubts about certain features of glossopterid fossils. When Pant (1958) found seeds of *Spermatites crystallinus* showing crystal marks over the outer cuticle, a lurking doubt remained about the crystal marks coming from the rock matrix or belonging to the seed surface. However, when Pant and Nautiyal (1960) found impressions of seeds on the leaf cuticles of *Glossopteris* and these showed cell outlines and crystals only in the region of the impressions of seeds, it became at once clear that the crystals belonged to the seed surface. When leaf cuticle of *Glossopteris* also showed impressions of sporangia of *Arberiella* and also disaccate spores prevailingly shed by sporangia of *Arberiella* it became clear that these were shed over glossopterid leaves due to their being held above the leaves in the life of plants. Thus even though permineralized fossils have their strong points and advantages, over compression and impression fossils, there are also other aspects in which compression fossils are superior to permineralized ones.

ACHIEVEMENTS OF STUDIES ON PERMINERALIZED GLOSSOPTERID FOSSILS

In view of the above mentioned facts I am compelled to point out that an otherwise excellent summary of the achievements made by studies of permineralized fossils has unfortunately erred in making it appear that the structural features of the glossopterid gymnosperms were discovered for the first time by studies of permineralized fossils when many of them had been known already on the basis of earlier studies of compressions and impressions. *The credit of the permineralized fossils lies mainly in vividly confirming structural features which had been inferred from impression and compression fossils and we must all admit that is the contribution of paramount importance made by studies of permineralized fossils.*

BLECHNOXYLON IS A *GLOSSOPTERIS*

There are also some other points about the account of Pigg and Trevitt (1994) which need correction. These authors have, for example, mentioned that *Blechnoxylon talbragarense* (Etheridge, 1899) "was recognized as a seed plant by Seward (1910) particularly on the basis of its typically gymnospermous stem as cut in transverse section" but they did not mention that Seward (1910, p. 510) had instead unequivocally stated "Although the leaves of *Blechnoxylon* are much smaller than those of *Glossopteris*, I am now disposed to regard the genus as closely allied or even generically referable to *Glossopteris*. The crowded disposition of leaves is like that in *Glossopteris* ..... The absence of reticulum of anastomosing veins can no longer be considered a fatal objection to the suggestion that the Australian type may be a species of *Glossopteris*". Seward had nowhere suggested that *Blechnoxylon* was a seed plant and the above mentioned statements of Seward were supported by Pant and Singh (1974). Subsequently, Pant and Nautiyal (1984a) re-examined the type material and they supported Seward's ideas on the basis of their having seen a few cross connections between forks of adjacent veins particularly in Museum Slide no. AM 152 (Original No. 6309) and other resemblances between leaves of *Glossopteris talbragarense* and leaves of *Glossopteris*, like those of *G. hispida* (Pant, 1958) in the presence of multicellular hairs. It is necessary to point out that small leaves too are no bar to the reference of *G. talbragarense* to *Glossopteris* since even smaller leaves of that genus have been described by Zeiller (1896) and Pant and Nautiyal (1987).

INTERGRADATION OF PERMINERALIZED AND OTHER KINDS OF FOSSILS

In connection with this discussion on impression, compression (incrustation) and permineralized fossils it is important to point out that these various kinds of fossils intergrade, e.g., a permineralized fossil can be more or less compressed and partially decayed out during preservation. Likewise a compression (incrustation) fossil may also be partially permineralized and infiltrated with mineral matter. This was actually observed in the wood of *Buriadia* by Pant and Nautiyal (1967).

VERTEBRARIA COULD BELONG TO A ROOT OR STEM

It must also be pointed out that attached leaves of *Glossopteris* and other glossopterids have been reported by various workers from time to time. Zeiller (1896), Oldham (1897), Dolianiti (1954) and Pant (1977) found them attached to axes which presented features of *Vertebraria* but others found them attached to axes which lacked typical rectangular areas of *Vertebraria* (Walton & Wilson, 1932). Vascular tissues of *Vertebraria* were first described by Walton and Wilson, (1932) and later by Pant (1956), Pant and Singh (1968) and others. Authors like Schopf (1965), described permineralized axes of *Vertebraria* and thought that their exarch protoxylem indicated that these were roots. But it was pointed out by Pant and Singh (1974) and Pant (1977) that primitive stems were quite like roots in having exarch protoxylem and *Vertebraria* could even be a stem. Indeed Pant (1977) thought that *Vertebraria* axes could represent roots as well as stems. Pant (1958b) also described young roots of *Vertebraria* where he could even see endogenous root primordia slightly behind root apices as they occur in roots. Some of these thin roots were attached to *Vertebraria* axes. *Vertebraria* could indeed be a rhizomorph an organ like stigmarian axes which can neither be termed a root nor stem. These organs clearly suggest that Nature often defies strict definitions.

CONCLUSION

The present reappraisal and review of the work on glossopterids by various workers reminds me of J.G. Saxe's poem.

"It was six men of Indostan"
(or any other country)
"To learning much inclined
Who went to see the elephant
(Though all of them were blind).
....
....
And so these men of Indostan
Disputed loud and long
Each in his own opinion
Exceeding stiff and strong,
Though each was partly in the right,
All were in the wrong"

Like the six men different palaeobotanists either observe impressions, compressions (incrustations) or permineralizations of the fragmented plant bodies. They all obtain only partial views of the original plants, and therefore, it is necessary that they do not remain oblivious of the observations made on other kinds of fossils to correlate and consider their own observations with those made by others to obtain correct ideas about the fossil plants under their investigations.

REFERENCES

Chaloner WG 1958. Isolated megaspore tetrads of *Stauropteris burntislandica*. *Ann. Bot.* (N.S.) **22**: 197-204.

Croft WN & George EA 1959. Blue green algae from the Middle Devonian of Rhynie, Aberdeenshire. *Bull. Brit. Mus. (Nat. Hist). Geol.* **3** (10): 339-353.

Dolianiti E 1954. A flora do Gondwano inferior am Santa Catarina, 4. O Genero *Vertebraria*. *Notas prelim. Estud. Div. Geol. Miner. Bras.* **81**: 1-5.

Etheridge R 1899. On a fern (*Blechnoxylon talbragarense*) with secondary wood forming a new genus, from the Coal-Measures of the Talbragar District, New South Wales. *Rec. Austr. Mus.* **3**: 135-146.

Feistmantel O 1876. On some fossil plants from the Damuda Series in the Raniganj Coalfield collected by Mr. J. Wood-Mason. *J. Asiat. Soc. Bengal* (**2**): 329-382.

Feistmantel O 1881. The fossil flora of the Gondwana System. The flora of Damuda Panchet Divisions. *Mem. geol. Surv. India Palaeont. indica*. Ser. **12** (3): 78-149.

Friis EM 1983. Upper Cretaceous (Senoniam) floral structures of juglandalean affinity containing *Normapolles* pollen. *Rev. Palaeobot. Palynol.* **39**: 161-188.

Friis EM 1985. Angiosperm fruits and seeds from the Middle Miocene of Jutland (Denmark). *Kongl. Danske Vidensk. selskab, Selskab Biol. Skrifter* **36**: 1-35.

Friis EM, Chaloner WG & Crane PR (Editors) 1987. *The origin of angiosperms and their biological consequences*. Cambridge Univ. Press.

Gould SJ 1991. *Wonderful life*. Penguin Books, London.

Harris TM 1938. *The British Rhaetic Flora*. British Museum (Nat. Hist), London.

Lacey WS, Van Dijk DE & Gordon-Gray KD 1974. New Permian Glossopteris flora from Natal. *S. Afr. J. Sci.* **70** (5): 154-156.

Lacey WS, Van Dijk DE & Gordon-Gray KD 1975. Fossil plants from the Upper Permian of Mooi River District of Natal, South Africa. *Ann. Natal Mus.* **22** (2): 349-420.

Oldham RD 1887. On a plant of *Glossopteris* with part of the rhizome attached, and on the structure of *Vertebraria*. *Rec. geol. Surv. India* **30** (1): 45.

Pant DD 1949. On the occurrence of *Pityosporites* Seward in a Lower Gondwana tillite from Australia and its possible relationship with *Glossopteris*. *Proc. Indian Sci. Congr., Allahabad* : 10-11.

Pant DD 1956. On two compressed Paleozoic axes: *Stigmaria ficoides* and *Vertebraria indica*. *Ann. Bot. n.s.* **20**: 419-429.

Pant DD 1958a. On the structure of some leaves and fructifications of the Glossopteris flora of Tanganyika. *Bull. Brit. Mus. (Nat. Hist.) Geol.* **3**: 127- 175.

Pant DD 1958b. Structure of some roots and spores from the Lower Gondwana (Permo-Carboniferous) of East Africa. *Vijnana Parishad Anusandhan Patrika* **1**(4): 231-244.

Pant DD 1977. The plant of *Glossopteris*. *J. Indian bot. Soc.* **56**: 1-23.

Pant DD 1982. The Lower Gondwana gymnosperms and their relationships. *Rev. Palaeobot. Palynol.* **37**: 55-70.

Pant DD 1987. Reproductive biology of Glossopterids and their affinities. *Bull. Soc. fr. Actual Bot.* **134** (2): 77-93.

Pant DD 1992. Forests of India through the ages. *J. Sen Memorial Lecture* **1**: 11-31. (Seventh lecture 1987). Calcutta University, Calcutta.

Pant DD & Chauhan DK 1996. On *Sagittophyllum* and *Laceyphyllum*, two genera of glossopterid leaves from Lower Gondwanas. *Dabar Festscrift*. (in Press).

Pant DD & Chowdhury A 1977. On the genus *Belemnopteris* Feistmantel. *Palaeontographica* **B164**: 153-166.

Pant DD & Gupta KL 1968. Cuticular structure of some Indian Gondwana species of *Glossopteris* Bgt. Pt. I. *Palaeontographica* **B124**: 45-81.

Pant DD & Gupta KL 1971. Cuticular structure of some Lower Gondwana species of *Glossopteris* Bgt. Part 2. *Palaeontographica* **B132**: 130-152.

Pant DD & Khare PK 1974. *Damudopteris* gen. nov.— a new genus of ferns from the Lower Gondwanas of Raniganj Coalfield, India. *Proc. R. Soc. London* **B186**: 121-135.

Pant DD & Nautiyal DD 1960. Some seeds and sporangia of Glossopteris flora from Raniganj Coalfield, India. *Palaeontographica* **B107**-41-61.

Pant DD & Nautiyal DD 1965. Seed bearing *Ottokaria*-like fructifications from India. *Nature* **207**: 623-624.

Pant DD & Nautiyal DD 1967. On the structure of *Buriadia heterophylla* (Feistmantel) Seward & Sahni and its fructification. *Phil. Trans. R. Soc. London* **B252** (774): 27-48.

Pant DD & Nautiyal DD 1984a. Notes on *Glossopteris talbragarense* (Etheridge Jr.) comb. nov. and some other Australian glossopterids. *Phyta* **4, 5**: 33-37 (1981-1982).

Pant DD & Nautiyal DD 1984b. On the morphology and structure of *Ottokaria zeilleri* sp. nov., a female fructification of *Glossopteris*. *Palaeontographica* **B195**: 127-152.

Pant DD & Nautiyal DD 1987. *Diphyllopteris verticillata* Srivastava, the probable seedling of *Glossopteris* from the Palaeozoic of India. *Rev. Palaeobot. Palynol.* **51**: 31-36.

Pant DD, Nautiyal DD & Chauhan DK 1984. *Sagittophyllum* gen. nov., a new glossopterid leaf. Developmental and comparative aspects of plant structure and function: 195-198.

Pant DD, Nautiyal DD & Tiwari SP 1985. On some Indian Lower Gondwana compressions of seeds. *Palaeontographica* **B196**: 31-78.

Pant DD & Singh KB 1971. Cuticular structure of some Indian Lower Gondwana species of *Glossopteris* Bgt. Part 3. *Palaeontographica* **B135**: 1-40.

Pant DD & Singh RS 1968. The structure of *Vertebraria indica* Royle. *Palaeontology* **11**: 643-653.

Pant DD & Singh RS 1974. On the stem and attachment of *Gangamopteris* and *Glossopteris* leaves. Part II. Structural features. *Palaeontographica* **B147**:42-73.

Pant DD & Srivastava GK 1968. On *Walkomiellospermum indicum* gen. et sp. nov. seed like bodies and alete megaspores from Talchir Coalfield, India. *Proc. Natn. Inst. Sci. India* **B29**(6): 575-584.

Pigg KD & Trevitt ML 1994. Evolution of glossopterid gymnosperms from Permian Gondwana. *J. Plant Res.* **107**: 461-477.

Schopf JM 1965. Anatomy of the axis of *Vertebraria*. *In*: Hadley JB (Editor)— *Geology and Palaeontology of the Antarctic Res. Ser. 6 Amer. Geophys. Union of Nat. Acad. Sci., Nat. Res. Council Washington D.C.*: 217-228.

Schopf JM 1982. Forms and facies of *Vertebraria* in relation to Gondwana coal. *Geology of the Central Transantarctic Mountains. Ant. Res.* ser.**36**: 37-62.

Scourfield DJ 1926. A new type of crustacean from the Old Red Sandstone (Rhynie Chert Bed, Aberdeenshire)- *Lepidocaris rhyniensis* gen. et sp. nov. *Phil. Trans. R. Soc. London* **B214**:133-187.

Seward AC 1910. *Fossil Plants,* **2**. Cambridge Univ. Press.

Surange KR 1952. The morphology of *Stauropteris burntislandica* P. Bertrand and its megasporangium *Bensonites fusiformis* R. Scott. *Phil. Trans. R. Soc. London* **B237**: 73-91.

Walton J 1923. On a new method of investigation of fossil plant impressions or incrustations. *Ann. Bot.* **37**: 379-390.

Walton J & Wilson JAR 1932. On the structure of *Vertebraria*. *Proc. R. Soc. Edinburgh* **52**(2): 200-207.

Whittington HB & Morris SC 1985. Extraordinary fossil biotas: their ecological and evolutionary significance. *Phil. Trans. R. Soc. London* **B311**: 1-192.

Zeiller R 1896. E'tude sur quelques fossiles en particulier *Vertebraria* et *Glossopteris* des environs de Johannesburg (Transvaal). *Bull. Soc. Geol. France, Paris* ser. 3, **24**: 349-378.

Vegetation and climate in Garhwal Himalaya during EarlyHolocene : Deoria Tal

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Sharma Chhaya & Gupta Asha 1997 Vegetation and climate in Garhwal Himalaya during EarlyHolocene : Deoria Tal. *Palaeobotanist* **46** (3) : 111-116.

Pollen analysis of 1.5 m deep profile from the western flank of Deoria Tal (Profile-II), situated in temperate belt of Garhwal Himalaya has unravelled the vegetation and climate of Early Holocene. The vegetation, traced back to about 6000 years and ^{14}C dated 2710 ± 150 years at 55-65 cm depth, comprised chiefly the Oak dominated forests associated with other broad-leaved taxa such as *Betula, Alnus, Rhododendron, Carpinus, Ulmus*, etc. Such an arboreal forest composition reflects warm-temperate humid climate prevalent in the region. A change to cooler climatic conditions is registered between 3500-3600 years B.P., as evidenced by the decline in Oak — the chief component, as well as in other associated broad-leaved elements with a corresponding rise in grasses and sedges. Anthropogenic activities are also recorded during this period, inferred by the first appearance of Cerealia- type pollen and encountered culture pollen. Subsequently, around 1,700 years B.P., restoration process of Oak forests commenced, thus indicating the amelioration in climatic conditions.

Key-words — Palynology, Palaeovegetation, Palaeoclimate, Garhwal Himalaya, Early-Holocene, India.

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साराँश

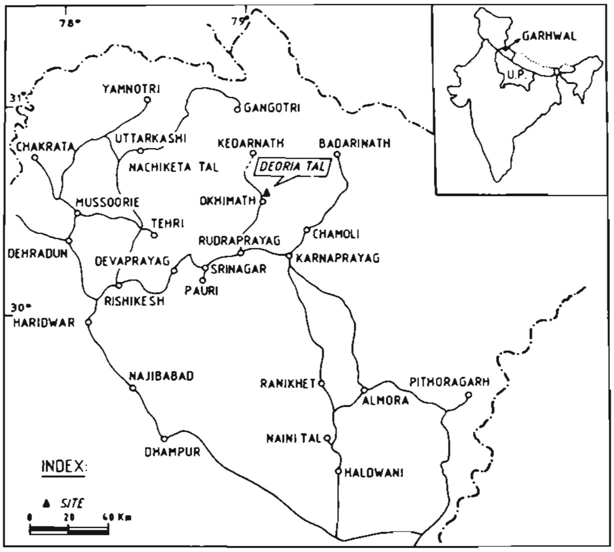
देवरिया ताल : प्रारम्भिक होलोसीन काल में गढ़वाल हिमालय में वनस्पति एवं जलवायु

छाया शर्मा एवं आशा गुप्ता

गढ़वाल हिमालय में शीतोष्ण क्षेत्र में स्थित देवरिया ताल (परिच्छेदिका- 2) के पश्चिमी तट से 1.5 मीटर गहरी परिच्छेदिका के परागकण विश्लेषण से प्रारम्भिक होलोसीन काल में विद्यमान वनस्पति और जलवायु के बारे में महत्वपूर्ण जानकारी मिली है। उपलब्ध वनस्पति, जो लगभग 6000 वर्ष पुरानी तथा कार्बन ^{14} द्वारा 2710±150 वर्ष की कालनिर्धारित की गई है, में *बिटुला, एल्नस, रोडोडेन्ड्रॉन, कार्पाइनस, अल्मस* आदि चौड़ी पत्तीयों वाले वर्गकों से सहयुक्त तथा मुख्यतया ओक से प्रभावी वर्गक विद्यमान हैं। इस प्रकार वृक्षीय वनस्पति की उपस्थिति से इस क्षेत्र में उष्णशीतोष्ण और नम जलवायु का होना प्रस्तावित होता है। लगभग 3500–3600 वर्ष पूर्व ओक की संख्या में कमी तथा घासों और सेजों की संख्या में वृद्धि से कुछ ठंडी जलवायु परिवर्तन के संकेत मिलते हैं। इसी अवधि में मानव गतिविधियों के भी संकेत मिले हैं। इसके पश्चात् लगभग 1,700 वर्ष पूर्व पुनः ओक से प्रभावी वनों में वृद्धि हो गई, जिससे जलवायवी परिस्थितियों में पुनः सुधार प्रदर्शित होता है।

GARHWAL Himalaya, the region lying between Himachal Pradesh and Kumaon Himalaya, received little attention to decipher the Quaternary vegetation and climate. However, Sharma (1985b) and Gupta and Sharma (1993) investigated the surface samples from the region to assess the pollen/vegetation relationship. Sharma and Gupta (1995) also carried out the pollen analysis of lacustrine sediments from Nachiketa Tal, situated in Uttarkashi District of Garhwal region and unravelled the palaeovegetation and corresponding climate since 1500 years B.P. Similar palynostratigraphical studies extended to cover Chamoli District in Garhwal region deal with recently investigated two profiles from Deoria Tal, i.e., Profile-I, dug out from a 3 m deep trench on the eastern flank of the lake (Sharma *et al.*, in press) and the present Profile-II to a depth of only 1.5 m from the western flank.

Deoria Tal is situated at an altitude of 2,727 m on Chopta-Ukhimath road, about 4 km from Sari Village between 75° 5' Long. and 30° 5' Lat. in Chamoli District (Text-figure 1). The lake is almost circular in outline having a circumference of about 150 m and is held sacred by local people.



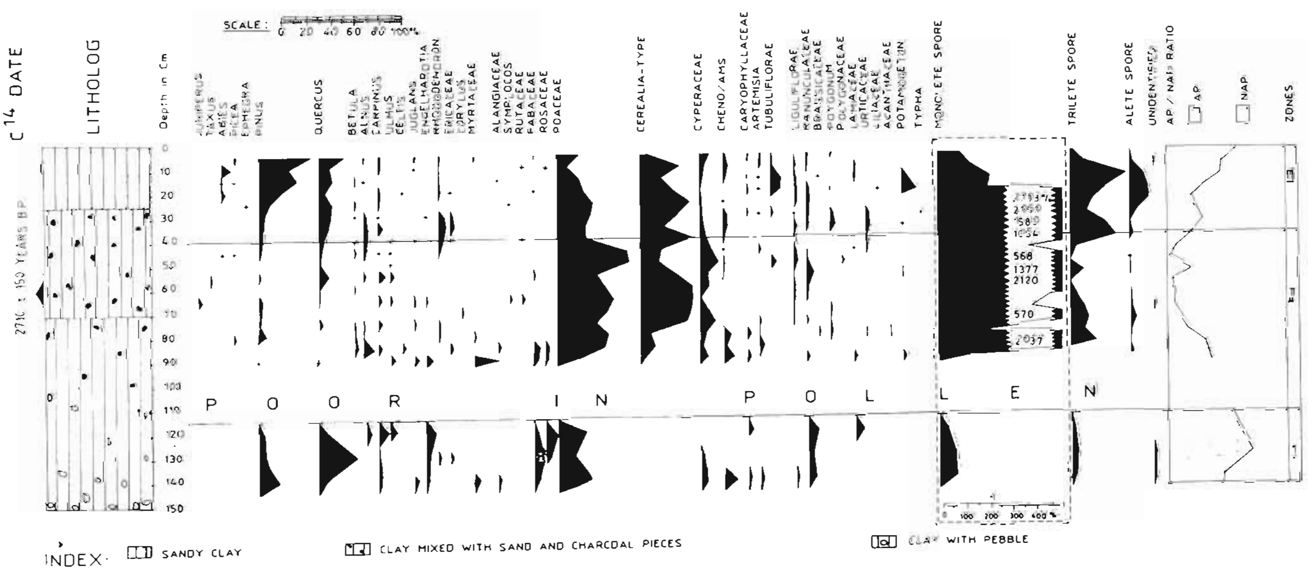
Text-figure 1—Sketch map showing location of Deoria Tal, Garhwal Himalaya.

VEGETATION

Deoria Tal lies in the temperate vegetation belt having broad-leaved mixed Oak forests all around. These forests predominantly consist of *Quercus semecarpifolia* associated with *Rhododendron arboreum, Alnus nepalensis, Ulmus wallichiana, Aesculus indica, Acer caesium, Engelhardtia vellutianum, Myrica esculenta, Pyrus malus,* etc. Commonly seen shrubby elements are—*Rubus ellipticus, Rosa* spp., *Berberis asiatica, Viburnum cotinifolium, Woodfordia fruticosa, Carissa spinarum,* etc. The herbaceous ground cover is quite gregarious showing prominence of grasses. Other noteworthy herbaceous components belong to Chenopodiaceae, Amaranthaceae, Polygonaceae, Asteraceae, Brassicaceae, Caryophyllaceae, Ranunculaceae, etc. contributing to the local thick ground vegetation cover.

MATERIAL AND METHODS

The present 1.5 m profile was dug out from the western flank of Deoria Lake. Since the lake is without any muddy or marshy margin, Hiller Peat Auger could not be operated for the required profile. Sampling was done at 5 cm interval from 0-100 cm depth and then from 100-150 cm at 10 cm interval of the lithocolumn, beyond which the column had a thick deposit of pebbles. Pollen and spores were retrieved following the usual procedure (Erdtman, 1943), using KOH, HF and acetolysis. Frequency percentages of recovered taxa have been calculated in terms of total terrestrial pollen.



Text-figure 2—Pollen diagram from Deoria Tal, Garhwal Himalaya (percentages calculated in terms of total terrestrial pollen).

LITHOSTRATIGRAPHY

The collected profile does not exhibit well demarcated stratifications and composed of sandy clay, clay mixed with sand, charcoal pieces and embedded pebbles.

The lithological details are as below :

0-25 cm - sandy clay
25-70 cm - clay mixed with sand and charcoal pieces
70-100 cm - clay with charcoal pieces
100-150 cm - clay with pebbles

RADIOCARBON DATE

The profile is radiocarbon dated 2710 ± 150 years B.P. at 55-65 cm depth. The samples from 100-120 cm depth failed to yield sufficient carbon contents required for another dating of the sample.

POLLEN ANALYSIS

Based on the pollen frequency fluctuations observed in case of significant elements, the pollen diagram (Text-figure 2) has been divided into three palynoassemblage zones and the vegetational succession is discussed from bottom of the lithocolumn upwards.

Zone-I (150-115 cm) : *Quercus-Pinus-Carpinus-Engelhardtia*-Fabaceae-Rosaceae, Poaceae-Ranunculaceae Assemblage Zone—The vegetational sequence begins with mixed Oak forest demonstrating the dominance of *Quercus* (9-34%), followed by *Pinus* (5-18%), *Carpinus* (3-9%) and *Engelhardtia* (2- 9%). Other arboreal taxa such as *Alnus* (5%), *Ulmus* (4%), *Juglans* (3%), Myrtaceae (6%), Alangiaceae (3%), *Rhododendron* (2%), *Betula* (1%), etc., are encountered in comparatively very low values. Shrubby elements belonging to Fabaceae (5-25%), are well represented throughout this zone followed by Rosaceae (4-9.5%).

Among nonarboreal elements, Poaceae (14-27%) dominate over the rest, Ranunculaceae (4-9%) is next in continued dominance though Cheno/Ams reach a value of 12 per cent but disappear around the middle of this zone. Other components of vegetation are Cyperaceae (2-6%), Caryophyllaceae (3-4.5%), Lamiaceae (8.5%), *Artemisia* (3%) and Liguliflorae (3%). Fern spores (monolete 66% and trilete 6%) encounter consistently throughout the zone. The overall AP/NAP ratio denotes the existence of mixed broad-leaved Oak forests in the region.

Zone-II (115-40 cm) : Poaceae-Cyperaceae-Fern Assemblage Zone—This middle zone towards the base between 115-90 cm depth is palynologically barren but the subsequent reconstructed vegetation above 90 cm is marked by the abrupt change in the vegetation compared to the scenario witnessed in preceding zone. Hence, the vegetation sequence gets discontinued at the beginning of this zone. *Quercus* exhibits a steep decline in its values, followed by *Pinus*. These two components are reduced to only 0.5-4 per cent and 0.5-6.5 per cent respectively. *Carpinus* and *Engelhardtia* also decline to 5-6.5 per cent each. *Alnus, Ulmus, Juglans, Betula*, Ericaceae and Alangiaceae, however, maintain more or less the same values as witnessed in previous zone. *Celtis, Corylus, Symplocos, Abies, Picea, Taxus, Ephedra* and *Juniperus* though with low frequencies make their first appearance in this zone.

Shrubby elements also exhibit a declining tendency as Fabaceae and Rosaceae are represented by 4-5 per cent and 2-2.5 per cent respectively towards the base. They further reduce to 1 per cent, and ultimately not represented at the top. Rutaceae makes its first appearance towards the top of the zone.

Nonarboreals (79-97%) flourished remarkably well during this zone showing distinct dominance of Poaceae (32-60.5%), followed by Cerealia type (4-44%). Cyperaceae has fluctuating position in this zone, though acquiring position next to Poaceae having 2.5-16 per cent values, dwindling down around the middle and soon regaining a high frequency later on. Relatively, *Artemisia* also appreciates with values increasing up to 5 per cent. Tubuliflorae (5%), Brassicaceae (2%), Polygonaceae (.5- 2%), Urticaceae (1-2%) and Acanthaceae (2%) are sporadic but new additions to the ground floristic composition. Cheno/Ams and Caryophyllaceae maintain more or less the same values as witnessed in earlier zone, whereas both Ranunculaceae and Lamiaceae are reduced to 1-7 per cent and 0.5-2 per cent respectively. Aquatic vegetation is registered by the poor representation of *Potamogeton* (1-4%).

Monolete fern spores abruptly get enhanced values compared to previous zone and trilete spores reach up to 23 per cent. Alete spores also appear in this zone with frequency up to 6 per cent. The overall AP/NAP ratio reflects open type forested conditions as compared to Zone-I

Zone-III (40-0 cm) : *Quercus-Pinus-Rhododendron* Poaceae Assemblage Zone—In this uppermost zone, arboreals (21- 58%) have an overall good representation reaching almost same values as already witnessed in Zone-I. *Quercus* gradually improves, demonstrating 22 per cent values at the top whereas *Pinus* surprisingly attains all time high values of 43 per cent from middle onwards in the zone. Another conifer *Abies* (2-7%) also registers a marked increase in the frequency at the upper part of the zone. *Rhododendron* alongwith other members of Ericaceae also get enhanced reaching 6 per cent and 4 per cent values respectively, whereas *Betula, Alnus, Carpinus, Celtis, Juglans, Picea, Symplocos* and Alangiaceae, etc., maintain more or less same values as seen in preceding zone but for *Engelhardtia* which declines. *Aesculus, Myrica* and *Salix* pollen are meagre. Also the values of shrubby elements, viz., Fabaceae, Rosaceae and Rutaceae are further reduced to 10.5-1 per cent, compared to their representation witnessed in the above zone.

Among the nonarboreals, Cerealia-type pollen acquire the most dominant position, reaching up to 45 per cent values and bringing Poaceae (9-29%) down to a subordinate position, particularly in the upper part. Cyperaceae (1.5-8%) also registers a distinct reduction in contrast to Zone-II. Similarly, Brassicaceae (10.5%), Cheno/Ams (0.5-4%), Caryophyllaceae (0.5-1.5%), *Artemisia* (0.5-1.5%) and Ranunculaceae (1-3%) too decline in their relative frequencies. Tubuliflorae (1-9%), Liguliflorae (1-4%), *Polygonum* (0.5-4%) and Urticaceae (1-4%) are better represented. Lamiaceae maintain more or less the same values as witnessed in Zone-II and Liliaceae pollen encountered for the first time in this zone. Aquatic vegetation is better represented with relative improvement in the frequency of *Potamogeton* (4-17%) in addition to the appearance of *Typha*.

Monolete spores maintain their extremely high values at the commencement of this zone but from the middle of the zone upwards gradually dwindles down (290-88%). Trilete and alete spores are encountered in high values (3-47% and 1-18%) than seen earlier. AP/NAP ratio reflects to the re-establishment of Oak forests in the region.

VEGETATION AND CLIMATE

The investigated lacustrine sediments from western Himalaya cover Himachal Pradesh (Sharma, 1985a; Sharma & Chauhan, 1988a; Sharma & Singh, 1974a, b; Bhattacharyya, 1988) and Kumaon Himalaya (Vishnu-Mittre *et al.*, 1967; Gupta, 1977; Gupta & Khandelwal, 1982; Sharma & Chauhan, 1988b; Chauhan & Sharma, 1996).

Similar palynostratigraphical studies have recently been carried out to generate proxy-climate signals for Garhwal Himalaya. The investigated 2 m deep profile from Nachiketa Tal—a lake situated in temperate zone of Uttarkashi District (Sharma & Gupta, 1995) and another 5 m deep profile from Chharka Tal (one amongst the conglomerate of seven lakes) though again from Uttarkashi region but situated in subalpine belt (Chauhan *et al.*, in Press) have unravelled the palaeovegetation and corresponding climate of Late-Holocene. In addition, two more profiles from the opposite flanks of the same lake situated in the temperate belt of Chamoli District in Garhwal Himalaya have been investigated. A 3 m deep Deoria Tal-I profile from the eastern flank was investigated earlier by Sharma *et al.* (in Press).

The present paper deals with the study of Deoria Tal-II profile from western flank unfolding the vegetation succession during the Early-Holocene. It is ^{14}C dated 2710+150 years B.P. at 55-65 cm depth, but based on lithostratigraphy and reconstructed vegetation of the earlier investigated Deoria Tal-I profile, the bottom of the present lithocolumn could be extrapolated to reveal the palaeovegetation of about 6000 years B.P.

The emerged vegetation history in Deoria Tal-II begins with well established Oak dominated forests in the region. The occurrence of *Pinus roxburghii* pollen in appreciable numbers, when it does not grow these days at this elevation, is the well established case of pseudorepresentation. These were transported from the lower mountain slopes where good chirpine forests exist. Sharma (1985b) and Gupta and Sharma (1993) have already pointed about this phenomenon of *Pinus* presence in such palynostratigraphical studies carried out in the Himalayas.

However, *Carpinus* and *Engelhardtia* — the two associates of *Quercus* together with Ericaceae, *Juglans*, Rosaceae, *Betula, Alnus* and *Ulmus* have a sporadic distribution in these forests. Ground vegetation was poor, dominated by Poaceae alongwith Ranunculaceae and feebly represented Cyperaceae, Cheno/Ams, Caryophyllaceae, etc. The overall emerging vegetal scenario demonstrates that the region during this period had warm-temperate humid climate as also indicated by the large number of encountered fern and other spores .

The vegetation of the period between 4600-3600 years B.P. remains concealed in the lithocolumn at 115-90 cm depth as the sediments did not yield sufficient pollen. However, *Quercus, Pinus, Ulmus* and Ericaceae have been recovered in poor numbers besides pollen of Poaceae, Cheno/Ams, *Potamogeton* and monolete fern spores.

Later, around 3600 years B.P., there was a catastrophic decline in the density of *Quercus* as well as other broad-leaved associates. *Carpinus* and *Engelhardtia* also declined. Thus, an over all reduction in the density of forests is witnessed in the region associated with corresponding abrupt rise in the ground vegetation cover indicated by appreciated values of Poaceae and Cyperaceae on one hand and the enhancement in Cerealia-type pollen with first appearance of several culture pollen on the other. Such a change in the vegetation scenario reflects a change in the climate to cooler and humid conditions as evident by exceptionally high frequencies of fern and other spores. Abundance of culture pollen, particularly the Cerealia-type, and presence of charcoal pieces in the sediment indicate intensive agricultural activities in the region.

The above phase continued till around 1700 years B.P., after which the restoration of forests is witnessed as evidenced by prominent increase in *Quercus* and its associated arboreals. Marked increase in the values of *Rhododendron* and other members of Ericaceae is also indicative of the commencement of such a change in the vegetation scenario. Continued appreciated values of Cerealia-type and other culture pollen further indicate well established agriculture in the vicinity of the lake. The recorded rise in the frequencies of arboreals and corresponding fall in nonarboreals during this phase is indicative of regeneration process of forests under ameliorated climatic conditions.

Comparison of two investigated profiles—Deoria Tal-I and Deoria Tal-II, have portrayed more or less identical picture of palaeovegetation succession. Vegetational history in the two is traced back to ± 4000 years B.P., in case of former and extrapolated to ± 6000 years B.P. in the later which begins with the existence of Oak dominated forests. Subsequent decline of these forests took place between 3500-4000 years B.P., and continued till around 1700-1800 years B.P., thereafter, the Oak forests were restored. These three palaeovegetation phases indirectly reflect to the warm-temperate humid climate under which these forests initially flourished in the region, followed by a change to cool temperate humid climate when Oak forests diminished and grass cover simultaneously increased. The climate once again changed to earlier warm-temperate humid conditions resulting into the restoration of the existing Oak forests in the region.

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REFERENCES

Bhattacharyya A 1988. Vegetation and climate during Post glacial period in the vicinity of Rohtang Pass, Great Himalayan Range. *Pollen Spores* **30** : 417-427.

Chauhan MS & Sharma C 1996. Pollen analysis of mid-Holocene sediments from Kumaon Himalaya. *Proc. Symp. NW Himalaya & Foredeep, Geol. Surv. India Spl Publ.* : 257-269

Chauhan MS, Sharma C & Rajagopalan G (1997. Vegetation and climate during Late-Holocene Period in Garhwal Himalaya. *Palaeobotanist* **46**(1,2) : 211-216.

Erdtman G 1943. *An introduction to pollen analysis*. Chronica Botanica Co., Waltham, Mass.

Gupta A & Sharma C 1993. Recent pollen spectra from Nachiketa Tal, Garhwal Himalaya. *Geophytology* **23** : 155-157

Gupta HP 1977. Pollen analytical reconnaissance of Post glacial deposits from subtropical zone in Nainital District, Kumaon Himalaya. *Palaeobotanist* **24** : 215-244.

Gupta HP & Khandelwal A 1982. Late Holocene palynology from the Lake in Sat Tal Valley, district Nainital, Kumaon Himalaya, U.P. *Geophytology* **12** : 313-321.

Sharma C 1985a. On the Late Quaternary vegetational history in Himachal Pradesh-3. Parasram Tal. *Geophytology* **15** : 206-218.

Sharma C 1985b. Recent pollen spectra from Garhwal Himalaya. *Geophytology* **15** : 87-97.

Sharma C & Chauhan MS 1988a. Studies in the Late-Quaternary vegetational history in Himachal Pradesh-4. Rewalsar Lake-II. *Pollen Spores* **30** : 395-408.

Sharma C & Chauhan MS 1988b. Palaeoenvironmental inferences from the Quaternary palynostratigraphy of Himachal Pradesh and Kumaon, India. *Proc. Indian natn. Sci. Acad.* **54A** : 510-523.

Sharma C & Gupta A 1995. Vegetational history of Nachiketa Tal, Garhwal Himalaya, India. *J. Nepal geol. Soc.* **10** : 29-34.

Sharma C, Chauhan MS & Rajagopalan G (in Press). Vegetation and climate in Garhwal Himalaya during last 4,000 years B.P. *J. Nepal geol. Soc.*

Sharma C & Singh G 1974a. Studies in the Late Quaternary vegetational history in Himachal Pradesh-1. Khajiar Lake. *Palaeobotanist* **21** : 144-162.

Sharma C & Singh G 1974b. Studies in the Late Quaternary vegetational history of Himachal Pradesh-2. Rewalsar Lake. *Palaeobotanist* **21** : 321-338.

Vishnu-Mittre, Gupta HP & Robert RD 1967. Studies of the Late Quaternary vegetational history of Kumaon Himalaya. *Curr. Sci.* **36**: 539-540.

Early Cretaceous *Athyrium* Roth from Northeastern China

Fen Chen, Shenghui Deng & Keqin Sun

Fen Chen, Shenghui Deng & Keqin Sun 1997. Early Cretaceous *Athyrium* Roth from Northeastern China. *Palaeobotanist* **46** (3): 117-133.

Four species of the Early Cretaceous genus *Athyrium, viz., A. cretaceum* Chen et Meng, *A. fuxinense* Chen et Meng, *A. hulunianum* Chen, Ren et Deng and *A. hailaerianum* Deng et Chen from Northeastern China have been systematically studied by scanning electron microscope. The palaeoecology of the Early Cretaceous *Athyrium* has also been discussed in detail in this paper.

Key-words — Pteridophytes, *Athyrium*, Fern, Early Cretaceous, Northeastern China.

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साराँश

उत्तर चीन से प्रारम्भिक क्रीटेश्यस कालीन *एथाइरियम* रोथ

फेन चेन, शेंघुई देंग एवं केकिन सन

उत्तर-पूर्वी चीन से प्रारम्भिक क्रीटेश्यस कालीन *एथाइरियम* प्रजाति की चार जातियों—ए. *क्रीटेश्यम* चेन व मेंग, ए. *फक्सिनेन्से* चेन व मेंग, ए. *हुलुनिआनम* चेन, रेन व देंग तथा ए. *हेलारियानम्* देंग व चेन का क्रमवीक्षण सूक्ष्मदर्शी द्वारा अध्ययन किया गया है। इसी शोध-पत्र में प्रारम्भिक क्रीटेश्यस कालीन *एथाइरियम* की पुरापारिस्थितिकीय विवेचना भी की गई है।

ATHYRIUM is a large genus of more than 200 species distributed in the temperate zone and mountain woodlands in the subtropics, especially in Himalayas, China and Japan. Of them, more than 100 species occur in China and form a centre of distribution in mountain woodlands of southeastern China (Wu et Ching, 1991). Only a few species are found in Europe and North America (Hsieh, 1986).

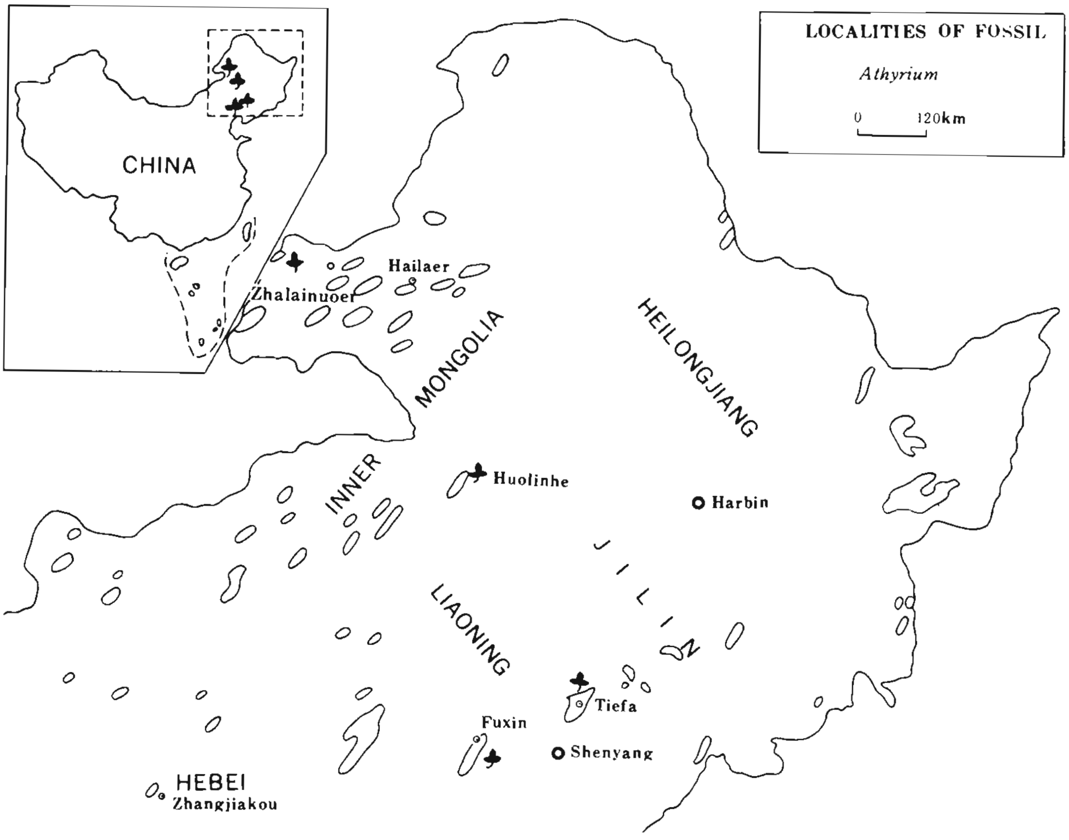
Very few fossils of *Athyrium* have been recorded in literature. *Athyrium crossii*, as an example, was described from the Tertiary of Denver Formation, North America. A poorly preserved pinna was described as *A. gracilium* Pabst (Pabst, 1968) from the sediments of the latest Cretaceous to Early Tertiary of America. Based upon some fertile material, two Early Cretaceous species *Athyrium cretaceum* and *A. fuxinense* and a possible one *Cladophlebis (Athyrium?) asymmetrica* were reported from Fuxin Basin, Liaoning, Northeast China (Chen *et al.*, 1988). These species were also found from the adjacent areas of Fuxin Basin (Deng, 1991a, 1991b, 1992). Recently, two new species: *A. hulunianum* and *A. hailaerianum* have been preliminarily described from Zhalainuoer Basin, Inner Mongolia by the authors (Chen *et al.*, 1993).

This paper is the result of systematic study of the material including a number of specimens collected recently. The main work has been focussed on the microstructures of reproductive organs *in situ*. The fossil specimens have been compared with the extant species of living *Athyrium*— *Athyrium filix-femina*. The palaeoecological characters of the Early Cretaceous *Athyrium* have been discussed in the present paper as well.

STRATIGRAPHY, MATERIAL AND METHODS

The material studied in this paper was collected from Fuxin Basin, Tiefa Basin, Liaoning Province and Huolinhe Basin, Zhalainuoer Basin, Inner Mongolia (Text-figure 1). The correlation between these four Mesozoic basins is shown in Table 1. The fossil bearing sediments belong to the Early Cretaceous.

1. Fuxin Basin— The Late Mesozoic strata in Fuxin Basin are represented by the Yixian, Jiufotang, Shahai, Fuxin and Sunjiawan Formations, in



Text-figure 1— Map showing the fossil localities.

upward sequence (Table 1). The Yixian Formation is characterized by thick volcanics. Jiufotang Formation is a series of fresh water lacustrine deposits, and both of the Shahai and Fuxin Formations are represented by coal-bearing units. The Sunjiawan Formation is composed of varicoloured sandstones and conglomerates which indicate arid or semiarid climatic conditions during deposition. The Fuxin Formation is rich in plant fossils including *Athyrium cretaceum* and *A. fuxinense*.

2. Tiefa Basin — The palaeogeographic environment of this basin as well as its geological age and the features of Late Mesozoic strata are

Table 1— Correlation of the Late Mesozoic Formations in Inner Mongolia and Liaoning Province, Northeast China

	Inner Mongolia			Liaoning	
	Zhalainuoer	Huolinhe		Fuxin	Tiefa
Albian	Qinglonggang Formation			Sunjiawan Formation	Sunjiawan Formation
Aptian	Yimin Formation	Huolinhe Formation	Upper member	Fuxin Formation	Xiaominganbei Formation
Neocomian	Damoguaihe Formation		Lower member	Shahai Formation	
Late Jurassic	Xinganling Group	Xinganling Group		Jiufotang Formation	Baijiagou Formation
				Yixian Formation	Datai Formation

PLATE 1

→

All specimens are housed in China University of Geosciences (Beijing). All figures are in natural size except where indicated. Scanning electron microscope pictures are marked with "SEM"

1-8. *Athyrium cretaceum* Chen et Meng

1. Fertile pinnae. Fuxin Formation, Fuxin Basin, Liaoning.

3-5, 8. Fertile pinnae; 3a, showing the sori. Xiaominganbei Formation, Tiefa Basin, Liaoning.

2, 6-7 Sterile pinnae. Xiaominganbei Formation, Tiefa Basin, Liaoning.


1

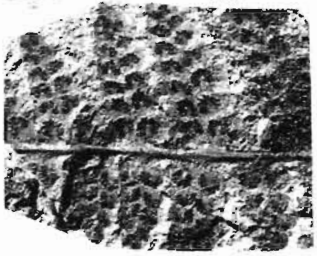

4

×3


5


2


6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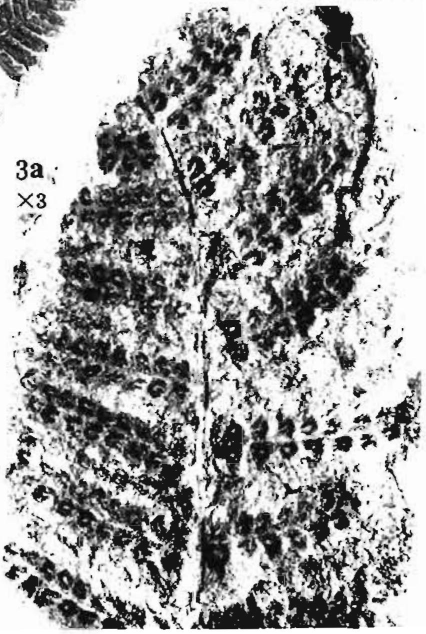
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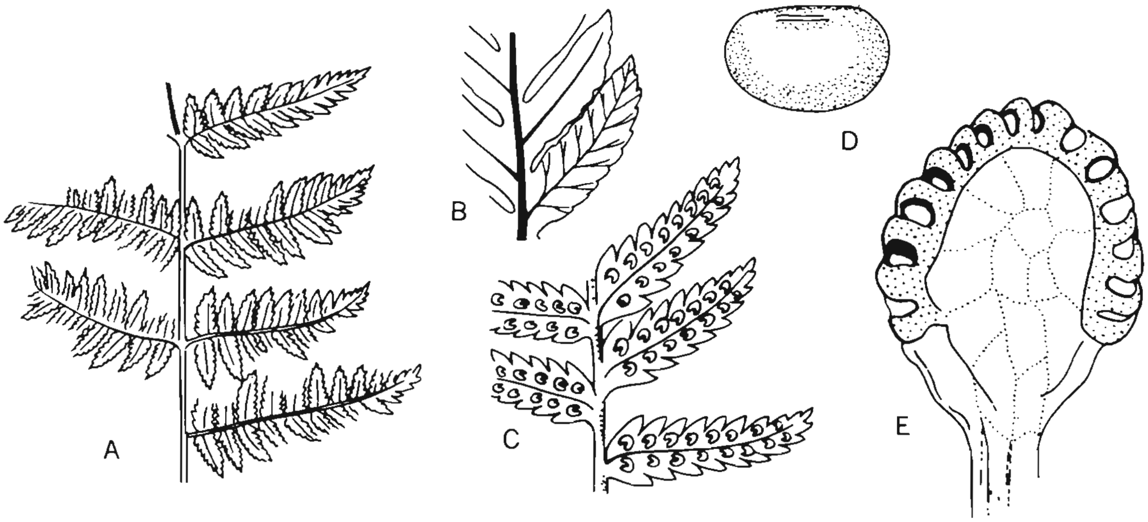
PLATE 1



Text-figure 2 —*Athyrium cretaceum* Chen & Meng ; **A**, frond x 1; **B**, sterile pinnules showing the venation x 4; **C**, fertile pinnules showing the sori x 4; **D**, spore x 600; and **E**, sporangium x 264.

similar to those of Fuxin Basin. The coal-bearing Xiaominganbei Formation, yielding *Athyrium cretaceum*, is equal to the Shahai and Fuxin Formations of Fuxin Basin (Table 1).

3. Zhalainuoer Basin — This basin lies in eastern Inner Mongolia (Text-figure 1). The Early Cretaceous coal-bearing strata of Damoguaihe and Yimin Formations are very abundant in plant fossils (Ren, 1986). *Athyrium hulunianum* and *A. hailaerianum* were discovered from the Yimin Formation.
4. Huolinhe Basin — The Huolinhe Formation, unconformably overlying the Late Jurassic volcanic rocks, is divided into lower and upper coal members. The lower member which contains *Athyrium cretaceum* and other plant fossils is regarded to early Early Cretaceous (Deng, 1991a).

All the specimens are well preserved compressions. Most of them are fertile fronds with carbonaceous remains which contain numerous sori and sporangia. Firstly, the specimens were observed under a stereomicroscope and then the *in situ* sori and sporangia removed from the matrix by bulk maceration of rock with hydrofluoric acid or directly transferred from the matrix with a needle. The black sori or sporangia were treated with Schulz's solution or sodium hypochlorite until they become brown and then examined under a light microscope. The sporangia then were treated with ammonium hydroxide or sodium hydroxide solution to get the spores released. In order to count the spores output accurately, some sporangia were isolated and moved to an acuvette (1-2 mm in diameter) carefully, and then broken with a needle. Some of the spores, sporangia and sori were studied under scanning electron microscope.

The specimens of the extant *Athyrium* were provided by Dr Zhang of the Institute of Botany, Academia Sinica.

PLATE 2

⟶

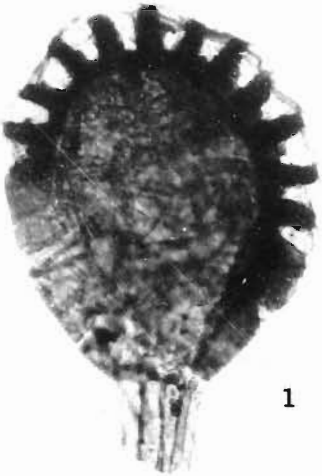
All specimens are housed in China University of Geosciences (Beijing). All figures are in natural size except where indicated. Scanning electron microscope pictures are marked with "SEM"

1-11. *Athyrium cretaceum* Chen et Meng. 1-7 Sporangia. 1, sporangium with a stalk, x 264, 2-3, x 132, 4 (SEM), x 270; 5 (SEM), x 300; 5a (SEM), x 1080, enlargement of fig. 5, showing the stalk; 6 (SEM), x 400; 7 (SEM), x 400; 7a (SEM), x 1000, enlargement of fig. 7 showing the thickened cells of the annulus.

8-9. Spores. 8, x 660; 9 (SEM), x 400; 9a. (SEM), x 1000.

10. Enlargement of Pl. 1, fig. 10 x 30 showing the sori.

11. Fertile pinnae, Huolinhe Formation, Huolinhe Basin, Inner Mongolia.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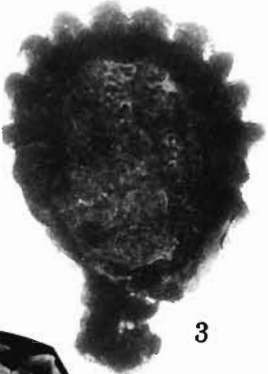
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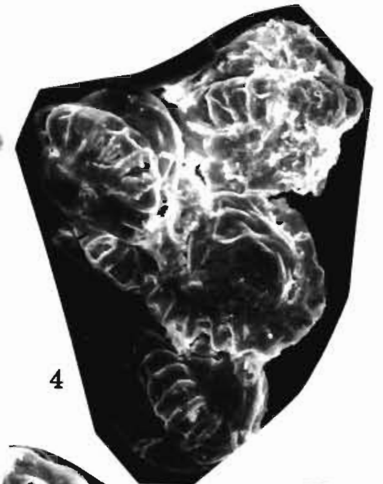
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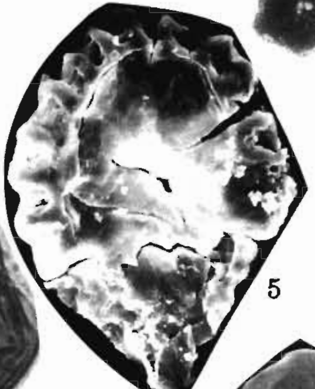
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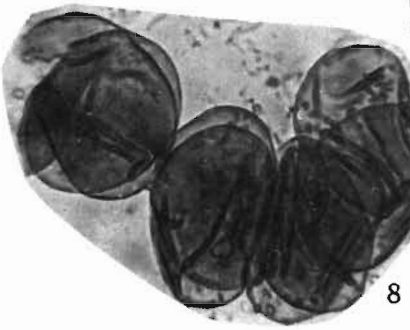
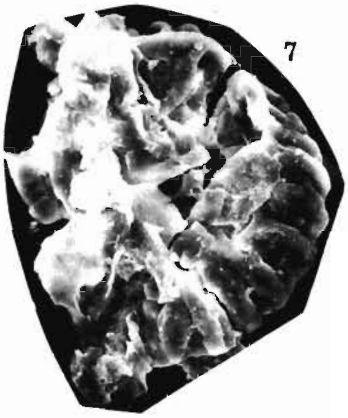

8


9a


9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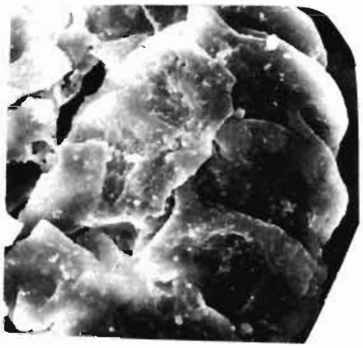
7a

×20 10


11


5 a

PLATE 2

DESCRIPTION

Family—Athyriaceae

Athyrium cretaceum Chen et Meng

Pl.1, figs 1-8; Pl. 2, figs 1-11; Text-figure 2

1988 *Athyrium cretaceum* Chen *et al.,* p. 42, pl.13, figs 5-9; pl.14, figs1-11; Text-fig. 14b.

1991 *Athyrium cretaceum* Deng, pl. 1, figs 1-2.

1992 *Athyrium cretaceum* Deng, pl. 4, figs 1-4.

Fronds— Medium size, over 15 cm long and 10 cm wide, bipinnate, triangular, elongated triangular or lanceolate in outlines.

Stipes and rachis— Stipes up to 6 cm long and 2 mm wide; smooth, with a longitudinal groove on the adaxial surface. Rachis smooth, 1-2 mm thick, weak, curved very often (Pl. 1, figs 3, 5), with a shallow and longitudinal groove on the upper side.

Pinnae and pinnules— Ultimate pinnae lanceolate, usually 2-5 cm long, 0.7-1.5 cm broad at the base, oppositely to alternately arranged, arising at right angles, with intervals of 0.8-2 cm between the adjacent pinnae. A pair of pinnae at the base of the frond usually asymmetrical and the pinnules on the basiscopic sides of these pinnae typically longer and larger than those on the acroscopic sides.

Pinnules typically lanceolate or triangular, 0.6-1.5 cm long and 0.3-0.5 cm wide at the base; apices acute; margins dentate with 6-9 pairs of triangular teeth. Pinnules in opposite or slightly katadromic at the bases and usually after 4-5 pinnules upwards turned into anadromic order (Pl. 1, figs 1, 5-6). The pinnules on the basiscopic side generally larger and arranged less crowded than those on the acroscopic side.

Venation— Pinnate, midvein slightly decurrent at the base and reaches up to the apex of the pinnule; lateral veins slender, simple or forked once or twice (Text-figure 2B).

Fertile pinnules and sori— Fertile pinnules are similar to the sterile ones. Sori attached to the lateral veins or their anterior branches, arranged in a single row on each side of midvein (Pl. 1, figs 1, 3-4, 8; Text-figure 2 C). One sorus in each tooth, 4-7 pairs or even 9 pairs in each pinnule. Sori typically hook or hoof-like, those at the bases of the pinnules usually semicircular, 0.3-0.6 x 0.5-0.8 mm in diameter, with about 45^0 to the midvein (Pl. 1, figs 3a, 8; Pl. 2, fig. 10), indusium present occasionally.

Sporangia and spores— Sporangia spherical or elliptic, 90-100x130-150 μm in size, stalk more than 200 μm long and about 30 μm in diameter (Pl. 1, fig. 7; Pl. 11, figs 4,6). Thin-walled cells of the sporangium polygonal, 40-50 μm in diameter. Annulus vertical, incomplete, composed of 13 to 15 thickened cells. Stomium dehisces transverse (Pl. 2, figs 1-7; Text-figure 2E). Spores bilateral, elliptic in polar view and kidney-like in equatorial view (Pl. 2, figs 8-9; Text-figure 2 D), 64 spores per sporangium. In mature spores, equatorial axis 30-45 μm long and polar axis 20-30 μm long, the ratio of two axes about 1.5. Some spores very small, less than 13 x 20 μm in size, supposed to be immature ones. Monolete, laesura usually 10-20 μm long, about half of the equatorial axis. Exine smooth, wrinkled.

Horizon and localities — Fuxin Formation, Fuxin Basin; Xiaominganbei Formation, Tiefa Basin; Lower member of the Huolinhe Formation, Huolinhe Basin.

Athyrium fuxinense Chen et Meng

Pl. 3, figs 1-10; Text-figure 3

1988 *Athyrium fuxinense* Chen *et al.*, p. 43, pl. 14, figs 12-13; pl. 15, figs 1-5; text-figure 14a.

Frond— Medium size, up to 20 cm long, 8-10 cm wide, tripinnate at the lower region and bipinnate at the upper region, elongated triangular or lanceolate in outline.

PLATE 3 →

All specimens are housed in China University of Geosciences (Beijing). All figures are in natural size except where indicated. Scanning electron microscope pictures are marked with "SEM"

(All the specimens are from Fuxin Formation, Fuxin Basin, Liaoning)

1-10. *Athyrium fuxinense* Chen et Meng

1-3. Sterile pinnae, arrow in fig. 1 showing the stipes.

4-5. Fertile pinnae, 4a, 4b; 5, enlargement of fig. 4, showing the fertile pinnules and sorus.

6. Spores in a sorus (SEM), x 600.

7-8. Sporangia (SEM), x 120.

9. Showing the thickened cells of the annulus (SEM), x 1000.

10. Spores, x 800.

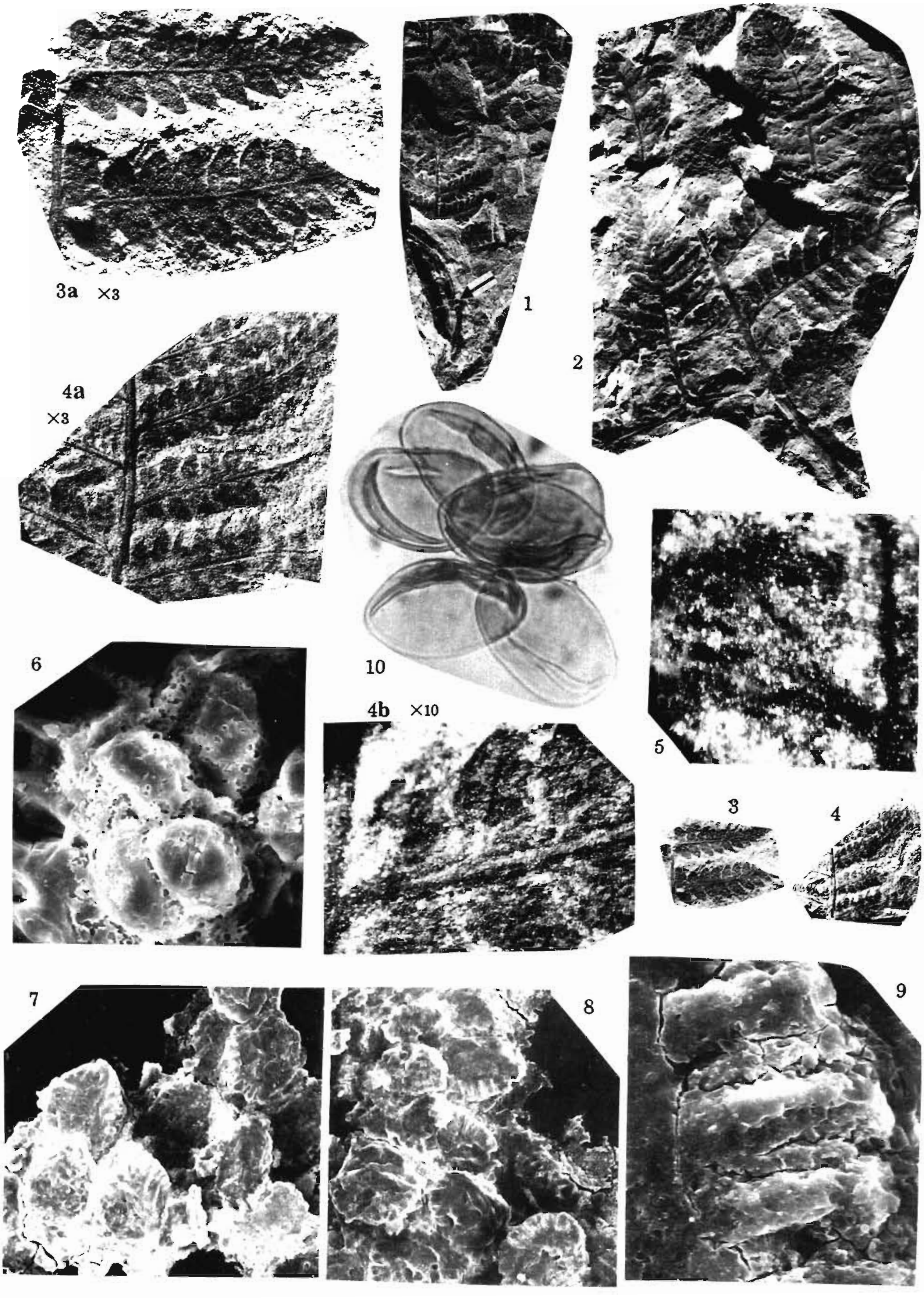

PLATE 3
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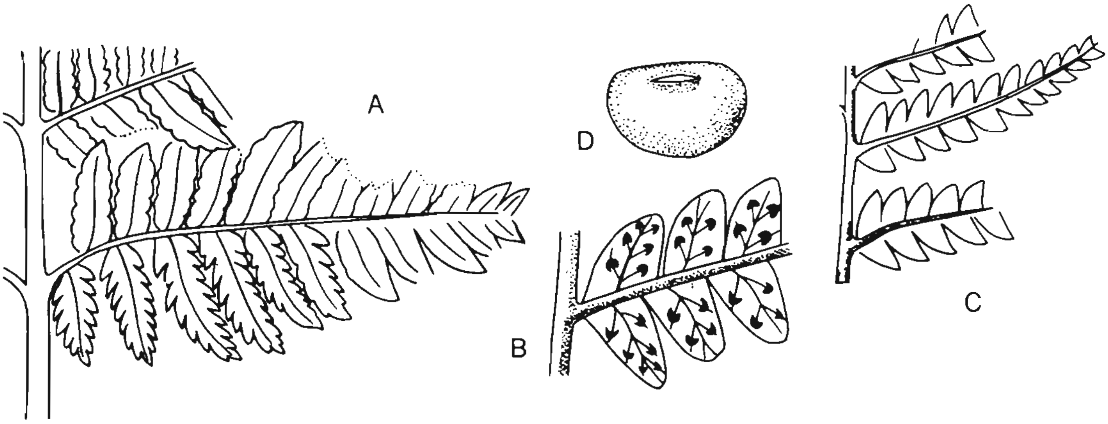


Text-figure 3 — *Athyrium fuxinense* Chen & Meng; **A**, lower part of a frond x 1; **B**, fertile pinnules showing the sori x 6; **C**, fertile pinna x 3, and **D**, spore x 600.

Stipes and rachis — Stipes clustered (Pl. 3, fig. 1), over 4 cm long, 3 mm wide, slightly curved, smooth, convex on the lower side with a longitudinal groove on the upper side. Ultimate rachis 0.2-0.3 mm wide, upper surface concave, lower surface rounded (Pl. 3, figs 3a, 4a).

Pinnae and pinnules — Penultimate pinnae arising at angles of 80°, opposite to subopposite, quite crowdedly arranged. A basal pair of penultimate pinnae 8-10 cm long and 4-5 cm broad. The upper part of the frond tending bipinnate. Ultimate pinnae lanceolate, acute, 2-3 cm in length and 0.7-1.5 cm in breadth, arranged in slightly opposite to katadromic order. Pinnules triangular, falcated or ligulate, 0.5-0.8 cm long and 0.3-0.4 cm wide, margins entire or lobed into teeth; apices pointed, acute or obtuse (Pl. 3, figs 1-3); slightly katadromic at the base and anadromic after 3-5 pinnules upwards (Pl. 3, figs 2-3; Text-figure 3 A).

Venation — Pinnate, quite fine, midvein reaches to two thirds of the pinnules, lateral veins simple or forked once.

Fertile parts and sori — Fertile pinnae reduced (Pl. 3, figs 4-4b), typically 1.5 cm long and 0.4 cm wide. Fertile pinnules ligulate or falcated, 2-3 mm long and 1.5-2.5 mm wide, apices obtuse, margins slightly lobed into 3-4 pairs of teeth. Sori rounded or hood-shaped, about 0.5 mm high, 0.5 mm wide, marking 60^0-70^0 angle to the midvein, situated at the lateral veins or the anterior branches of the lateral veins (Pl. 3, figs 4b, 5; Text-figure 3 B); usually 2-3 pairs in each pinnule; arranged in two rows. Sorus consisting of about 20 sporangia.

Sporangia and spores — Sporangia elliptic in lateral view, 100-150 μm in diameter with stalks. Annulus vertical, incomplete, composed of 13 thickened cells (Pl. 3, figs 7-9), output 60-64 spores per sporangium. Spores bilateral, elliptic in polar view and kidney-shaped in equatorial view. Equatorial axis 25-35 μm long and polar axis 20-30 μm long. The ratio of the two axes about 1.4. Monolete, laesura 15-18 μm long. Exine smooth, slightly wrinkled.

Horizon and locality — Fuxin Formation, Fuxin Basin.

Athyrium huluniianum Chen, Ren et Deng

PLATE 4 ⟶

All specimens are housed in China University of Geosciences (Beijing). All figures are in natural size except where indicated. Scanning electron microscope pictures are marked with "SEM"

(All the specimens are from Yimin Formation, Zhalainuoer Basin, Inner Mongolia)

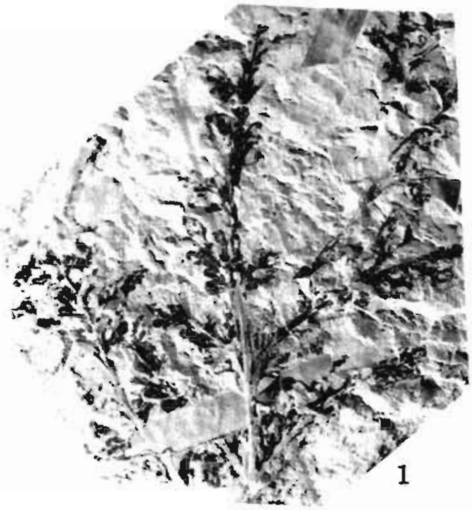
1-7. *Athyrium huluniianum* Chen, Ren et Deng

1. Fertile pinnae. 1a, enlargement of fig. 1.

2. Sterile pinnae. 2a, showing the rachis; 2b, showing the pinnule and venation.

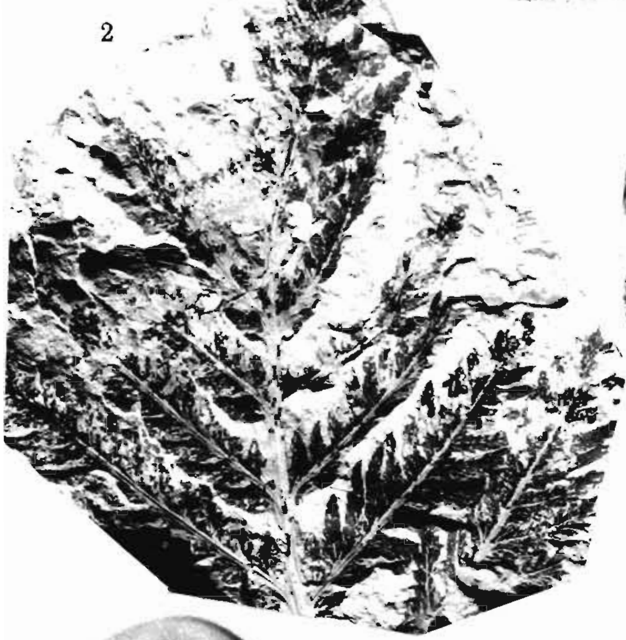
3-5. Sori 3-4 x 20; 5, x 30.

6-7. Spores. x 280; x 1300.


1


1a ×3


3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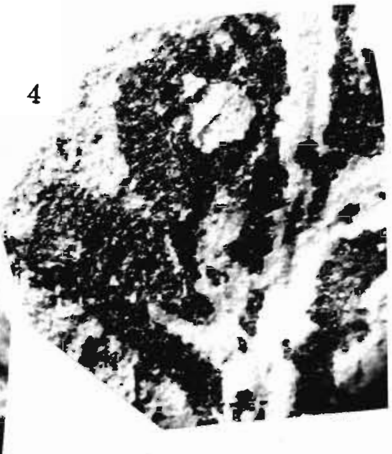
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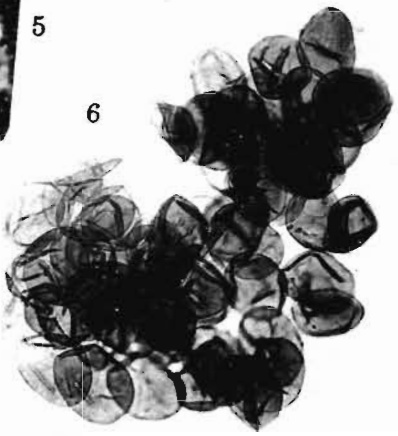
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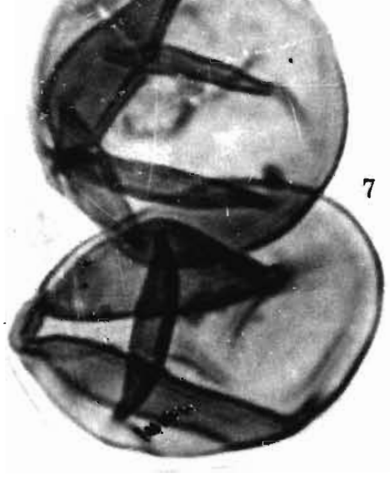

7


2a ×4


2b ×3

PLATE 4

Pl. figs 1-7; Pl. 5, figs 1-5; Text-figure 4

1993 *Athyrium huluntanum* Chen *et al.*, p. 562, pl. 1, figs 1-4, 9-11.

Frond — Medium size, triangular in outline, bipinnate at least, up to 8 cm long and 7 cm broad.

Rachis— Penultimate rachis quite strong, about 2-3 mm wide with a longitudinal ridge on the lower side; the ridge occupying one third of the rachis and expanded to about half of the rachis at the position where ultimate rachis arising (Pl. 4, fig. 2a); ultimate rachis 0.8 mm thick, abaxial side rounded, arising at acute angle, slightly decurrent at the base and curved forwards.

Pinnae and pinnules — Ultimate pinnae lanceolate, up to 3-5 cm long, 1-1.5 cm wide, apices acute, arising at angles of about 50^0, quite crowdedly arranged in opposite order (Pl. 4, fig. 2). Pinnules falcated, triangular or lanceolate, 1.0-1.2 cm long, 0.4 cm wide, widest at the base, slightly decurrent, apices tapering downwards, tip margins lobed into 6-8 pairs of teeth with acute apices. Pinnules attached at an angle of about 45^0 to the ultimate rachis, arranged in slightly katadromic order at the bases and anadromic after 4-5 pinnules upwards (Pl. 4, fig. 2). The first basiscopic pinnule decurrent, attached to the base of the pinna, close to its insertion.

Venation — Pinnate, midvein rather strong at the base, slender forwards and the apex usually flexuous. Lateral veins very slender, simple or forked once (Pl. 4, fig. 2b). The distal parts of the lateral veins usually thickened.

Fertile frond and sori — Fertile pinnae and pinnules are similar to the sterile ones. Sori borne on the abaxial surface of the pinnule, situated at the lateral veins or the anterior branches, 4-5 in a row on each side of the midvein, one in each tooth excluding the base ones which usually bear two. Sori on the lower part of the pinnule especially those at the base typically hoof or hook-shaped. The hoof-shaped ones symmetrical, 1.5-2.0 mm high and 1-1.5 mm wide. Of the hook-shaped ones, the side closer to the midvein parallel to the midvein and usually longer than the other part. Sori on the mid-upper region of a pinnule usually hook-like and those on the apices typically crescent-shaped or rectangular, 1-1.5 mm in length (Pl. 4, figs 1, 3-5; Text-figure 4 C). Sori with more than 60-80 sporangia.

Sporangia and spores — Sporangia typically rounded, a few elliptic in lateral view, about 180 μm in diameter or 150-180x180-200 μm in size, with long but thin stalks consisting of 3 files of cells (Pl. 5, figs 2, 4, 4a). Annuli incomplete, vertical, composed of about 13 thickened cells; stomium transverse (Pl. 5, figs 1-4; Text-figure 4E).

Spores bilateral, typically rounded or elliptic in polar view; equatorial axis 30-40 μm long and polar axis 25-35 μm long, the ratio of equatorial axis to polar axis 1.00-1.30, average 1.24; monolete, laesura 16-25 μm in length, exine smooth, usually with wrinkles on the surface (Pl. 4, figs 6-7; Pl. 5, fig. 5; Text-figure 4F).

Horizon and locality—Yimin Formation, Zhalainuoer Basin.

Athyrium hailaerianum Deng et Chen

Pl. 5, figs 8-9; Pl. 6, figs 1-6; Pl. 7, figs 1-11; Text-figure 5

1993 *Athyrium hailaterianum* Chen *et al.*, p. 563, pl. 1, figs 5-8, 12-13.

Frond— Small size, bipinnate, elongated triangular in outline, up to 4 cm long and 3 cm broad.

Rachis — Penultimate rachis quite slender, less than 1 mm thick, with a longitudinal groove on the upper side, two sides of the groove with sharp edges.

PLATE 5 ⟶

All specimens are housed in China University of Geosciences (Beijing). All figures are in natural size except where indicated. Scanning electron microscope pictures are marked with "SEM"

1-5. *Athyrium huluntanum* Chen, Ren et Deng

1-4. Sporangia. 1, (SEM), x 400; 2, sporangium with a stalk (SEM), x 330; 3, x 264; 4, sporangium with a stalk, 264; 4a, enlargement of fig. 4, showing the stalk, x 660.

5. Spores (SEM), x 1000.

6-7,10. *Athyrium filix-femina* (L) Roth.

6. Sporangium with a stalk, x 264.

7. Granulate spore (SEM). x 1200.

10. Sori, x 30.(Specimen of fig. 10 from Yunnan, Southeast China)

Athyrium hailaerianum Deng et Chen

8. Sterile pinna.

9. Sori. x 20 (Specimens of figs 8 and 9 are from Yimin Formation, Zhalainuoer Basin, Inner Mongolia).

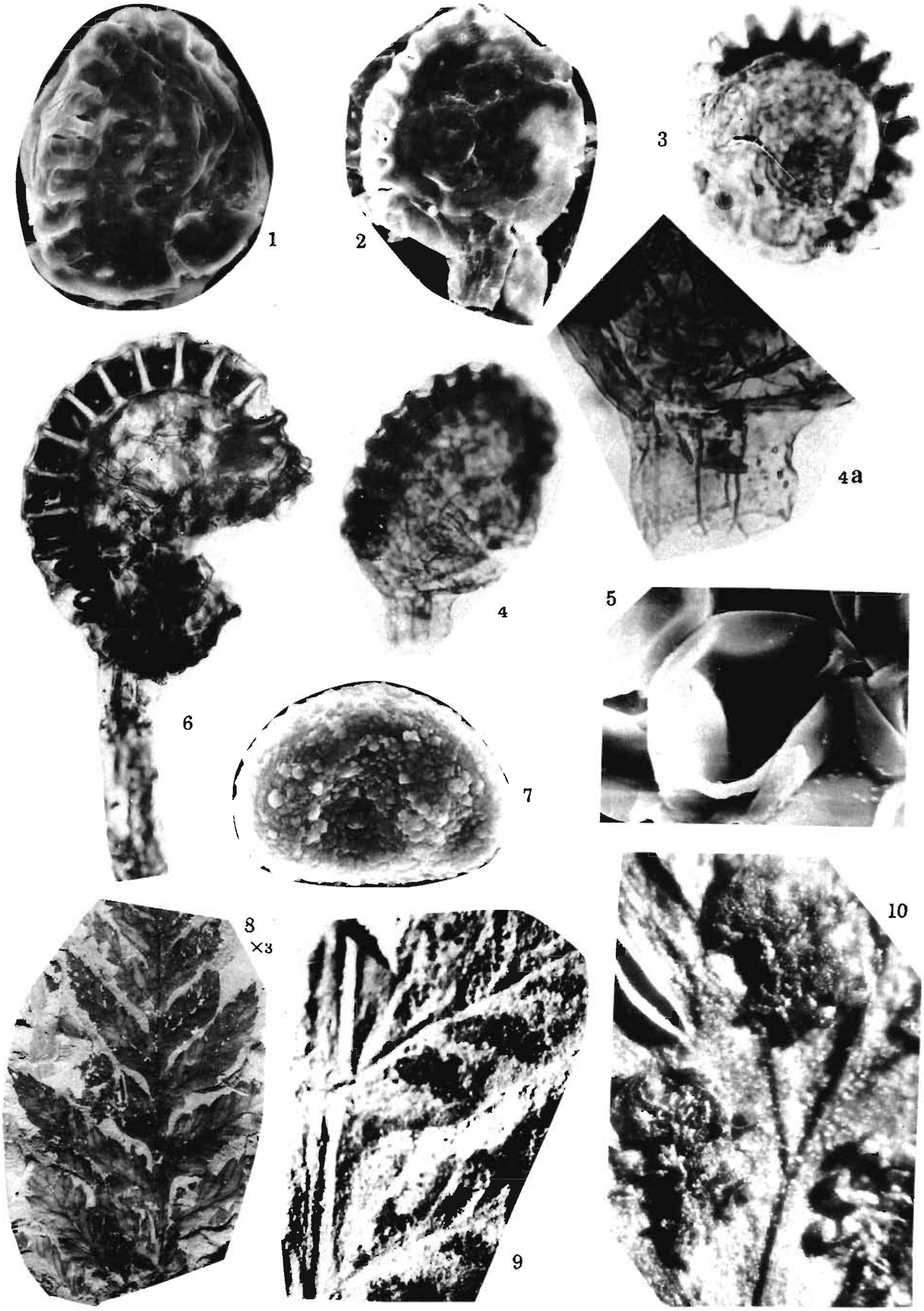
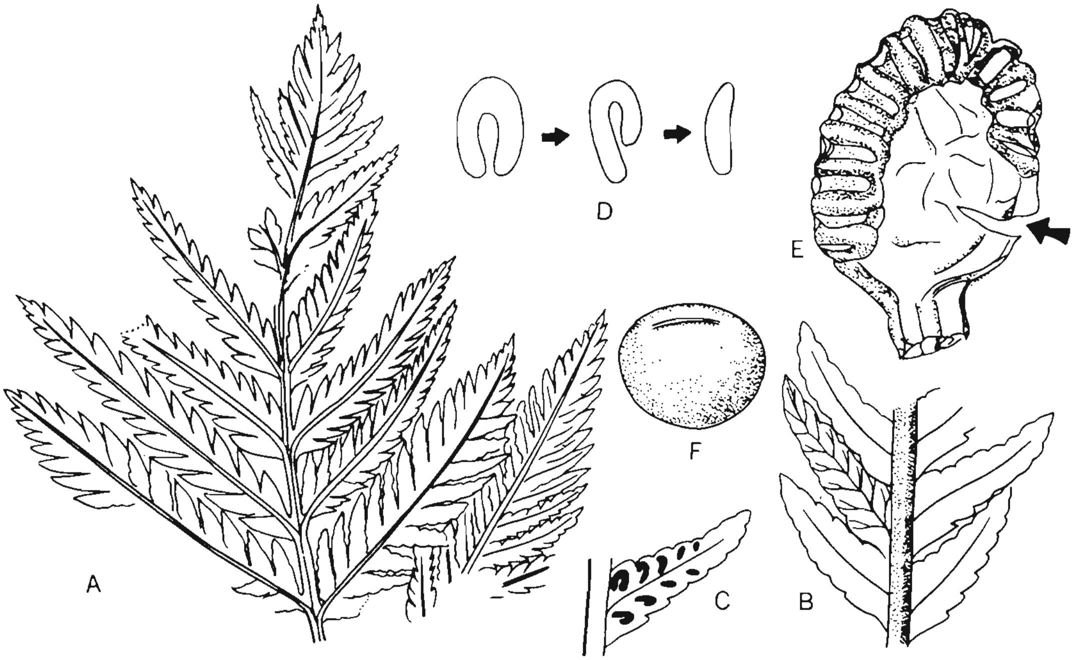


PLATE 5



Text-figure 4—*Athyrium hulunianum* Chen, Ren & Deng; **A**, sterile pinnae x 1; **B**, sterile pinnules showing venation x 3; **C**, fertile pinnule showing sori x 3; **D**, showing sorus x 15; **E**, sporangium showing annulus, the arrow shows stomium x 264; and **F**, spore x 600.

A fine longitudinal ridge of 0.2 mm broad on the lower side of the penultimate rachis. Ultimate rachis 0.2-0.5 mm thick, lower side convex with a fine ridge.

Pinnae and pinnules — Ultimate pinnae lanceolate, up to 5-6 cm long, 1.0-1.2 cm broad, alternately arranged, arising at angles of 40^{0}-45^{0} to the penultimate rachis, mid-upper part curved forward. Those on the apex of the frond slightly linear, usually 1-1.5 cm long and 0.2-0.3 cm broad, margins dissected into teeth with acute apices, alternately arising at angles of 30^{0}, rather crowdedly arranged. Pinnules lanceolate, apices acute, 0.4-1.0 cm in length and 0.2-0.4 cm in width, widest at the base, margins dissected into lobes with acute apices, making acute angle to the ultimate rachis, arranged in katadromic order at the bases of pinna and anadromic order after 4-5 pinnules upwards.

Venation—Venation pinnate. Midvein very slender, flexuous, reaching to the apices of pinnules. Lateral veins simple, forked once or twice.

Fertile frond and sori—Fertile frond is similar to the sterile ones. Sori borne abaxially, situated at the lateral veins, arranged in two rows, half way to the margins, oblique to the midvein at angles of 30^{0}-40^{0}. Commonly 4-9 sori in a row (Pl. 6, figs 3-4), one in each tooth except some developed ones usually with two sori at the base of pinnules. Sori varies in shape. Generally, at the lower region of a pinnule, the sori usually rounded or hoof-shaped, about 1 mm in diameter (Pl. 7, fig. 4); at the mid-upper region, sori usually very curved as hoof or hook-shaped (Pl. 7, fig. 2); and those at the top of a pinnule rectangular, crescent or banana-like (Pl. 7, fig. 2). Therefore, from the base to the apex of a pinnule, the forms of sori

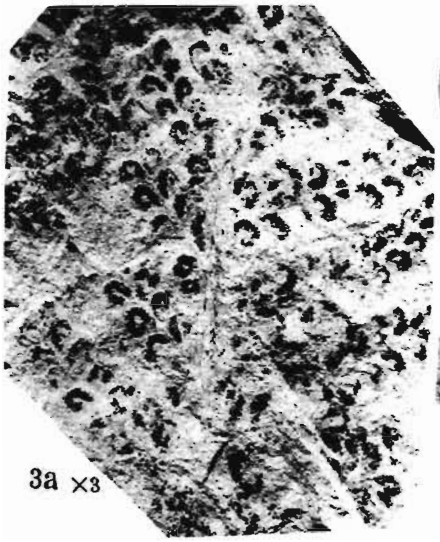
PLATE 6

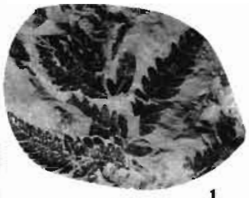
⟶

All specimens are housed in China University of Geosciences (Beijing). All figures are in natural size except where indicated. Scanning electron microscope pictures are marked with "SEM"

(All the specimens in this Plate are from Yimin Formation, Zhalainuoer Basin, Inner Mongolia)

1-6. *Athyrium hailaerianum* Deng et Chen
1-2. Sterile pinnae.
3-4. Fertile pinnae. 3a enlargement of fig. 3 showing the sori.
5. Spores (SEM). x 1200.
6. Sporangia in one sorus (SEM). x 260.


3a ×3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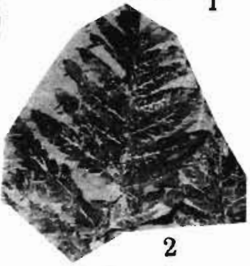
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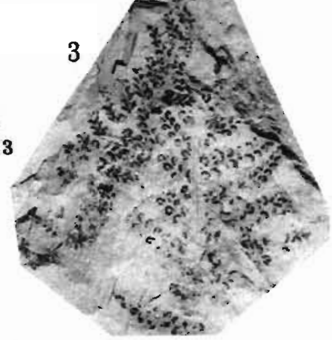
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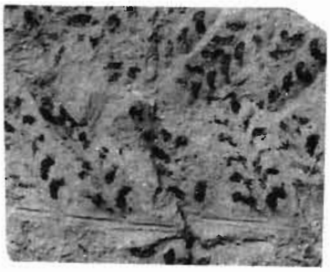

4
×3


5

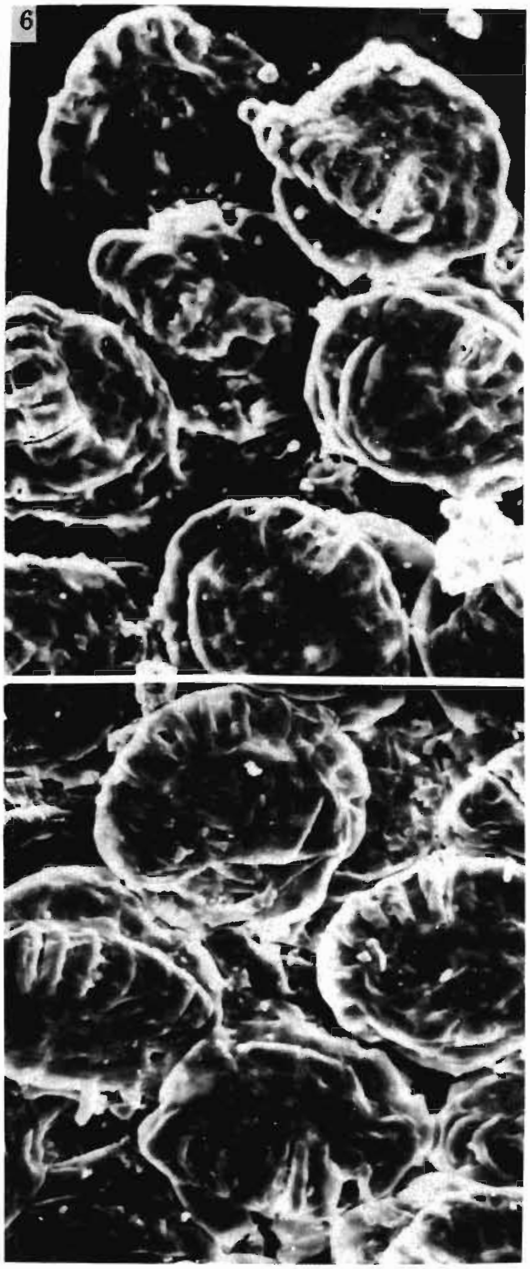

6

PLATE 6

changing gradually (Text-figure 5D) from rounded to crescent shape. In the upper region of a frond, sori usually crescent-shaped. One sorus comprises more than 80 sporangia (Pl. 7, fig. 1).

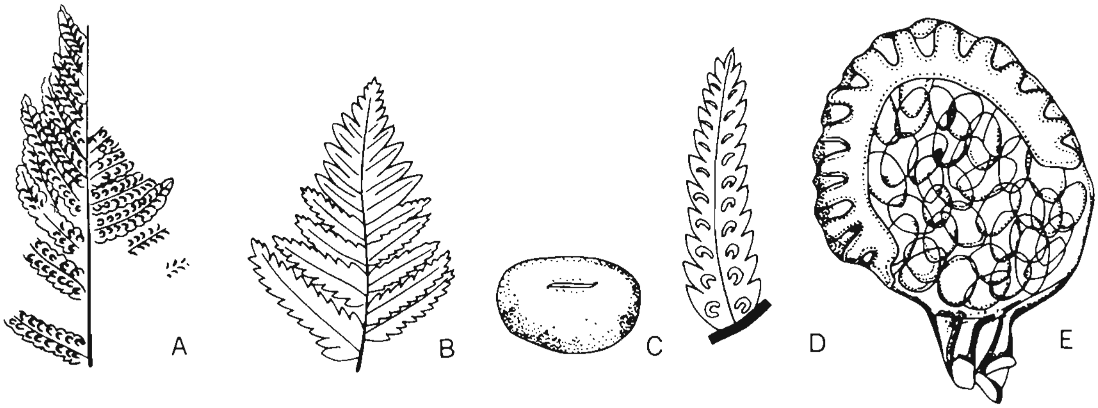
Sporangia and spores— Sporangia rounded or elliptic in lateral view, size about 120x180x200 µm, stalks about 20x40 µm in diameter, composed of 3 files of cells (Pl. 7, figs 7, 9; Text-figure 5E). Annulus vertical, incomplete, composed of 13-17 thickened cells. Stomium transverse (Text-figure 5E). Each sporangium comprises about 64 spores. Spores monolete, typically elliptic in polar view except a few rounded ones. The polar axis 22-25 µm (average 22.6 µm) long and the equatorial axis 30-35 µm (average 30.6 µm) long. The ratio of two axes 1.35. Laesura 13-20 µm long. Exine smooth, wrinkled (Pl. 7, figs 5, 10; Text-figure 5C).

Horizon and locality—Yimin Formation, Zhalainuoer Basin.

DISCUSSION

Four species described above can be distinguished from each other. *Athyrium hulunianum* is characterized by its strong rachis and oppositely arranged pinnae, and especially its large, hoof and hook-shaped sori. *A. hailaerianum* is distinct in its smaller size, slender rachis and a large number of sori which are gradually variable in forms from lower to upper regions of a pinna or a pinnule. *A. fuxinense* is the only one whose fertile pinnules are smaller than sterile ones. It can also be identified by its ligulate fertile pinnules and rounded or hook-like sori which are fewer in number and smaller in size. *A. cretaceum* is characterized by smaller size, triangular pinnules and regular hoof-like sori.

These four species show a similar pinnule arrangement of katadromic order at the base of a pinna and anadromic after 4-5 pinnules upwards. The sporangia of these species show similarity with each other. But those of *A. hulunianum* are relatively globular or rounded in lateral view and a little larger than that of the others. The annuli of all these species are vertical and composed of 13-17 thickened cells, commonly 13. The sporangia possess long but slender stalks which are composed of 3 tier of cells as shown in *A. hulunianum* and *A. hailaerianum* (Pl. 5, fig. 4; Pl. 7, fig. 9). It seems that



Text-figure 5—*Athyrium hailaerianum* Deng & Chon; **A**, fertile frond x 1; **B**, sterile frond x 1; C, spore x 1; **D**, fertile pinnule showing the sori x 3; and **E**, sporangium showing the annulus, stalk and spores in the sporangium x 264.

PLATE 7

→

All specimens are housed in China University of Geosciences (Beijing). All figures are in natural size except where indicated. Scanning electron microscope pictures are marked with "SEM"

1-11.	*Athyrium hailaerianum* Deng et Chen
1.	Sporangia in one sorus. x 110
2-4.	Sporangia at different positions of a pinnule. x 30.
5,10.	Spores (SEM). x 600; x 1500.
6-9, 11.	Sporangia. 6-7 (SEM), x 450; 7a (SEM), showing the stalk, x 600; 8-9, x 264; 9a, showing the stalk, x 800, 11 (SEM), x 450.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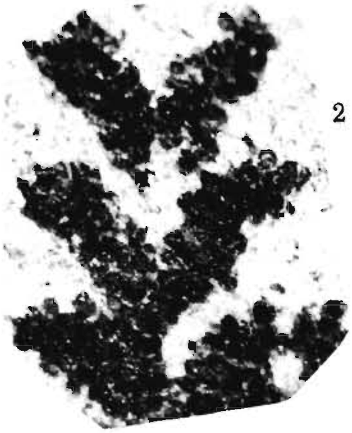
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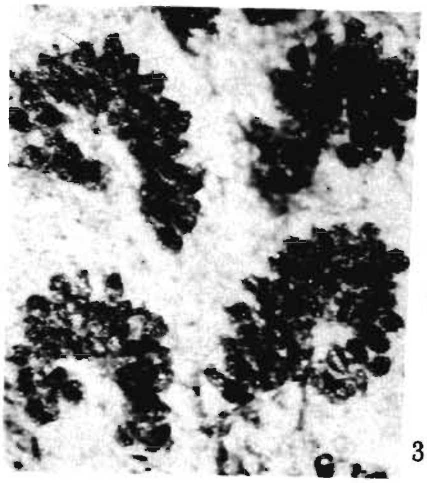
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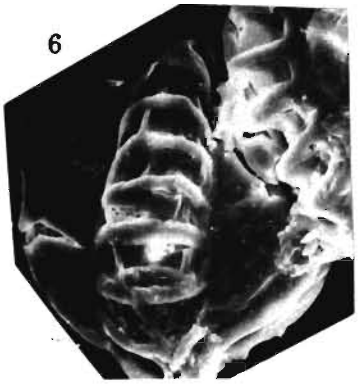
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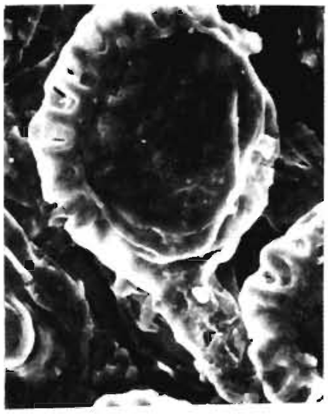
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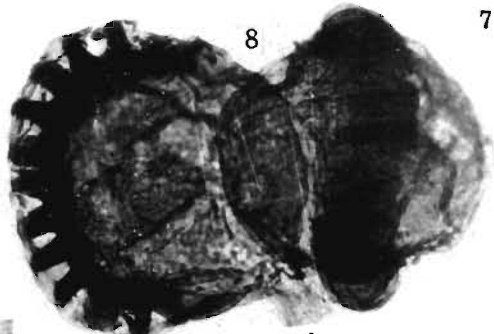
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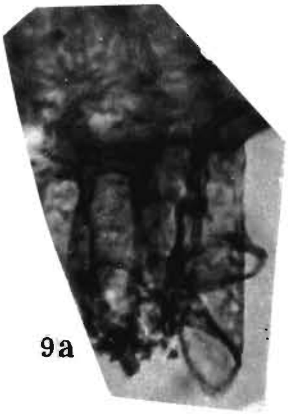
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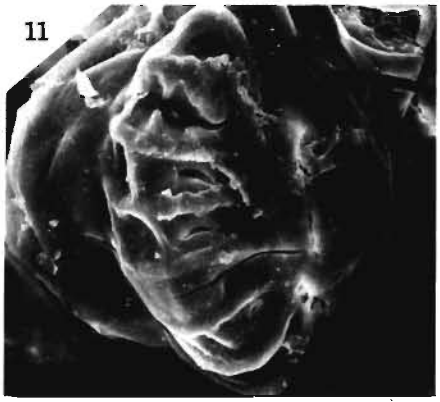
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PLATE 7

a single sporangium bears 64 spores, although in some cases it is determined to be less than this number. Spores of the four species are quite similar in shape excluding those of *A. huluntanum* which are rather rounded (Pl. 4, fig. 7; Pl. 5, fig. 5).

The present fossils can be closely compared with the extant *Athyrium* especially in the sori, indusia, sporangia, annuli and spores. Although the sori and indusia of the extant *Athyrium* are variable in forms, they are typically hook or hoof-shaped, occasionally linear or crescent-shaped as well as that of the fossils. The indusia of the extant *Athyrium* are usually broken or dispersed on the maturity of sori. Additionally, the morphology of sterile portions of the fossils shows closeness to some species of extant *Athyrium*.

Of the living *Athyrium, A. filix-femina* (L) Roth, *A. sinense* Rupr. and *A. brevifrons* Nakai can be compared most closely with the fossil species. *A. filix-femina*, the generic type, widely distributed over Europe, North America and Asia, is close to *A. cretaceum* on the outlines of its fronds and pinnules. The pinnules of *A. filix-femina* are characterized by their triangular-lanceolate forms, acute apices, slightly contracted bases and dissected margins. Usually, a single developed pinnule of *A. filix-femina* has 5-8 pairs of sori, generally one sorus in each tooth. The shapes of the sori change gradually from the lower to upper regions of a pinnule as from hoof or hook to crescent or strip-shaped as well as that of *A. hailaerianum*. *A. sinense* and *A. brevifrons* which have limited geographic distribution in Northeast China are also similar to the fossils in the outlines of the pinna, the pinnules and the sori, especially the variance of sori. The pinnules of these living species are arranged in katadromic order at the base of pinnae and in anadromic order after 4-5 pinnules upwards as in present fossils. In *A. filix-femina,* the pinnule arrangement is shown on several specimens from the United States, Sweden, Poland, Switzerland and China. The sporangia of the living *Athyrium* are elliptic or globular, about 200 µm in diameter (Pl. 7, fig. 6), with stalks of 180-200 µm long. The stalks consist of 3 files of cells. The annuli are vertical type and composed of 13-16 thickened cells. But the annulus of *A. filix-femina* extends up to the stalk (Pl. 7, fig. 2). The spores are monolete as that of the fossils but their exine or perine are usually sculptured with granules (Pl. 7, fig. 5).

Dryopteris, a monolete spore fern, is close to the present fossils on the basis of morphology of frond, pinnae and somewhat pinnules, but its sori and indusia are typically circular or rounded-kidney shaped. The kidney-shaped indusium is usually with a sinus on its back. Moreover, the exine or perine of spores are commonly sculptured with rugulae (Zhang *et al.,* 1976; Wu & Ching, 1991).

In *Asplenium,* the sori are typically elongate or crescent-shaped and therefore can be distinguished from *Athyrium*.

A specimen of an ultimate pinna from the latest Cretaceous-Early Tertiary deposits of Northeastern Washington, America, was described as *Athyrium gracilium* Pabst (Pabst, 1968). Its pinnules are much larger than that of the present specimens. The specimen differs greatly from the extant *Athyrium* in having elongate sori. *Polypodites polysorus* Prynada from the Omusukchan, Russia (Samylina, 1976; pl. 12, figs 1-3) possesses crescent or hook-shaped or elongate sori as those of *A. hailariaenum*. An Early Cretaceous fossil from south Primorie, Russia identified as *Asplenium samylina* Krassil. (Krassilov, 1967; pl. 21, figs 1-7) is characterized by its rounded hook or crescent-shaped sori as well as those of *Athyrium hailariaenum*. The specimens both from Omusukchan and South Primorie probably belong to *Athyrium*.

Eogymnocarpium sinense Lee et Yhe (Li *et al.,* 1986) referred to Athyriaceae has similarities with the present specimens on the outline of leaves, but differs from *Athyrium* in its rounded or elliptic sori, oblique annuli and a wide range of spores (48-128 in number). Moreover, its pinnules are larger than that of the present specimen.

PALAEOECOLOGY

The studied specimens mainly belong to the flood-plain or lacustrine facies sediments, such as mudstone and muddy siltstone. Most of them were preserved as single leaf and in very few cases several leaves preserved together.

The fossils are usually found in association with fern like *Acanthopteris gothanii* Sze, *Coniopteris concinna* (Heer) Chen *et al.*, *Cladophlebis* spp. and gymnosperms such as *Pterophyllum liaoningense* Meng et Chen, *Nilssonia* spp. and *Ginkgo manchurica* (Yabe et Oishi) Meng et Chen. This indicates that the remains of *Athyrium* were not preserved in the original place where they were growing. But since the fossils are well preserved, they had not been tansported for a long distance before being fossilized. As the pinnae are typically arranged at quite wide intervals, the basal pinnae are usually asymmetrical and the fronds commonly in triangular shape. *Athyrium* is possibly a shade loving fern probably living in woodlands.

According to the palaeomagnetic study, the Early Cretaceous *Athyrium* has only been discovered in Northeastern China and Russia. Northeastern China is close to the present area in latitude in the Early Cretaceous (Fan, 1990) and belongs to the temperate phytogeographical province and in the temperate zone (Chen *et al.*, 1988; Chen, 1990). The vegetation is dominated by Ginkgoales and long leaf Coniferales. Meanwhile, *Athyrium* has also not been found in lower latitude areas, such as North China and South China which represent semiarid or hot-dry palaeoclimate in Early Cretaceous. According to the palynological information, the distribution of dispersed monolete spores from the Lower Cretaceous was controlled by temperate-humid climate in time and space (Deng, 1995). They were mainly distributed in Northeast China. Consequently, the Early Cretaceous *Athyrium* is possibly a thermophilic and hygrophilous fern.

The extant *Athyrium*, having more than 200 species, are typical temperate ferns distributed in the temperate zone and high mountains in the subtropics. Most of them live in woodlands in the Himalayan area, China and Japan, especially the mountain areas of Yunnan, Southwest China. The type species *A. filix-femina* is widespread especially in moist woodlands, along stream banks and in rainy region extending to a considerable altitude on mountains (Page, 1982). The ecological characters of early *Athyrium* are similar to the living genus.

ACKNOWLEDGEMENT

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REFERENCES

Chen F, Meng XY, Ren SQ & Wu CL 1988. *The Early Cretaceous flora of Fuxin Basin and Tiefa Basin, Liaoning Province.* Geological Publishing House, Beijing.

Chen F 1990. Early Cretaceous palaeobotanic provinces of China and adjacent regions. *In :Tectonopalaeogeography and Palaeobiogeography of China and adjacent regions* : 336-347 China Univ. of Geosci. Press, Wuhan.

Chen F, Deng SH & Ren SQ 1993. Two new species of the Early Cretaceous fern *Athyrium* Roth. *Acta* **35**(7): 561-566.

Ching RC 1964. On some confused genera of the Family Athyriaceae. *Acta Phytotax.sin.* **9**(1): 41-84.

Copeland EB 1947. *Genera Filicum.* Chronica Botanica Co., Waltham, Mass.

Deng SH 1991a. Early Cretaceous fossil plants from Huolinhe Basin in Inner Mongolia. *Earth Sci. J.Graduate School, China Univ. Geosci.* **5**(2): 147-156.

Deng SH 1991b. Early Cretaceous floras from Huolinhe Basin, Inner Mongolia, Tiefa Basin and Fuxin Basin, Liaoning Province. Studies on species, palaeosynecology and climatic events in Early Cretaceous. *Ph.D. Thesis* (unpublished).

Deng SH 1992. New materials of Filicopsida of the Early Cretaceous flora from Tiefa Basin, Liaoning Province. *Earth Sci. J.China Univ. Geosci.* **17**(1): 7-14.

Deng SH 1995. Characteristics of the Late Mesozoic monolete ferns from China and their palaeoclimatic, evolutionary significance. *Geol. Rev.* **41**(2): 39-47

Fan DJ, Guo YB, Tang XD & Yu GH 1990. Mesozoic paleomagnetic study of the North China. *Int. Symp. Tectonic Evolution and Dynamics of Continental Lithosphere. The Third All China Conference on Tectonics, slected papers* (II): 182-192. Science Press, Beijing.

Hsieh YT 1986. The classification of *Athyrium* Roth. *Bull. bot. Res.* **6**(4): 129-135.

Krassilov VA 1967 *Early Cretaceous flora of South Primorie and its significance for stratigraphy.* Nauka, Moscow.

Li XX, Ye MN & Zhou ZY 1986. *Late Early Cretaceous flora from Shansong,* Jiaohe, Jilin Province, NE China. *Palaeontologia Cathayana* **III**: 1-143.

Pabst MB 1968. *The flora of the Chuckanut Formation of Northwestern Washington: The Equisetales, Filicales and Coniferales.* Univ. of California Press, Berkeley, Los Angeles.

Page CN 1982. *The ferns of Britain and Ireland.* Cambridge Univ. Press.

Samylina VA 1976. *The Cretaceous flora of Omsukchan (Magadan District).* Komarov Bot. Inst., Nauka, Leningrad.

Wu SH & Ching RC 1991. *Fern families and genera of China.* Science Press, Beijing.

Zhang XC 1992. Taxonomy of *Athyrium* Roth Subgen. *Athyrium* in Yunnan. *Acta Phytotax. sin* **30**(3).

Zhang YL *et al.* 1976. *Sporae Pteridophytorum Sinicorum.* Science Press, Beijing.

TWENTY FOURTH BIRBAL SAHNI MEMORIAL LECTURE

Plant tissue culture and biotechnology

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Plant tissue culture has progressed steadily ever since its inception in 1902. The initial experiments related to various tissues that could sustain prolonged in vitro conditions. The differential response of the cultured tissues under variable chemical milieu provided the necessary impetus to utilize the technique in a profitable manner. Over the years efficacy of the technique became apparent when noticeable in vitro morphogenic responses could be used to unravel the mysteries of growth and differentiation. Expectedly, therefore, any morphogenic event expressed in vitro could be correlated to the specific components of the nutritive medium.

By 1970s the applicability of the technique came to be realized with the possibility of exploring somatic hybridization, micropropagation of recalcitrant species, haploid and triploid plants, and finally genetic manipulations. Today, plant tissue culture has become an integral part of biotechnology and is being routinely employed for the improvement of crops and legumes—the back-bone of human nutrition that can also aid in the amelioration of malnutrition of millions of sufferers. The ultimate success with the transfer of 'nif'-gene to non-leguminous plants would help save millions of dollars in chemical fertilizers which can then be profitably used for the welfare of the human race.

Key-words—Tissue culture, Haploids, Triploids, Micropropagation, Fertilization Control, Biotechnology.

IN the following description the genesis of the technique as conceived by the German scientist Haberlandt (1902) and the present status of plant tissue culture and its role in biotechnology is elaborated. Plant tissue culture is a rapidly advancing area of research, and it is possible to control growth, development and differentiation of almost all parts (explants) of plants on suitable nutrient media (many exceptions). From the beginning of the 20th century, orchid propagation through culture of seeds and plant parts has been a thriving profession (see Prakash & Pierik, 1993).

HISTORICAL

In 1902, Haberlandt (Figure 1) suggested the concept of totipotency of plant cells. He himself did not succeed in culturing plant cells, but predicted that on appropriate nutrient media the cells will divide, grow and differentiate. His predictions have been amply justified and demonstrated (see Johri, 1971).

Discoveries made in the 1930s by P.R. White (Figure 2), R.J. Gautheret (Figure 3) and P. Nobécourt laid the foundation for further work in tissue culture. In 1934, Gautheret succeeded in culturing cambial

Figure 1 — G. Haberlandt (Germany) — Father of Plant Tissue Culture. For the first time he cultured isolated tissues and organs.

Delivered by B.M. Johri on November 14,1994, at the Birbal Sahni Institute of Palaeobotany, Lucknow. I (BMJ) feel honoured for the invitation to deliver the 24th Professor Birbal Sahni Memorial Lecture.

Figure 2—P.R. White (Maine, NY, USA). Initiated the technique of continuous culture of explants on a defined chemical medium that provided the necessary impetus for successful culture of several other explants. He also formulated the culture medium used by various investigators.

cells of tree species including *Salix capraea* and *Populus nigra*, and observed their proliferation for a few months, on Knop's solution containing glucose and casein hydrolysate (CH). He (Gautheret, 1939), for the first time, established continuously-growing tissue cultures from carrot and Jerusalem artichoke root cambium. At the same time, White (1939) also reported the establishment of such cultures from tumour tissue of the hybrid *Nicotiana glauca* x *N. langsdorfii*. Similar results were obtained independently by Nobécourt (1937). In subsequent years further research carried out on other plants was also supportive of the concept of totipotency. Vimla and Hildebrandt (1965; Figure 4) demonstrated the totipotency of isolated single cells of tobacco that regenerated plantlets in cultures.

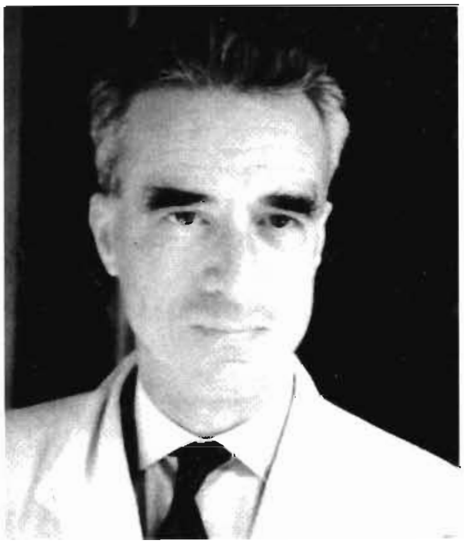


Figure 3—R.J. Gautheret (Sorbonne, Paris). Cultured lateral meristem and established the continuous culture procedure.

Figure 4—A.C. Hildebrandt (Wisconsin Univ., Madison, USA). Successfully demonstrated single cell suspension culture and its ultimate regeneration into plantlets.

In 1975, Skoog (Figure 5) and Miller suggested that the differentiation of various organs is under the controlled mechanism of exogenously supplied hormones to the medium. Later, with Murashige (1962), the most widely used medium was formulated.

Nitsch (1951; Figure 6) also formulated the nutrient medium for in vitro culture of selected explants. He could achieve success in culturing isolated ovaries and anthers.

One of the most striking features of plant tissue culture has been the isolation and fusion of protoplasts (Cocking, 1972). The important practical application of protoplast culture/somatic hybridization was successfully applied to tobacco and other plants by Melchers (1977; Figure 7). He demonstrated the fusion of protoplasts of tomato and potato. The hybrid developed and produced flowers and fruits called 'pomato', and the suckers 'topato', the latter were thick and flat, full of starch grains (equivalent of potato).

A few biotechnological studies during yesteryears may be mentioned. Pasteur (1866; see Purohit 1994), the famous French Scientist and a great

Figure 5—F. Skoog (Wisconsin Univ., Madison, USA). Discovered Kinetin and (alongwith Murashige) formulated the most extensively used culture medium that has proved successful for the induction of morphogenic response in various explants. Skoog (alongwith Miller) also demonstrated the appropriate ratio of auxin and cytokinin for selective regeneration of shoots, roots or both.

saviour of human suffering, was approached by the French wine-makers seeking his advice to prevent the contamination of wine. Pasteur discovered that if the broth was maintained at a specific temperature, bacterial contamination did not occur. Thus, the wine industry was saved.

Figure 6—J.P. Nitsch (Gif-Sur-Yvette, France). Besides the culture of ovaries, he also accomplished haploid regeneration through anther culture. The medium formulated by him is used in the in vitro culture of selected explants.

Figure 7— G. Melchers (Max Planck Institute, Tubingen, FRG). Besides several other achievements, he suggested the concept of somatic hybrids that could blend the economic features of two useful species; the concept of 'pomato' and 'topato' was proposed.

An English bacteriologist, Alexander Fleming (1929; see Irving & Herric, 1949) was working (in a London hospital) on *Staphylococcus* and *Streptococcus*. After a short holiday, when he returned to his laboratory, he noticed that in a particular petri dish the bacterial colonies looked unhealthy and were fringed by a somewhat semi-transparent area. From the contaminated colonies, Fleming was able to prepare an extract to contaminate fresh bacterial colonies. He reached the correct conclusion that the extract was antibacterial. The extract when administered to a female patient in the hospital arrested bacterial infection which caused bed-fever after child birth. It took almost four years when the organism, which restricted the growth of bacteria, was identified as *Penicillium;* its metabolic product as 'Penicillin'. After several years an organization was set up at Rome for industrial production of Penicillin; the collaborators were Florey and Chain. For this life-saving drug, Sir Alexander Fleming, Sir Howard W. Florey and Ernst B. Chain shared the Nobel Prize in 1945.

Another biotechnical episode relates to Tamiya (1959)—a Japanese physiologist, who set up a large-scale centre (near Tokyo) for the commercial culture of *Chlorella*. *Chlorella,* in 1950s and 1960s, was considered to be an excellent source of protein for human needs. After harvest, the small-scale experimentally produced *Chlorella* was dehydrated, decolorized, deodorized and powdered. For a trial, the *Chlorella* powder was used as a filler in cookies for human consumption. The people who ate the cookies never felt any unusual taste or smell. Finally, Tamiya set up an industrial plant (with large, open tanks filled with liquid nutrient medium) that proved unsuccessful due to recurrent contamination.

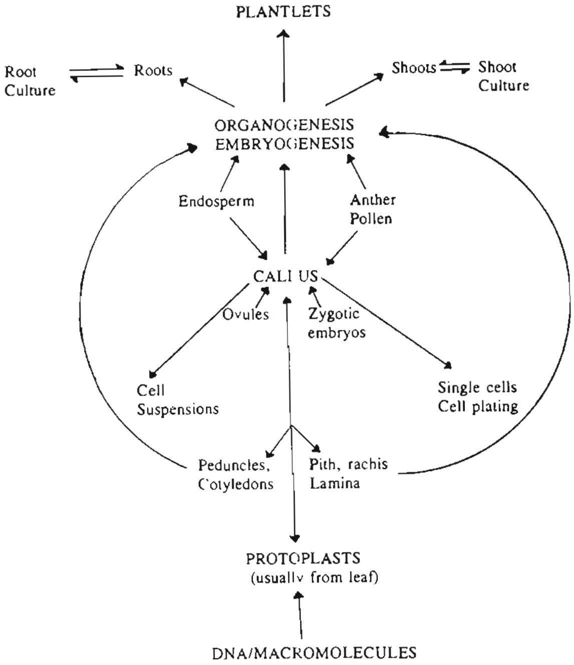
In 1950s and 1960s, Tulecke (1957; USA) succeeded in a mass suspension culture of pollen-derived cells of *Ginkgo*. The tube nucleus in the pollen grain divided and the daughter nuclei also divided ad infinitum. In spite of all efforts, there was no differentiation of tissues and organs.

Nitsch (France) also raised a mass culture of cells of the edible part of apple but the cells lost all the sugar they had at the beginning and no further sugar was synthesized in the cells (Pers. comm.). The usual storage product in cultured cells is starch; rarely oil.

There has been considerable work on the tissue and organ culture of bryophytes, pteridophytes (excellent material for experimental studies) and gymnosperms. A very spectacular example is the growth and differentiation of the excised young embryos of the fern, *Todea barbara*. This is the only fern known in which the egg and younger proembryos can be isolated from the venter of the archegonium and independently cultured. The growth and differentiation was comparable to in vivo growth and development (DeMaggio & Wetmore, 1961).

Maximal attention has been devoted to the growth, development and differentiation of organs, tissues, cells, and protoplasts of flowering plants (Angiosperms). These are cultured on suitable nutrient media — liquid media (stationary or agitated), and on semi-solid (gelled with agar) media. The glassware for culture, media, and explant (plant part for culture), must be fully aseptic. The cultures are grown under controlled temperature, light and humidity. The mass culture of cells and tissues is utilized to obtain chemicals (secondary metabolites; some used as medicines) and a large number of regenerants for large-scale propagation of plants (see Razdan, 1995).

When organs and tissues are cultured, the cells divide and often form a callus (mass of undifferentiated cells). The callus can be grown (by repeated sub-cultures) for as long as one desires. The callus differentiates and produces roots, shoots and plantlets (see Text-figure 1). The latter can be transferred to pots, and then to the field (see Srivastava & Steinhauer, 1981a, b). Using plant tissue culture technique, disease-free *Chrysanthemum, Dianthus, Solanum tuberosum* (see Quack, 1977), and disease resistant and transgenic (genetically engineered) tobacco (see Prakash & Pierik, 1993) plants have been developed. In cultures the explant may or may not produce callus, embryos, roots, shoots, and plantlets. The determining factor is the nutrient media on which the culture is raised. Through plant tissue culture, it has now become possible to obtain food additives such as carotenoids from *Daucus*, betamine from *Beta* and crocin from *Crocus;* metabolites of food, for example, capsicin from *Capsicum* and stevioside from *Stevia* (see Ravishankar &



Text-figure 1—In vitro propagation. Various manipulations through tissue culture technique (after Mantell *et al.*, 1985).

Venkataraman, 1993), products of medicinal value, and in addition, in the improvement in processing for enhancement of quality and quantity of food products, and bio-pesticides (see Berlyn, 1984; Beiderbeck & Knoop, 1988).

Presently, almost every University and many Research Institutes are engaged in plant tissue culture research. It is now possible to grow all types of young and mature cells, and tissues and organs of different plants on appropriate nutrient media. In some cases if the explants are not amenable to culture, it is usually due to deficiency in the medium and suitable stage of development and physiological status of the explant.

NUTRIENT MEDIA

The nutrient media contain a number of major and minor inorganic salts, organic compounds to provide nitrogen and carbon, growth promoters—auxins, cytokinins, gibberellins, and complex organic compounds like casein hydrolysate, yeast extract and coconut water (milk). If aseptic conditions are not maintained all through the period of growth, the cultures become infected with bacteria and fungi. Such cultures have to be promptly discarded.

Depending on the endogenous level of metabolites, some tissues grow on simple media containing only organic salts and a carbon source. But most tissues require vitamins, amino acids and growth substances. The commonly used media are those devised by White (1954), Murashige and Skoog (1962), Nitsch (1969), and others. For every tissue the most promotive medium has to be selected.

Quite often the investigators use undefined medium. As soon as the growth and differentiation has been attained by omitting one or more ingredients, a defined nutrient medium can be formulated so that any further omission of any ingredient will affect growth and differentiation. For the multiplication of agricultural and horticultural crops, forest trees, medicinal plants, and others, nutrient media have to be synthesized in relation to the age of explant, and maximal growth and differentiation in minimal time.

The multiplication of selected elite clones from the specific parent lines in *Eucalyptus* and *Tectona* (Gupta *et al.*, 1980,1981), or from the hybrids, is obtained through micropropagation or somatic embryogenesis. The production of disease-resistant and disease-free regenerants, improved varieties of plants and hybrids are all included in 'Biotechnology'.

The tissue culture procedures permit the study of physiology, genetics, molecular aspects, and effects of specific nutrients (individually and collectively). In some instances low temperature treatment of explants (before culture) results in much better growth and differentiation as in anther cultures of a number of species (see Srivastava & Johri, 1988).

With a short incubation period (after implanting the explant on nutrient media), the superficial cells—especially the injured cells at cut ends of the explant—divide and redivide forming a mass of cells (callus). In many cases the callus does not differentiate, but differentiation can be brought about by transferring the undifferentiated tissue to root and shoot-forming media, leading to differentiation of plantlets such as in *Artemisia, Delonix* and others (Gulati *et al.*, 1996; Gupta *et al.*, 1996).

OVARY CULTURE

To study the precise requirements for fruit development and fruit physiology, Laibach and Kribben (1949) devised a method by which young flowers or fruits of *Cucumis sativus* could be excised and grown under aseptic conditions on a nutrient medium.

Following the first attempt by LaRue (1942), considerable success has been achieved in culturing the pollinated ovaries (Figure 8) of several species (Sachar & Kanta, 1958; Johri & Sehgal, 1966; Guha & Johri, 1966). In culture the ovaries often fail to grow into full-sized fruits (in the restricted space of culture vial). Ito (1961, 1966) developed a partial sterile

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Abbreviations used—Ad - Adenine; BAP6 - benzylamino purine; BM - Basal medium; CH - Casein hydrolysate; 2,4 - D - 2,4 - dichlorophenoxyacetic acid; GA - Gibberellin; IAA - Indole-3 - acetic acid, IBA - Indolebutyric acid; 2-ip-2 isopentenyl adenine; KN - Kinetin; M - Molar; MS - Murashigê and Skoog's medium; NAA - L naphthalene acetic acid; Wk/s - Week (s); WM - White's medium; YE - Yeast extract.

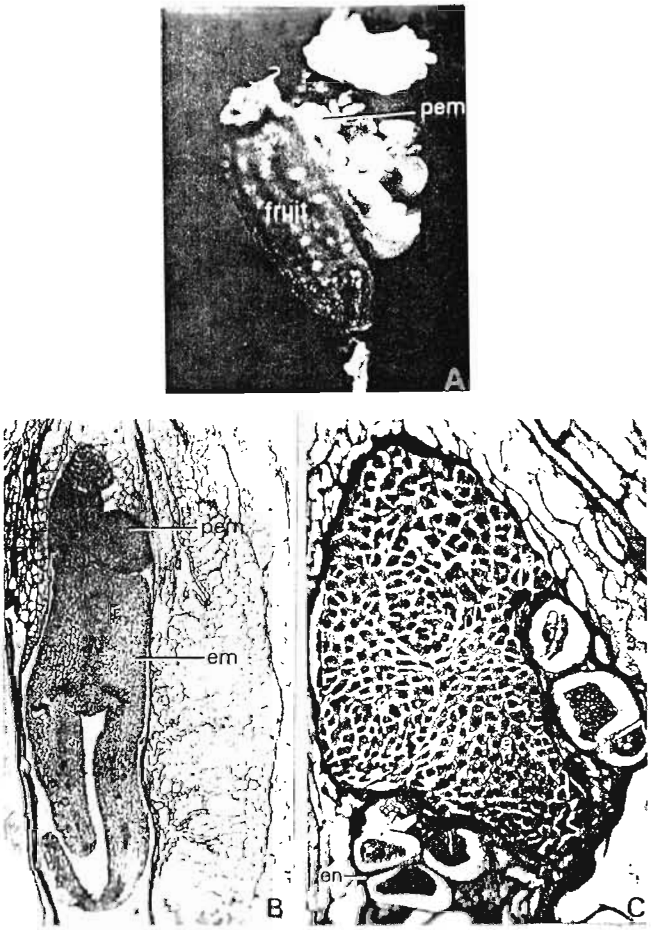


Figure 8— A-C *Anethum graveolens*, ovary culture. **A.** Ruptured fruit, 20 wks after inoculation and BM+YE (500 mg/1), shows a polyembryonal *(pem)* mass; **B.** 5-wk-old culture (longisection mericarp), grown on BM +CH (1000 mg/1.) shows mature embryo *(em)* and accessory proembryos *(pem)*; **C.** longisection of upper part of mericarp, 4 wks after inoculation, cultured on BM+CH (1000 mg 1), shows five proembryonal masses, note endosperm *(en)* cells (after Johri & Sehgal, 1963.)

culture technique to overcome this problem. The ovary cultue has dual objectives; to obtain viable hybrids from normally unsuccessful crosses, and to overcome seed dormancy (Tukey, 1938). Subsequently, various growth factors which influence the in vitro culture of ovary have also been studied (Rau, 1956; Sachar & Kanta, 1958; Chopra, 1962). Significant role of floral organs in fruit development has been emphasized by several workers (P. Maheshwari & Lal, 1961; Chopra, 1958; Guha & Johri, 1966).

Ovary culture has been successfully employed to overcome various other impediments such as the failure of pollen germination on the stigma, or the slow and insufficient growth of pollen tube, as well as precocious abscission of flower (Rao, 1965; Shivanna, 1965). Through ovary culture technique, polyembryony could also be induced successfully in various species (Johri & Sehgal, 1966; Sehgal, 1972; Mitra & Chaturvedi, 1972). The culture of ovaries of apomicts has helped in understanding the nature of stimulus provided by pollination. Investigations on ovary culture revealed two important aspects: (a) detached ovaries are capable of autonomous growth and bear fertile seeds, and (b) growth pattern in vivo and in vitro is comparable (Rangan, 1982).

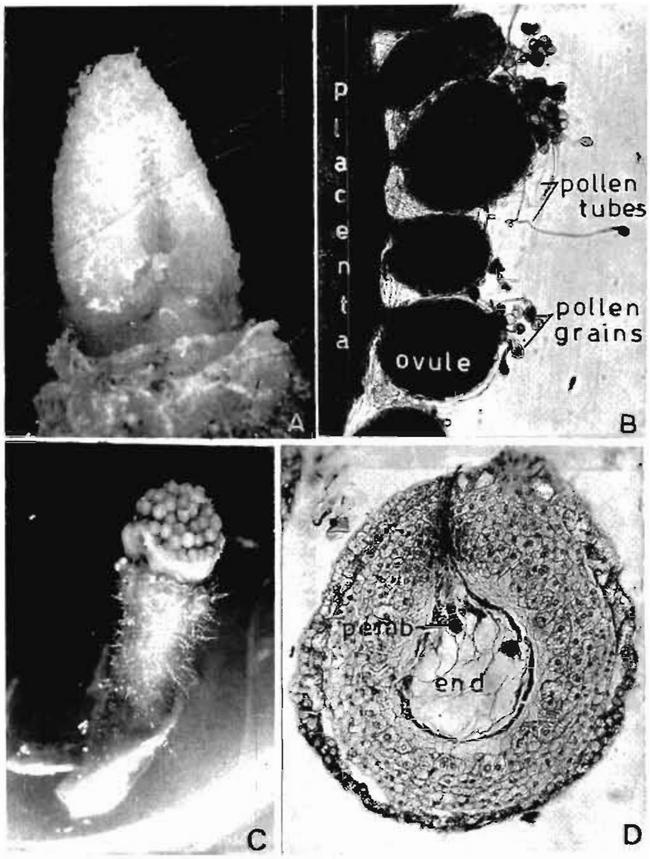


Figure 9—A-D. *Petunia axillaris*, placental pollination. **A.** Both placentae of ovary with its entire mass of ovules dusted with pollen; **B.** free-hand transection through self-pollinated placentae, 24 days after culture; note marginal portion of one placenta, four ovules, many pollen grains and pollen tubes; **C.** 24 days after placental, self-pollination; note mature seeds; **D.** longisection of young seed, 7 days after self-pollination; note the proembryo *(pemb)* and endosperm *(end)*. (after Rangaswamy & Shivanna, 1971).

OVULE CULTURE

In comparison to ovary culture, not much attention has been paid to ovule culture. The first report on ovule culture dates back to 1932 when White cultured the ovules of *Antirrhinum;* he obtained haploid callus. LaRue (1942) was unsuccessful in obtaining mature seeds through ovule culture of *Erythronium.* The first successful report of ovule culture leading to fertile mature seeds is by Nirmala Maheshwari (1958) in *Papaversomniferum.* She cultured the fertilized ovules of *P. somniferum* on a nutrient medium containing kinetin and observed that kinetin triggered the growth and differentiation of embryo in ovule. However, this initial rate of growth was not maintained for long and the length of embryos in cultured ovule was less than that of embryos in nature. The additive role of placental tissue in the growth and maturation of seeds has been emphasized by Chopra and Sabharwal (1963) in pollinated ovlues of *Gynandropsis gynandra.*

The growth of embryo is related to the age of the ovule at culture (Siddiqui, 1964; Guha & Johri, 1966). Eid *et al.* (1973) concluded that the difference in the rate of growth is associated with the developmental stage of endosperm present in the ovule in culture. This has also been demonstrated that the osmotic concentration has a significant influence on the growth of excised embryos (Mauney, 1961; P. Maheshwari & Rangaswamy, 1965). In 1971, Uchimiya obtained haploid callus by culturing unfertilized ovules of *Solanun melongena.* This opens up new vistas in regeneration of haploid plants of maternal origin.

The major contribution on ovule has been test-tube pollination and fertilization (Kanta *et al.,* 1962; Kanta & P. Maheshwari, 1963; P. Maheshwari & Kanta, 1964). The work on culture of ovule and seeds of angiospermic parasites (Rangan & Rangaswamy, 1968) enables unravelling the intricacies of host-parasite relationship and development of embryos in seeds that are shed at immature stage. For plant breeders ovule culture can be an indispensible tool in obtaining seedlings from crosses which are normally unsuccessful because of abortive embryos. Similarly, success with test-tube fertilization opens up new avenues in hybridization programmes, specially in overcoming incompatibility barriers.

NUCELLUS CULTURE

Besides zygotic embryos, the adventitious embryos are also of much value since they are genetically uniform and reproduce the characters of maternal plant/parent without inheriting the variations brought about by gametic fusion. In addition, embryos originating from the nucellar tissue in *Citrus* are not only of help in obtaining virus-free plants but also of great advantage in citri-culture for propagating desirable varieties.

Through tissue culture technique, factors affecting the formation of adventitious embryos have been studied. Nucellar embryony has been reported from a natural polyembryonic species of citrus *(C. monocarpa)* by Rangaswamy (1958). He concluded that 'freed from the restraining influence of the integuments and grown on a suitable medium the nucellar tissue of *Citrus monocarpa* becomes activated to unlimited growth, and yields a continuous supply of nucellar embryos". Bitters *et al* . (1972) extended these studies to several other mono- and polyembryonic, as well as seedless varieties of *Citrus.*

Through a series of experiments on nucellar embryony, it has been concluded that the lack of stimulus of pollination and /or fertilization can no longer be considered as a limiting factor for nucellar embryogenesis (Button & Bornman, 1971; Mitra & Chaturvedi, 1972).

Most of the studies focus on nucellar culture of both mono- as well as polyembryonic type of *Citrus* varieties. Attempts to induce nucellar embryony in *Luffa cylindrica* and *Trichosanthes anguina* (Rangaswamy & Shivanna, 1975) have been unsuccessful. Nucellar polyembryony has been induced in *Vitis vinifera* (Mullins & Srinivasan, 1976) and *Cynanchum vincetoxicum* (Haccius & Hausner, 1976). All these taxa do not show natural polyembryony.

Although several embryos and plantlets can be obtained from a single cell of nucellus, the percentage of success varies from species to species. To make the technique more viable and widely applicable, it is advisable first to study the physiological changes underlying embryogenesis. To induce adventive embryony in those plants in which it does not occur in nature, and its control in those plants in which it exists as a normal feature, offers a challenging problem.

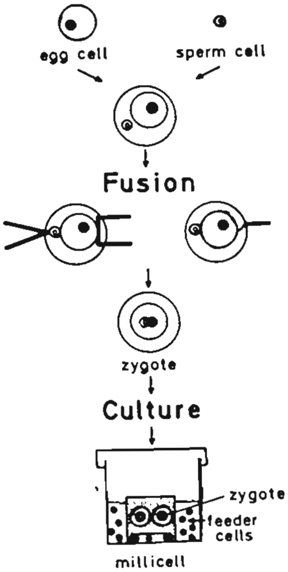
IN VITRO POLLINATION AND FERTILIZATION

The fusion of male and female gametes to form a zygote serves as a very valuable source of new combinations of genetic material. Through tissue culture technique it has become possible to overcome natural incompatibility, and to introduce new characteristics of genetic information from more distantly-related species, thus widening the gene pool (Kranz & Lörz, 1993).

For fertilization at the single cell level, the isolation of viable gametes is prerequisite. The gametes are genetically coded so that new genetic combinations occur in zygotes, and the embryos. These progenitor cells are therefore the most useful source for studies in embryogeny. Using floral explants, ovaries, ovules and mature pollen coupled with embryo rescue (Stewart, 1981), in vitro pollination (including placental pollination) and fertilization have been achieved leading to the production of new hybrids (Zenkteler, 1990). In vitro-formed zygotes have 'natural competence' for division (Figure 9) and can be used for understanding the cell cycle and differentiation.

The fertilization process at the cellular level relates to isolation of sperms and egg cells. This has been achieved by various workers in *Nicotiana, Torenia, Zea* and *Plumbago.* Successful attempts have also been made for artificial fertilization in *Torenia* by injecting sperm cells directly into the embryo sac. Through this technique, effects of non-gametic cells on the development of artificially produced zygote can also be expressed effectively.

Kranz and Lörz (1994) have studied (Figures 10-11; Text-figure 2) in vitro fertilization through fusion of isolated protoplasts of single egg and sperm cell of maize in a mannitol solution (400-430 mosmol/kg H_2O) containing 0.05 M $CaCl_2$ at pH 11.0 followed by cell division of the fusion product (the zygote). The electrofusion-mediated in vitro fertilization using isolated gametes is a logical extension of this work (Kranz & Lörz, 1990; Kranz & Dresselhas, 1996; Kranz *et al.*, 1991).



Text-figure 2—*Zea mays,* electrofusion-mediated in vitro fertilization. Isolated sperm and egg cells were transferred to fusion droplets, and pairs of gemetes were fused electrically after dielectrophoretical alignment on one of the electrodes. For culture, the fusion products were transferred individually to "Millicell" in sets surrounded by feeder cells (after Kranz *et al.*, 1991:courtesy Kranz).

The detection of development of specific gene in only one or a few reproductive cells or zygote (via PCR-polymerase chain reaction), and also the transfer of foreign genes into gametes (via electroporation), as well as into zygotes (via microinjection), also

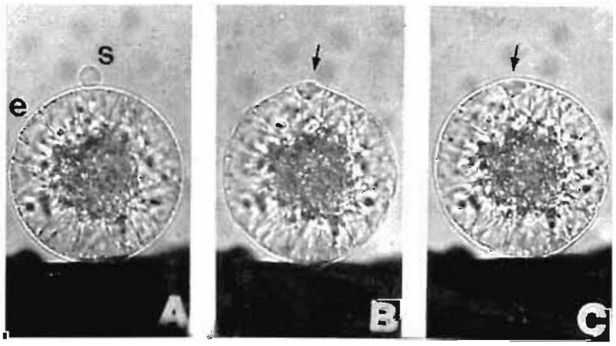


Figure 10—**A- C** *Zea mays,* fusion of sperm *(s)* cell protoplast and egg cell *(e)* protoplast in a 400 mosmol mannitol solution containing 0.05 M $CaCl_2$ at pH 11.0; bar=10 μm. **A.** Adhesion of the egg *(e)* and the sperm *(s)* cell protoplast; **B.** fused egg cell protoplast and sperm cell protoplast; **C.** microcallus (after 5 days of fusion) (after Kranz & Lörz, 1994; courtesy: Kranz).

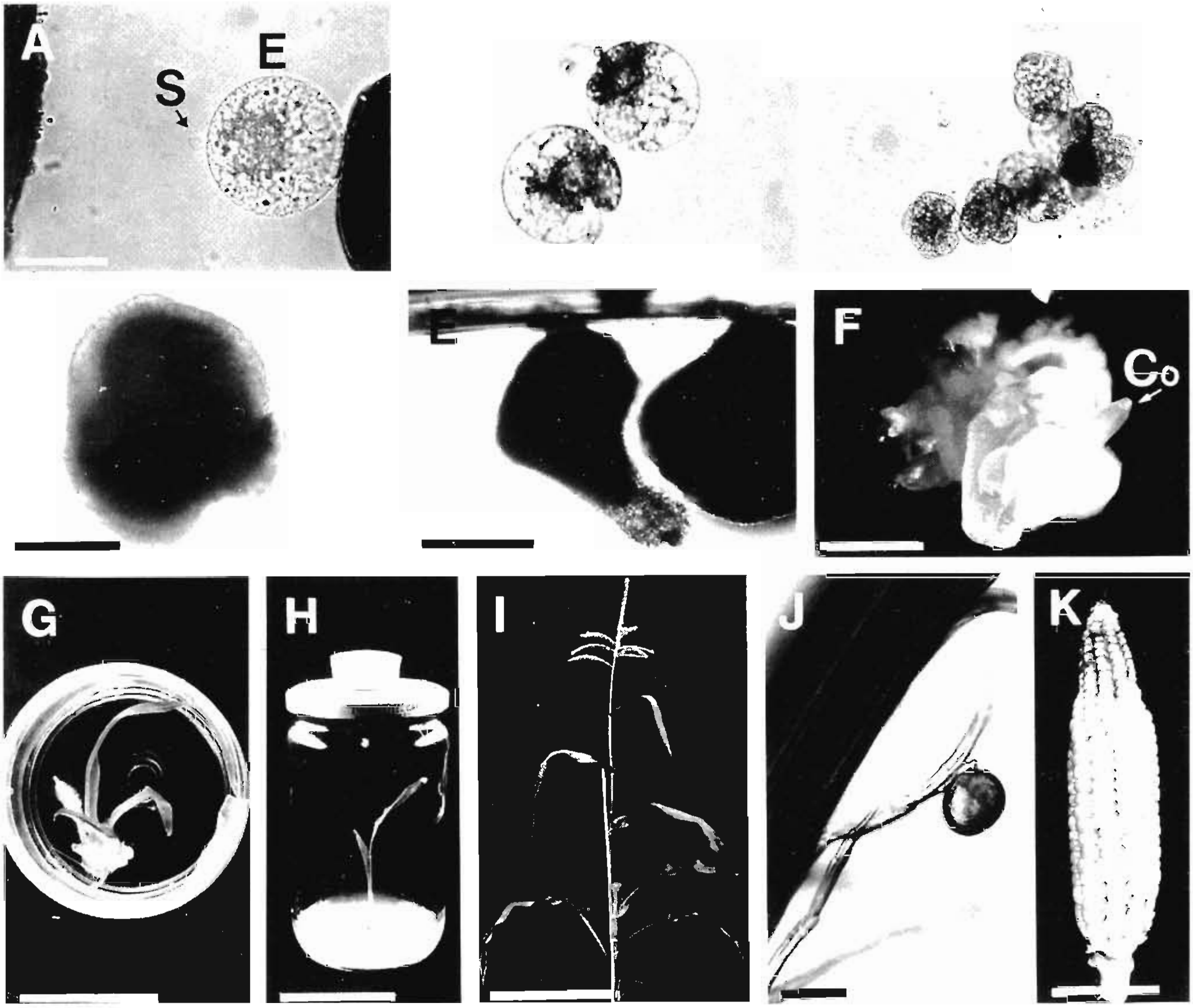


Figure 11—A-K. *Zea mays,* in vitro fertilization, through electrofusion. **A.** Alignment of egg cell protoplast (E) with a sperm cell protoplast (S); bar-50 cm; **B.** first cell division (after 42 hrs of fusion); **C.** multicelled structure (after 5 days of fusion); bar- 100 cm; **D.** polarized multicellular structure with an outer cell layer at one pole, and vacuolate cells at the other end (after 12 days of fusion); bar-200 μm; **E.** transition-phase embryo (after 14 days of fusion); bar-200 μm; **F.** compact white and green tissue, arrow indicates coleoptile *(Co)*(after 30 days of fusion); bar-4 mm, **G.** plantlets after 35 days of fusion; bar-2 cm; **H.** plantlet after 39 days of fusion; bar-6 cm; **I.** flowering plantlet after 39 days of fusion; bar-6 cm; **J.** self-pollination, one hour after pollen grain deposition, the pollen tube penetrated the red-colored trichome, the grain contents move into the style; bar-100 μm, **K.** cob after 148 days of fusion; bar-4 cm (after Kranz & Lörz, 1993; courtesy Kranz).

appears to be promising (Kranz *et al.*, 1991), as synchronized single cells can be used.

Besides, transmission of alien cytoplasm to study biparental inheritance of cytoplasm-determined characters, has also been achieved through the above method. However, in higher plants using non-electrical approaches are necessary to study cell-cell interaction: adhesion, fusion, and recognition (Russell, 1992; Chasan, 1992; 1993; Goodman, 1993; Faure *et al.*, 1993).

Regeneration as well as karyology of complete plantlet via zygotic embryogenesis of single maize zygote produced by in vitro fusion of isolated single gametes has already been reported by Kranz and Lörz (1993). With the cultivation of in vitro-formed zygote, transformation becomes the first priority.

Figure 12—*Quercus lebani*, embryo culture. Differentiation of embryoids from cultured middle segment of embryos on MS + IAA (2.0 ppm) + 2-ip (5.0 ppm) + adenine sulphate (30.0 ppm) + CH (1000 ppm), 8-wk-old (unpublished; courtesy Srivastava).

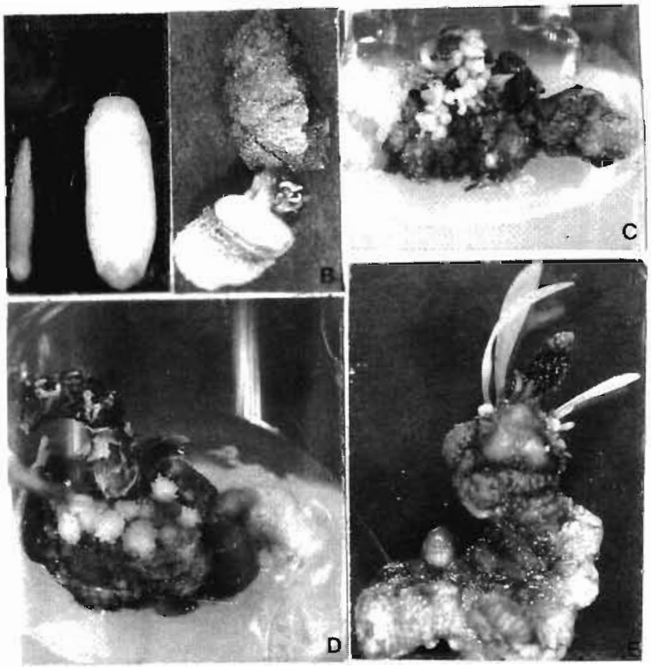


Figure 13—A-E *Dendrophthoe falcata*, embryo culture. **A.** Mature embryo without and with endosperm; **B.** 10-wk-old embryo grown on WM + IAA (1 ppm) +YE (500 ppm) shows callused cotyledons (upper region); also note the proliferated radicular end (basal region); **C.** 10 (right side) and 20-wk-old (left side) callus on WM + IAA (0.5 ppm) + CH (500 ppm) shows a large number of papillate structures; **D.** 15-wk-old proliferated seedling with buds from embryo cultured with the endosperm; **E.** 20-wk-old seedling shows a large number of accessory leaves (after Johri & Bajaj, 1963).

Subsequently, it would then be possible to manipulate gametes individually (prior to their fusion), thus opening up a new field of study in experimental embryology and biotechnology.

EMBRYO CULTURE

Interest in embryo culture dates back to the work of Hannig (1904). He cultured embryos (of different age) of *Raphanus* spp. and *Cochlearia danica* and obtained transplantable seedlings. Embryo culture provided information on the physiology of development and growth of the embryo.

A stimulus for further progress in this field was provided by Laibach (1925) who demonstrated the use of this technique in all those crosses where viable seeds are not formed. He suggested to excise the embryos and grow them in a nutrient medium.

The embryo culture technique has been utilized for raising hybrids of unsuccessful crosses. Hybridity of the surviving plantlets reared by embryo culture has been established through karyotype mapping, and isozyme profiles. The technique has also been utilized for the induction of polyembryony as in *Quercus* (Figure 12) and *Dendrophthoe* (Figure 13). The technique of embryo culture has also been successfully employed in raising plants from interspecific or intervarietal crosses as in *Lilium* (North, 1975), *Allium* (Doezel *et al.*, 1980), *Solanum* (Sharma

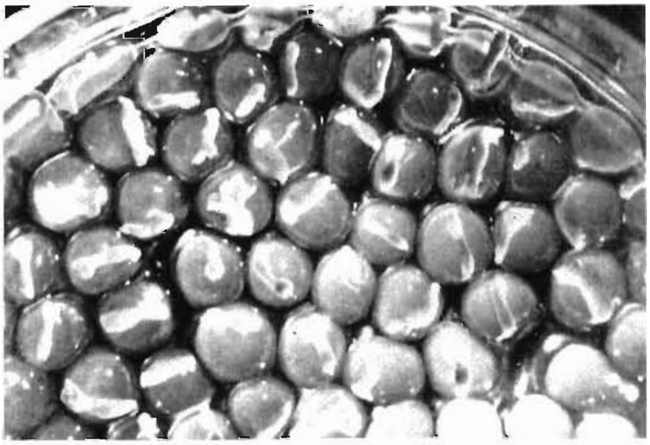


Figure 14—Synthetic seeds. Embryos of alfalfa encapsulated in alginate beads. Each capsule is 4-6 mm in diameter and contains one embryo (after Fuji *et al.*, 1987)

et al., 1980), and cherry (Ivanicka & Pretova, 1980), and intergeneric hybrids *Triticum* and *Aegilops* (Cheuca *et al.*, 1977), barley and rye (Pickering & Thomas, 1979), and wheat and rye (Taira & Larter, 1978).

Morphogenesis of cultured embryos is significantly influenced by the exogenous supply of growth regulators. Both indolebutyric acid (IBA) and α-naphthalene acetic acid (NAA) increase the number of roots in the embryo of *Iris* (Stoltz, 1977). This technique has proved useful in comparison of growth rate of embryos developing in vivo and in vitro, and physiological and biochemical changes in the developing seeds.

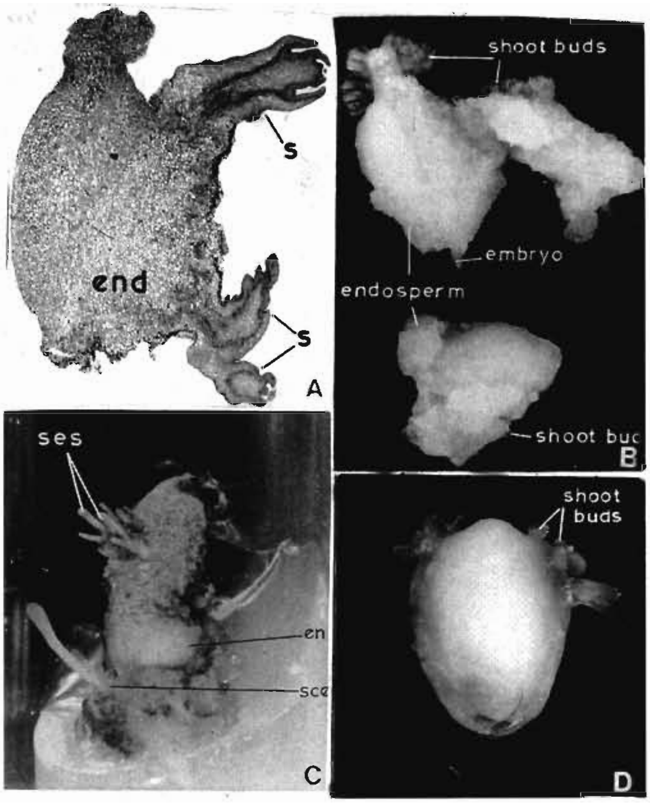


Figure 15—A-D. Endosperm culture. **A.** *Exocarpus cupressiformis*, section of endosperm (*end*) with differentiated shoot buds (*s*) on WM + IAA (2.0 ppm) + KN (5.0 ppm) + CH (500 ppm), 6-wk-old (after Johri & Bhojwani, 1965); **B.** *Leptomeria acida*, differentiation of shoot buds in 12-wk-old sub-cultured endosperm callus on WM + IAA (2.5 ppm) +KN (5.0 ppm) + CH (1000 ppm) (after Nag & Johri, 1971); **C.** *Dendrophthoe falcata*, 15-wk-old culture with shoot and many leaves, on WM + IAA (5.0 ppm) + KN (10.0 ppm) + CH (1000 ppm) (after Nag & Johri, 1971); **D.** *Taxillus vestitus*, 8-wk-old culture of endosperm-half on WM + BAP (2.0 ppm) (after Nag & Johri, 1971).

SYNTHETIC SEEDS

Synthetic or artificial seeds are encapsulated (originally only the somatic embryos produced in tissue cultures) in a synthetic polymer coating which functions as 'endosperm' and seed-coat (Figure 14). Besides the somatic embryos, now even the 'vegetative regenerants/propagules' capable of developing into a complete plantlet, shoot meristems, apical and axillary shoot buds of *Mentha arvensis* and *Morus indica* and callus-derived adventitious buds can also be encapsulated as in *Atropa belladonna, Dioscorea floribunda* and *Hyoscyamus muticus.* This is a new concept which is applicable even to crops which are not seed-sown (see Shekhawat *et al.*, 1995).

The encapsulating agents are agar, polyox, alginate, gelrite, carageenasa, polyacrylamide, nitrocellulose and ethylcellulose. Sodium alginate is commonly used due to its solubility at room temperature and formation of a complete permeable gel with calcium chloride (see Prakash & Pierik, 1993). The 'beads' (synthetic seeds) can be stored at 4°C in dark in sterile dry petri plates sealed with parafilm. For germination, the beads are rinsed with sterile water, and surface dried.

The production of synthetic seeds of somatic embryos enclosed in a protective covering has been proposed as a 'low-cost-high-volume' propagation system. The inherent benefits of this system are inbuilt in the production of a large number of somatic embryos, and the use of conventional seed-handling technique for embryo delivery (see Prakash & Pierik, 1993).

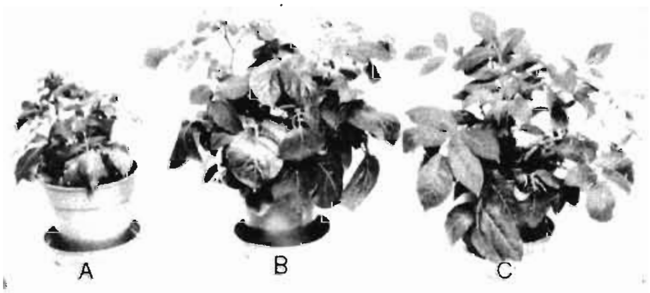


Figure 16—A-C. *Solanum* sp., interspecific hybrid. **A.** S. *tuberosum*, dihaploid parent (24 chromosomes); **B.** tetraploid somatic hybrid (48 chromosomes); **C.** *S. brevidens*, diploid parent (24 chromosomes). (after Jones, 1988).

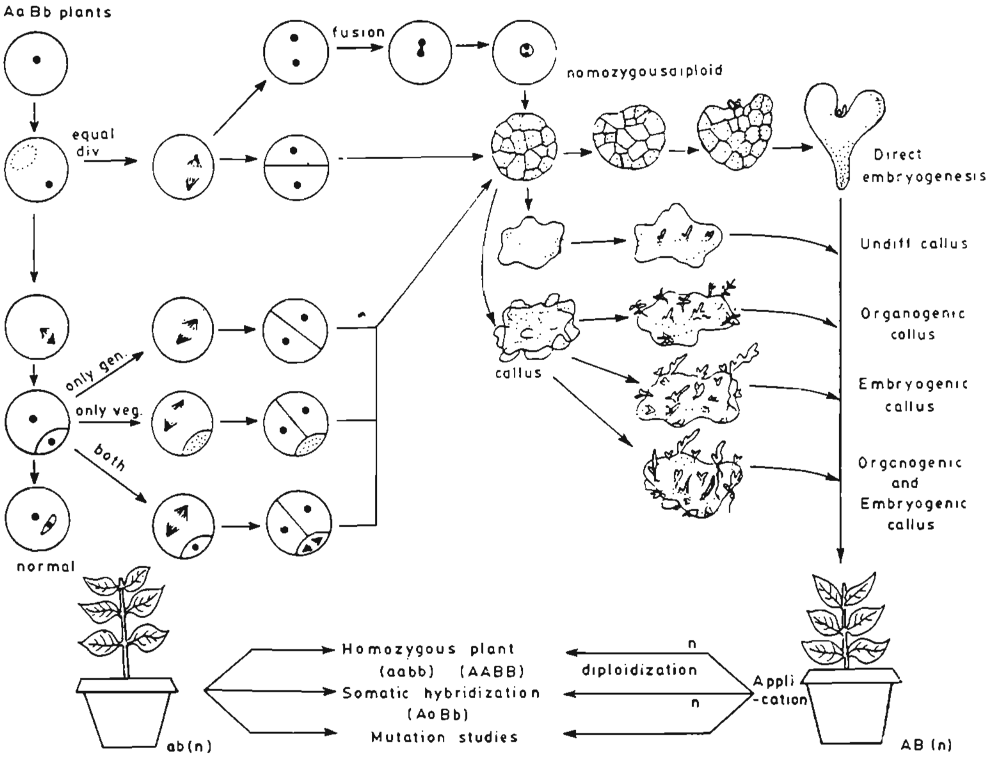
The synthetic seeds have a distinct advantage over micropropagation, such as economy, space, culture medium, time and expenditure, allow easy transportation, transplantation, and storage, and conservation of propagules (see Shekhawat *et al.*, 1995).

HAPLOID PLANTS THROUGH ANTHER/ POLLEN CULTURE

The haploid plants are of great value for breeding and study of fundamental genetics of higher plants. In angiosperms haploid cells are present only in anthers and ovules. The anthers, carrier of progenitor of male gametes, are much easier to excise. Starting from a single cell and ending in a whole organism passing through a series of cell divisions and differentiation, the microspores have now been shown to be totipotent (Text-figure 3).

The culture of pollen grains of higher plants was first attempted by C.D. LaRue (1954). Since then the totipotent nature of pollen grains has been exploited with varying success. The first successful differentiation of haploid plants was reported by Sipra Guha and S.C. Maheshwari in 1964 in anther cultures of *Datura innoxia* and *D. stramonium.* Subsequent studies have aimed at optimizing the different physical and chemical factors for obtaining maximal number of plantlets from pollen (in the cultured anthers). Besides other factors (physical and chemical), prechilling treatment of the flower buds is essential for successful regeneration of plantlets from pollen. Generally, pollen cultured prior to or after the first mitosis, give a positive response by producing typical embryoids or callus masses. During embryogenic process, the pollen either divides into two unequal cells (vegetative and generative) and both or only one of them takes part in the development of embryoid/plantlet, or the pollen divides into two equal cells, and the derivatives of both cells contribute in plantlet formation (Text-figure 3; Srivastava & Johri, 1988).

Androgenesis occurs when a microspore or pollen grain is induced to shift from a gametophytic



Text-figure 3—Anther culture. Differentiation of embryoids from pollen grains, possible pathways in embryogenic pollen grains, and utilization of regenerated haploid plantlets (*DIV*—division, *GEN*—generative cell, *VEG*—vegetative cell, *UNDIFF*—undifferentiated) (after Srivastava & Johri, 1988).

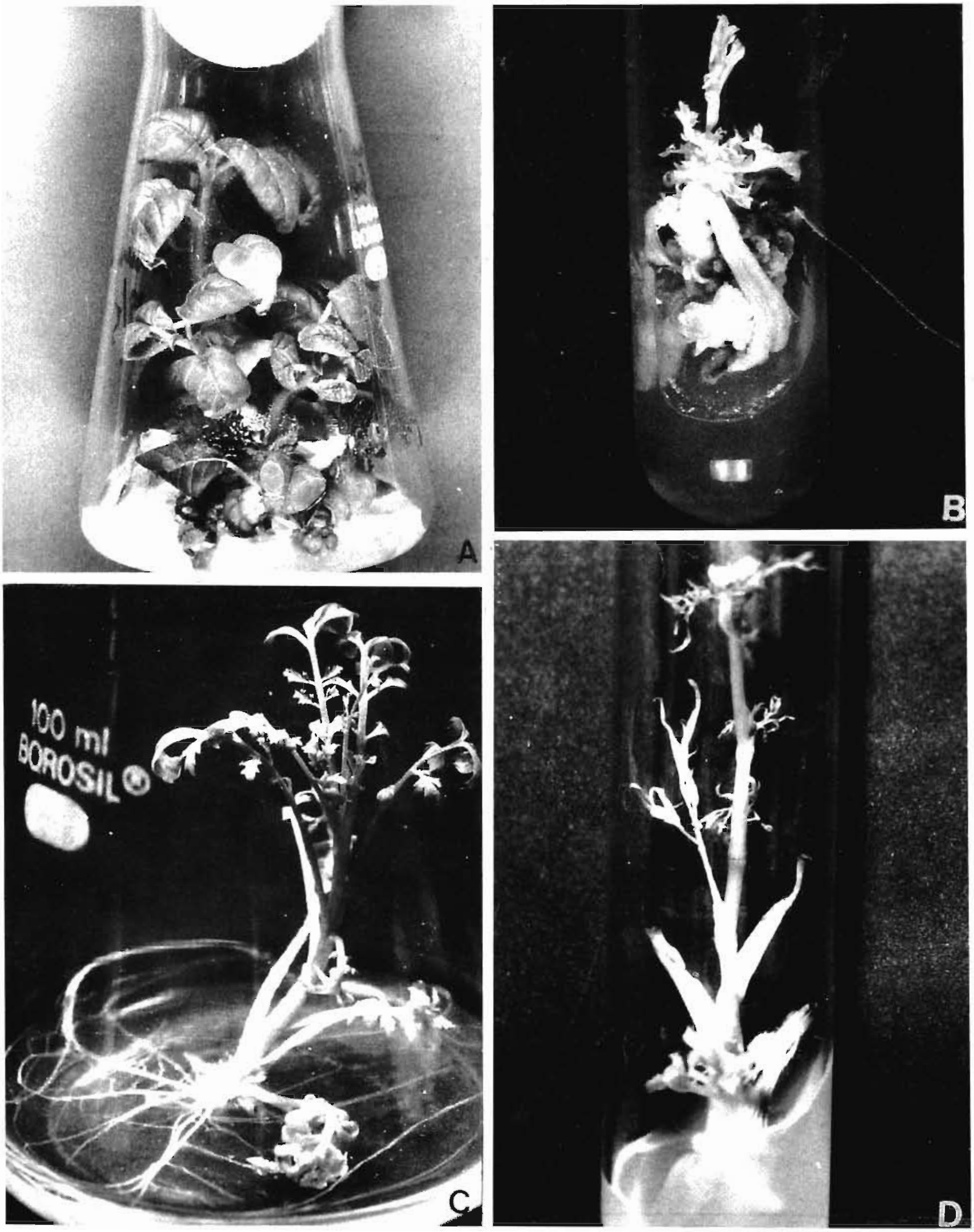


Figure 17—A-D. In vitro multiplication of medicinal plants. **A**. *Datura innoxia*, 12-wk-old androgenic cultures on MS + glutamine (100 ppm); **B**. *Ammi majus*, 6-wk-old regenerated callus on MS + IAA (0.5 ppm) + KN (2.0 ppm) + adenine (40 ppm) + CH (500 ppm); **C**. *Lepidium sativum*, 8-wk-old plantlet on MS + IBA (0.1 ppm); **D**. *Ammi majus*, 12-wk-old plantlet with flower buds, on MS + glutamine (100 ppm). (A, after Srivastava *et al.*, 1993; B,D, after Purohit *et al.*, 1995; C, after Pande *et al.* unpublished).

to sporophytic pathway. The single-celled pollen grains represent an ideal system to analyze the embryogenic process in angiosperms. Since the haploids contain only one set of chromosomes, the genes present, even the recessive ones, are expressed in phenotype. However, through diploidization of these haploids, homozygous and fertile *Nicotiana* are readily obtained, enabling the selection of desirable gene combinations. Employing this technique, four breeding lines of tobacco differing in alkaloid yield (Collins *et al.*, 1974), and homozygous recombinants of *Hyoscyamus niger* with enhanced alkaloid content, have been obtained (Corduan & Spix, 1978).

Androgenic haploids and the homozygous diploids are of much interest to plant breeders and geneticists. In the production of new mutant forms, haploids provide excellent material for experimentation as in *Nicotiana tobacum* (Nitsch, 1969) and *Brassica napus* (Hoffmann, 1978). Yet another application in one-step transfer of genotypes of inbred lines into cytoplasm that causes male sterility has been observed in haploids of cereals, e.g., maize (Goodsell, 1961; Kermicle, 1973).

Factors controlling pollen embryogenesis of higher plants (Vasil & Nitsch, 1975) can be studied by culturing the isolated microspore. The technique ensures the production of more isogenic progenies in *Nicotiana tabacum* than anther culture and, therefore, is more efficient in mutagenic studies (see Vasil, 1980).

After the discovery of pollen haploids, 35 years ago by Guha and SC Maheshwari and its great utility in breeding programmes, the advances in this area have been rather spectacular. The main obstacle, however, facing anther cultures is the lack of response from pollen grains of several crop plants and other species of economic importance. To overcome the problem, Wernicke *et al.* (1978) developed a technique for the isolation of potential embryogenic

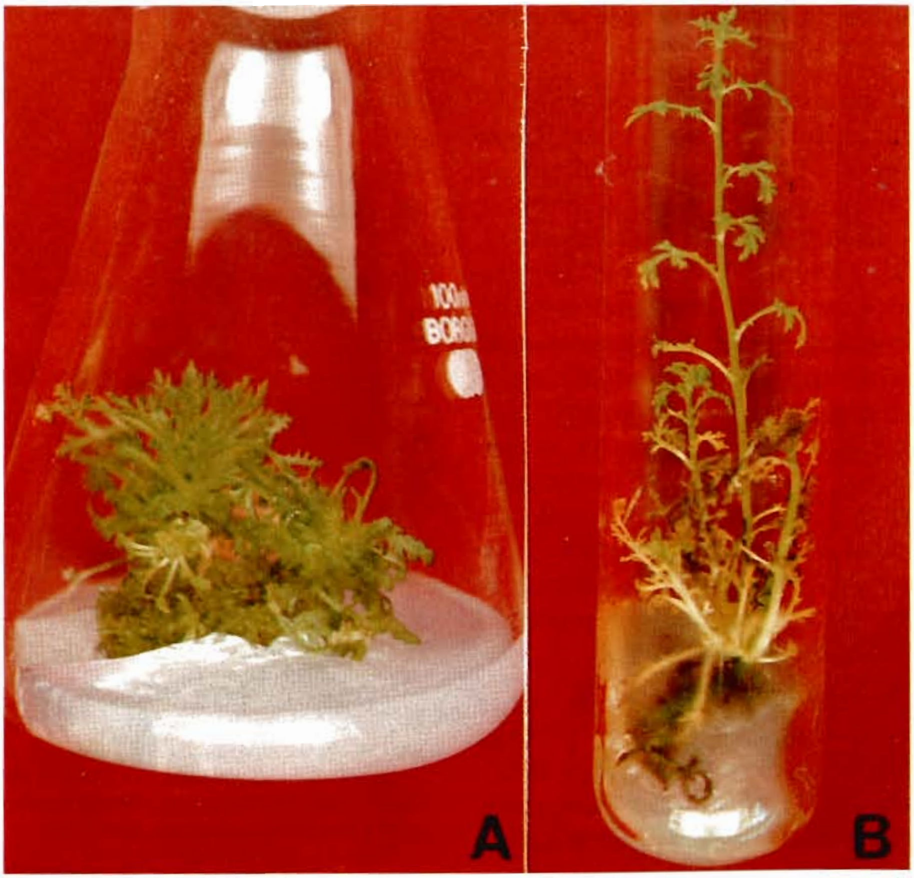


Figure 18—A-B. *Artemisia annua, micropropagation.* **A.** Multiple shoot differentiation on MS + BAP (3.0 ppm) + G^3A_3 (0.1. ppm) **B.** direct regeneration from flower buds on MS + NAA •0.1 ppm) + BAP (3.0 ppm) (after Gulati *et al.*, 1996).

pollen grains of *Nicotiana* from the microspore population which enhances the haploids in low-yielding species.

ENDOSPERM CULTURE

Unlike gymnosperms, the development of nutritive tissue (endosperm) in angiosperms is postponed until after fertilization (triple fusion) and is usually triploid. Improper development of endosperm may lead to the abortion of embryo as it has a direct and dynamic influence on the differentiation of embryos. The first report on the culture of endosperm of maize is by LaRue (1947); only callus developed but differentiation did not occur.

While investigating the factors affecting the growth of endosperm, the essentiality of nitrogen source other than minerals was also realized. It was confirmed that casein hydrolysate (CH) or yeast extract (YE) are essential supplements for the endosperm culture of *Cucumis* (Nakajima, 1962). The level of cell organization in the developing endosperm has indicated a regulatory role in callus formation.

The culture of mature endosperm is more responsive than the immature endosperm (see Figure 15). Most of the reports on endosperm culture are from semi-parasitic angiosperms. A few autotrophic taxa subsequently provided good results (Bhojwani, 1966; Masuda *et al.*, 1978). In cultures the differentiation of root, shoot, haustoria and plantlets establish the totipotency of the triploid endosperm tissue. The failure of mature endosperm to proliferate, if cultured without the embryo, emphasises the concept of 'embryo factor'. Srivastava (1971) has shown that the 'embryo factor' can be replaced by pretreatment of endosperm with GA_3. For example, in *Scurrula* and *Taxillus* shoots emerge directly from the endosperm explant (see Johri, 1971) whereas in *Jatropha* and *Putranjiva* regeneration is preceded by callusing (see Srivastava & Johri, 1978).

Organ differentiation in endosperm cultures has been demonstrated in parasitic (see Johri, 1971) as well as autotrophic species: *Croton* (Bhojwani, 1966), *Jatropha* (Srivastava, 1971), *Putranjiva* (Srivastava, 1973), *Oryza* (Nakano *et al.*, 1975), apple (Mu *et al.*, 1977) and other taxa.

Shoot buds differentiate directly without prior callusing in the cultured mature endosperm of semi-parasitic taxa as in *Scurrula* and *Taxillus*. In the autotrophic members, the endosperm usually forms a callus mass followed by the differentiation of shoot buds or roots, as in *Jatropha* and *Putranjiva* .

The only reports on the differentiation of roots and plantlets from the callus of the immature endosperm are in rice (Nakano *et al.*, 1975) and apple (Mu *et al.*, 1977).

PROTOPLAST CULTURE AND SOMATIC HYBRIDS

Since isolated protoplasts are generally free from one another, they constitute the nearest possible

Figure 19—A-B. *Betula pendula*. **A.** Shoot bud culture to show regeneration of numerous plantlets after 8 wks on MS + IAA (2.0 ppm) + BAP (5.0 ppm) + Ad (20.0 ppm); **B.** leaf culture to show differentiation of a number of leafy shoots, after 5 wks on MS + NAA (2.0 ppm) + Zeatin (2.0 ppm) + Ad (30.0 ppm) (after Srivastava & Steinhauer, 1981a).

approach to isolate cell suspension of higher plants and, as such, are increasingly used in several areas of plant cell biology. The most promising use of protoplast culture is the production of genetically-engineered plants involving the fusion of protoplasts from different genetic backgrounds, and regeneration into an intact hybrid plantlet exhibiting the characters of both parents (Figure 16). Somatic cell fusion or 'parasexual hybridization' is a novel approach to develop rare hybrids of sexually incompatible and sterile parents. Cocking and his group at Nottingham (England) demonstrated the use of $NaNO_3$ in protoplast fusion. The production of heterokaryon was first reported by Power *et al.* (1970), from maize. A critical factor in studies on induced-fusion between two unrelated protoplasts relates to the 'selective markers' to identify the heteroplastic fusion products.

The successful production of a mature interspecific hybrid plant *(Nicotiana glauca* X *N. langsdorfii)* by fusion of leaf protoplasts has been reported by Carlson *et al.* (1972). Melchers *et al.* (1978) could raise intergeneric hybrid, the so-called 'pomato' and 'topato', between potato (*Solanun tuberosum)* and tomato *(Lycopersicon esculentum)*. The hybrid flowered and fruited, and the fruits resembled tomato. Instead of the usual 'round' potato tubers, however, the underground 'suckers' were thick and elongated and stored abundant starch. In this case the analysis of ribulose triphosphase carboxylase proved to be a convenient marker to demonstrate the hybrid nature of the plant.

Quite recently, the scientists at the University at Solan (India) have produced a hybrid between tomato *(Lycopersicon esculentum)* and 'Shimla mircha' (*Capsicum frutescense)*. Rattan and Sharma–the two agricultural scientists, have produced this hybrid. The new hybrid is tolerant to early blight and brick-eye rot. These investigators claim that the hybrid could be grown in the plains and mid-hills. Rattan also points out that the 'hybrid' has a thick skin and stands better transportability.

L. Zenkteler (Poznan, Holland) using in vitro pollination and fertilization, obtained an intergeneric hybrid between *Melandrium* and *Nicotiana*. Further studies have not been attempted.

DISEASE-FREE PLANTS

Plants are prone to systemic infection with fungi, bacteria and viruses, and are also attacked by insects, pests and nematodes. A clean and healthy stock can be used for propagation through conventional means, but can be difficult and costly. Plant tissue culture eliminates these systemic diseases in *Begonia, Carnation, Asparagus* and *Prunus*, etc. (see Quak,1977; Prakash & Pierik, 1993) but do not guarantee freedom from diseases.

The first step in obtaining disease-free culture is to ensure that the mother plant (from which explants are taken) does not have any disease symptom.

Theoretically, the use of antibiotics seems feasible to overcome the contamination problems. But unfortunately, plant tissues are sensitive to antibiotics and show variable responses according to their genotype. The damage is mainly to the plastids or mitochondria within the plant cells (Zamski & Umiel, 1978), and prolonged exposure of cells or tissues to antibiotics can result in the development of resistance through mutation in cytoplasmic genes or cytoplasmic DNA (Maliga *et al.*, 1973; Umiel & Goldner, 1976). In other cases antibiotics increase the growth rate of cultured tissues, sometimes in a spectacular way. Such results have been reported with penicillin (see George & Sherrington, 1984), streptomycin and tetramycin (Nickell, 1952), and phosphomycin (Phillips *et al.*, 1981).

There is a variable concentration of virus in the cells of an intact plant with the assumption that apical shoot and root meristems may contain scanty or no virus at all, micropropagation is used as an effective means of removing virus infection. This can be achieved by culturing apical meristem or nucellus as in *Citrus* (see Prakash & Pierik, 1993).

GENETIC STABILITY

The physical make up and appearance of a plant (its phenotype) is governed by its genotype (genetic constitution) and the maintenance of genetic constitution of a particular clone is (so-called genetic stability) an important factor in tissue culture. Besides, occasionally originating from genetically variable mother plant tissue, genetic variation may arise directly in culture. Endoreduplication is more prevalent in cultures that have been maintained for a long period.

Another reason is the failure of spindle formation during mitosis or the occurrence of abnormal multipolar instead of usual bipolar spindles. Synthetic plant growth regulators are implicated in

Figure 20—A-D. *Delonix regia,* regeneration from leaf callus. **A.** Compact green callus after 8 wks on MS + NAA (0.1 ppm) + BAP (3.0 ppm); **B.** shoot initiation after 10 wks on MS + NAA (0.1 ppm) + BAP (3.0 ppm); **C.** multiple shoot differentiation after 6 wks on MS + IAA (2.0 ppm) + KN (5.0 ppm); **D.** further growth of regenerants on MS + IBA (1.0 ppm) (after Gupta *et al.,* 1996).

Figure 21—P. Maheshwari (Univ. of Delhi). He initiated in vitro studies at the Department of Botany, University of Delhi, and helped many institutions to undertake such studies. He and his group, for the first time, suggested the technique of in vitro pollination and fertilization; and also guided work on in vitro culture of various reproductive organs.

inducing genetic changes in tissue cultures (see Thorpe, 1980).

Genetic variation, the somaclones have been induced by tissue culture. Also, new strains of plants from callus, 'calliclones', have been generated. A gradual increase in the proportion of cells with a typical chromosome complements is considered to be one of the main reasons why tissue cultures of many plant species lose regeneration ability with progressive age (see Bayliss, 1980).

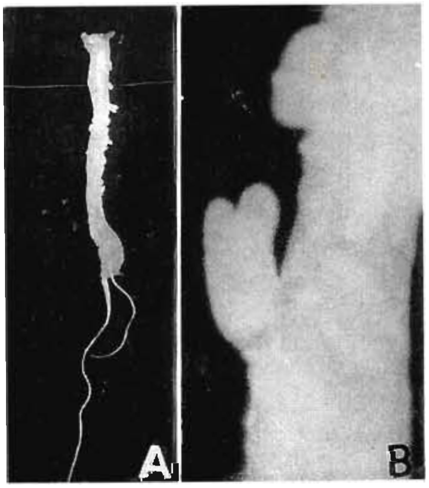


Figure 22—A-B. *Ranunculus sceleratus,* shoot bud culture. **A.** regenerated plantlet, stem studded with embryoids; **B.** part of stem with fully-differentiated dicotyledonous embryo (after Konar & Nataraja, 1969).

To overcome this problem one has to monitor the phenotypic, cytological and molecular level characteristics, and ascertain their correlation with the phenotypes at an early stage. Suspected variations at an early stage can be screened by various means, i.e., chromosome counts in mitotic cell, measurement of the DNA per cell, chloroplast counts in stomatal guard cells, measuring stomatal size (de Klerk, 1990), through isozyme and protein patterns (O'Connel *et al.,* 1986; Karp *et al*., 1987; Kobayashi, 1987; Maheshwaran & Williams, 1987). Such tissues/ plants become eliminated from the clone. Maintaining genetic stability is the quintessential factor in meeting the ever-rising demand of in vitro-raised plants of economic value.

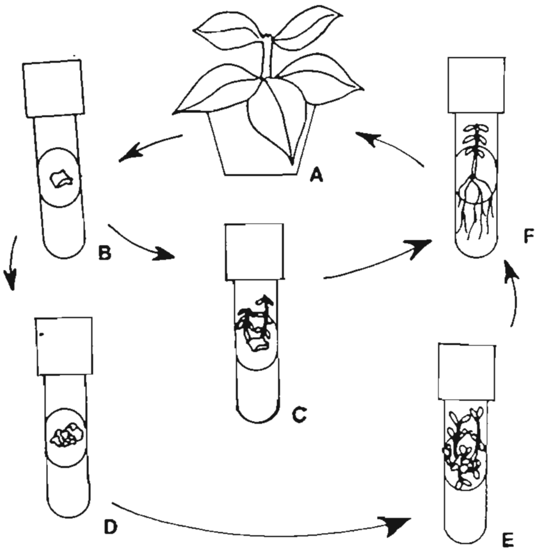
APPLICATIONS

The use of plant tissue culture for the production of industrial products has long been of much interest: drugs, breweries, milk products, flavours, fragrances, essential oils, pigments, sweetners and others. These chemicals are the secondary metabolites produced during culture. Plant cell cultures have advantages, as compared to intact plants (Figures 17, 18; Text-figure 4). The rate of cell growth in cultures and biosynthesis of chemicals is quite high in a short period. Suspension culture is a very effective mechanism of incorporating precursors into cells than in whole plants. Natural sources for the manufacture of these products are not enough to meet the ever-growing need of industrial production, although it has been possible to exploit the technique for large-scale production of selected plants (Figures 19, 20; Text-figure 5). Bioreactors are now being utilized to grow mass culture of cells.

The industrial potential of plant cell cultures is unlimited and will be exploited more and more as the years go by (see Prakash & Pierik, 1993; Razdan, 1995). A fairly large number of industrial concerns have been established in India and abroad, to exploit the in vitro culture methods for commercial benefits.

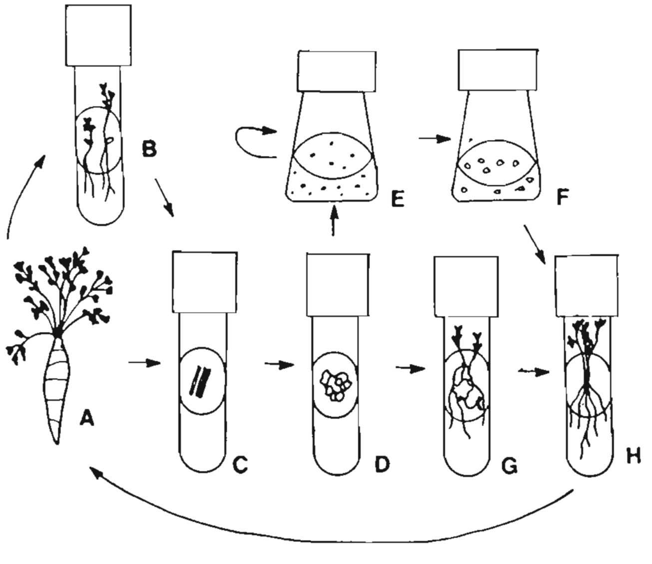
PLANT TISSUE CULTURE STUDIES AT THE UNIVERSITY OF DELHI

At the Department of Botany, University of Delhi, tissue culture researches were started in 1955-



Text-figure 4—A-F. *Nicotiana tobacum*. **A.** Plant grown in green-house; **B.** leaf section inoculated on nutrient medium; **C.** shoot differentiation directly from the epidermal cells explant on medium containing 1M BA (but no 2, 4-D); **D.** differentiation of callus from leaf section cultured on agarized nutrient medium containing 4.5 M 2, 4-D; **E.** shoot developed from the callus transferred to medium containing BA (but no 2, 4-D); **F.** fully differentiated plantlets on harmone-free medium (after Tisserat, 1985).

56, under the leadership of Professor P. Maheshwari, FRS (Figure 21). The investigations mainly related to test the efficacy of the technique in morphogenic expression of various explants. In *Cuscúta* (Baldev, 1959) the vegetative shoot apex could be transformed into floral apex by controlling light/dark regime.



Text-figure 5—A-H. *Daucus carota,* Somatic embryogenesis. **A.** Carrot plant; **B.** seedling; **C-D.** callus develops in 4 wks; **E-F.** suspension culture from callus; in liquid medium (without 2,4-D), somatic embryos differentiate; **G.** callus and plantlets on agarized medium, on transfer to medium without 2,4-D also produces somatic embryos and plantlets; **H.** rooted plantlets (after Tisserat, 1985).

In vitro pollination and fertilization was demonstrated by P. Maheshwari and Kanta (1964) in *Eschscholzia* and *Argemone* spp., and Shivanna (1965) in *Petunia*. In due course normal seeds with endosperm and embryo are produced (see Shekhawat *et al.,* 1995). Several workers from the Botanical Institute, Prague (Czechoslavakia), and Zenkteler (Poznan, Poland) worked at the Delhi University to familiarise themselves with the in vitro pollination and fertilization techniques. Later at Poznan, Zenkteler (1970) successfully raised intergeneric hybrids between *Melandrium album* (Caryophyllaceae) and *Datura innoxia* (Solanaceae).

During 1956-1966, the pollinated ovaries of several plant species including *Aerva tomentosa, Anethum graveolens, Foeniculum vulgare, Hyoscyamus niger* and *Tropaeolum majus* were successfully cultured (Shekhawat *etal.,* 1995). Chopra (1962) reported development of parthenocarpic fruits, of the same size as obtained in vivo, from unpollinated ovaries of *Althea rosea* cultured on modified Nitsch's nutrient medium (NM) with IBA (20mg/1) or kinetin (KN) (0.5mg/1). With the success in ovary culture it became possible to culture ovules at even earlier stages. Nirmala Maheshwari (1958) obtained mature seeds of *Papaver somniferum* by culturing excised ovules containing zygote or two-celled pro-embryo. Sachar and Kapoor (1959) cultured pollinated and unpollinated ovules of *Zephyranthes.* The stimulatory role of placental tissue in the growth of ovules of *Gynandropsis gynandra* was demonstrated by Chopra and Sabharwal (1963).

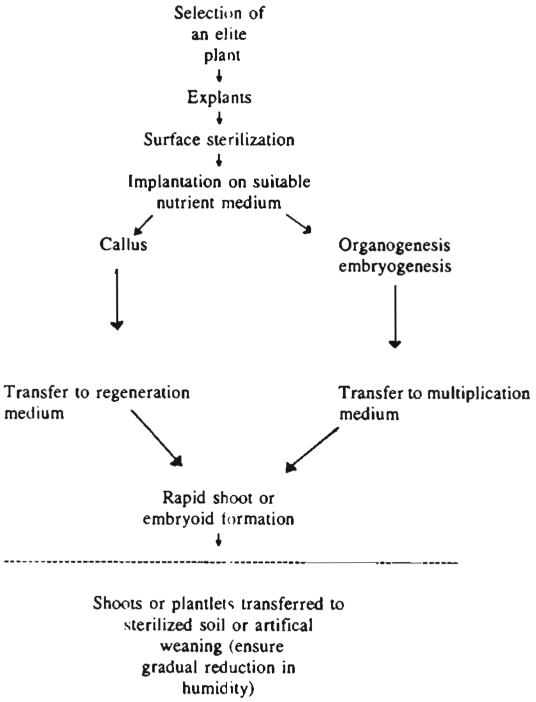
A significant discovery is the development of haploids from pollen grains (through anther culture) in *Datura innoxia* (Guha & S.C. Maheshwari, 1964). This technique has been widely used to raise haploids (especially in rice in China) for genetical studies.

Another important achievement of the Delhi School is the demonstration of the triploid shoots differentiated in endosperm cultures of *Exocarpus cupressiformis* (Santalaceae) by Bhojwani (Johri & Bhojwani, 1965; see Shekhawat *et al.*, 1995). Srivastava succeeded in raising triploid plantlets in mature endosperm cultures of *Jatropha panduraefolia* and *Putranjiva* (Euphorbiaceae) (Johri & Srivastava, 1973; Shekhawat *et al.*, 1995).

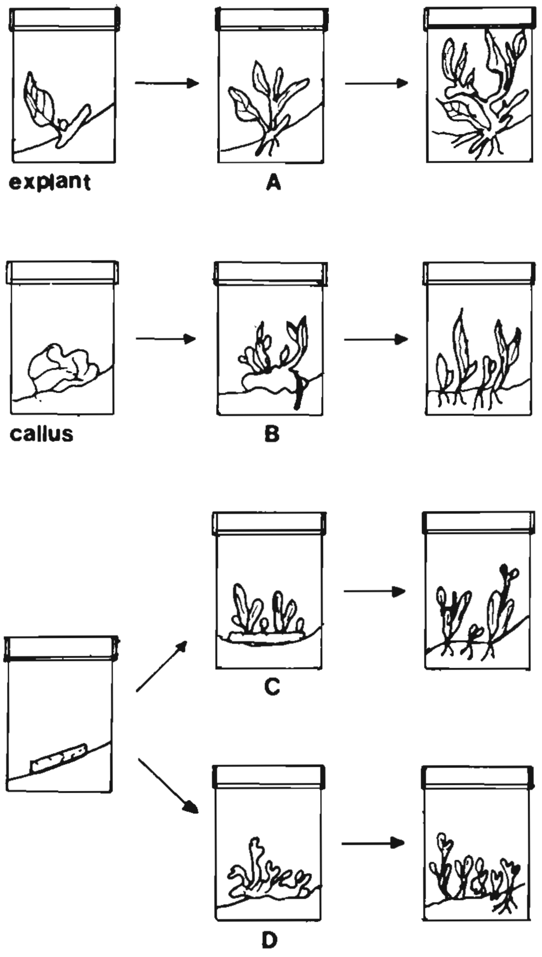
Many other plant parts have also been cultured. Of these, the embryo culture of Loranthaceae has yielded much new information. Differentiation of epidermal embryoids (Figure 22) on the stem of in vitro-raised plantlets, in floral bud cultures of *Ranunculus* was reported by Konar and Nataraja (1965).

CONCLUSIONS

Cellular totipotency—a porperty endowed only to plant cells, is the basis of micropropagation. The discovery and subsequent use of plant hormones—auxins, cytokinins and gibberellins, further strengthened the concept of organogenic differentiation. The widespread use of tissue culture technique has many advantages (Text-figures 6, 7) like in vitro cloning (Table 1) which is an important tool in speeding up propagation, and the production of disease-free plants, hybrid plants, haploids through anther and ovule culture, and also triploids through endosperm culture. The compatibility barriers can also be overcome through in vitro fertilization and embryo rescue.



Text-figure 6—Schematic representation to show in vitro procedures for raising shoot and plantlets.



Text-figure 7—A-D. Micropropagation through culture of axillary buds. **A.** growth of axillary bud; **B.** differentiation of adventitious buds on callus; **C.** direct differentiation of buds on explant; **D.** induction of somatic embryogenesis.

Table 1—Clonal Propagation Systems

Greenhouse cuttings

a) Maintains genetic uniformity; b) Rooting of plantlets generally required prior to plantation; c) High cost per plantlet; d) Size of mother plant determines multiplication rate.

Micropropagation

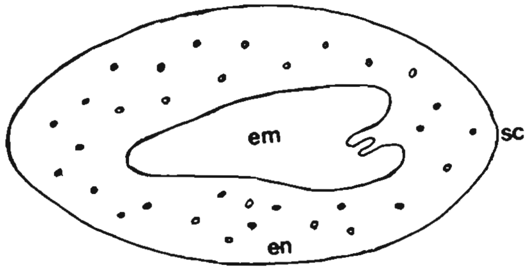
a) Ensures genetic uniformity; b) Acclimatization of plantlets essential prior to transplantation; c) Cost per plantlet high; d) Multiplication rate relatively low.

Artificial seeds

a) Maintains genetic uniformity; b) Direct delivery of propagules to the field; c) Cost per plantlet low; d) Rapid multiplication.

To cope with the ever-increasing human population, the need of the hour is to increase the food production which must receive the highest priority. Plant tissue culture is a powerful and potential tool which would help in replacing the entire population of low-yielding and diseased plants. With proven positive economic impact, raising in vitro plants offers immense scope for further exploitation of the technique. The production of secondary metabolites of medicinal interest is now a favourite area of research. Even after several decades of research in this exciting area, the problem of low productivity and instability of plant cells in cultures continue to be the main bottleneck. Rapid industrialization and urbanization have imbalanced our ecosystem. In order to save our rich heritage and genetic diversity of economically valued plants, there is an urgent need to either alter the environment that is incomprehensible or raise such plants so as to suit the polluted environment. Raising stress-tolerant plants through in vitro technique is a boon to this problem.

The potentiality of synthetic seeds (Text-figure 8) lies in their vital role as rapid, inexpensive and universal clonal delivery system to propagate plants (Table 2). However, the problems encountered in their production and application need further research.



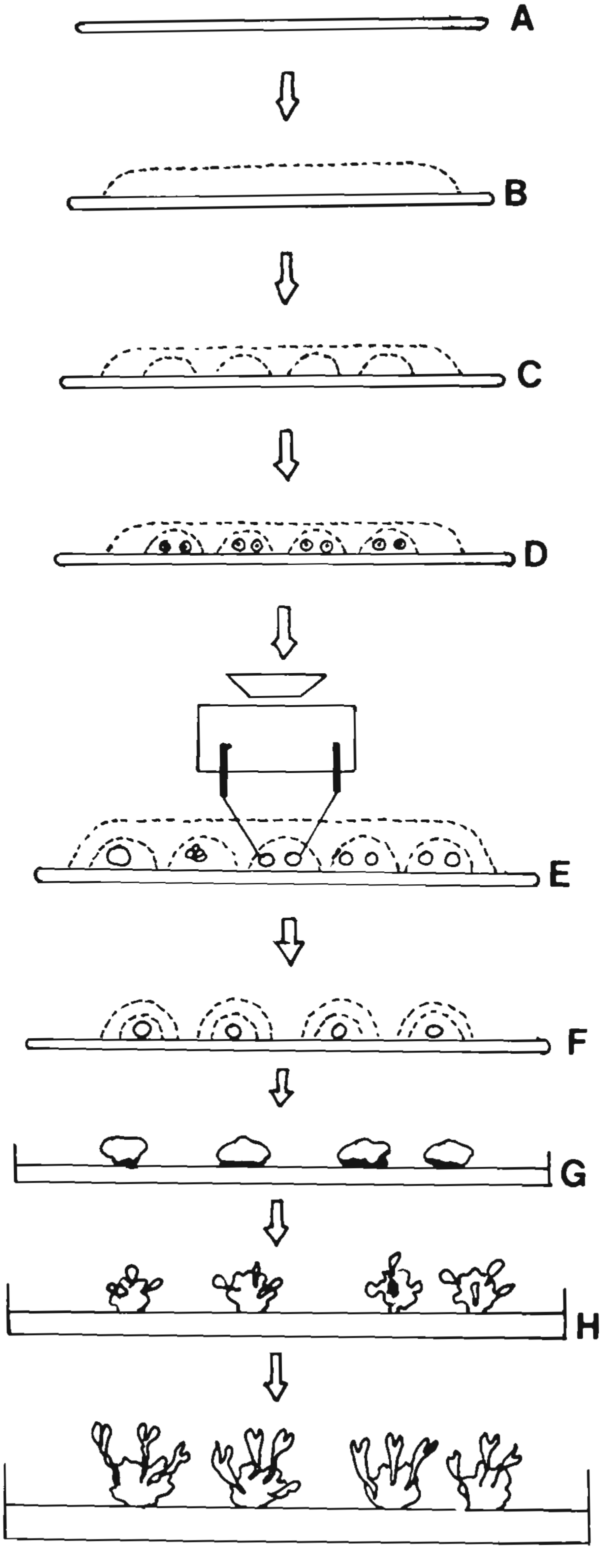
Text-figure 8—Synthetic seed. Somatic embryo (em) is encapsulated, in 'artificial endosperm' (en) covered with 'artificial seed-coat' (sc). In vitro differentiated shoot buds can also be encapsulated (after Fujii *et al.*, 1987).

Table 2—Crops that may benefit from artificial seeds

Hybrid Rice	Rapid propagation of F_1 hybrids.
Potato	a) Due to genetic instability, true seed can not be used; b) Propagation by cut tuber pieces are prone to diseases; c) Low storability of tuber pieces is a major problem in the tropics.
Geraniums	a) True seed costs are high; b) Vegetatively propagated.
European seedless Cucumber	a) True seed is expensive.
Garlic	a) Vegetatively propagated cloves have high carryover of virus and nematodes.
Gerbera/Daisy	a) Cost high.

Besides, one of the most striking developments witnessed in the field of tissue culture is the isolation, culture and fusion of protoplasts. A more recent approach is the genetic manipulation and regeneration of these cultured or fused protoplasts (Text-figure 9). Progress in recombinant DNA technology for the production of transgenic plants has been so spectacular that by the turn of the century we may hope our dream coming true for growing crops which have been manipulated to market specifications by adding, subtracting or modifying the threads of life (DNA).

Thus, during the last 50 years or so, following plant tissue culture procedures, significant advances have been made in understanding the growth, development and differentiation of plant parts. In future much attention will have to be paid to the isolation of male and female gametes of flowering plants and their use as tools of biotechnology, regeneration of isolated cells and protoplasts following genetic transformation, molecular biology and biochemical mechanisms of embryogenesis, production of artificial seeds, in vitro preservation of germplasm, and application of plant cell and tissue culture for understanding the basic features of differentiation. Tissue culture techniques will be used for screening and inducing disease susceptibility and resistance, and in breeding salt- and metal-resistant crops.



Text-figure 9—**A-I**. Procedure for electrofusion of protoplasts. **A**. Silicon coverslip; **B**. mineral oil; **C**. fusion microchamber, **D**. pairs of protoplast in the microchamber; **E**. Positioned micro-electrodes to induce fusion of the protoplasts; **F**. fused protoplasts in the microchamber; **G**. callus derived from the fusion product; **H**. differentiation/embryogenesis; **I**. further growth of shoots/plantlets (after Jones, 1988).

Attention will also have to be paid to produce triploid trees for rapid growth and biomass production, and increasing genetic base. Micropropagation of elite trees for tree improvement should also be given high priority. It is essential to device desired tissue culture techniques for individual crop plant species.

'Plant Tissue Culture' and 'Biotechnology' will be increasingly used in studies on Physiology, Biochemistry, Cell and Molecular Biology, Protoplasts and Somatic Hybrids, Micropropagation, Genetics and Plant Breeding, and Space Research.

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REFERENCES

Baldev B 1959. In vitro responses of growth and development in *Cuscuta reflexa* Roxb. *Phytomorphology* **9** : 316-319.

Bayliss MW 1980. Chromosomal variation in plant tissues in culture. *In*: Vasil IK (Editor)—*Int. Review of Cytology. Suppl IIA. Perspectives in plant cell and tissue culture*: 113-114. Academic Press, New York.

Berlyn J 1984. Plant cell cultures—A future source of natural products? *Endeavour* n.ser. **8**: 5-8.

Beiderbeck R & Knoop B 1988. Enhanced production of secondary substances : Addition of artificial accumulation sites of cultures. *In*: Bajaj YPS (Editor)—*Biotechnology in agriculture and forestry, medicinal and aromatic plants* I. **4**: 11-12. Springer-Verlag, Berlin.

Bhojwani SS 1966. Morphogenetic behaviour of mature endosperm of *Croton bonplandianum* in culture. *Phytomorphology* **16**: 349-353.

Bitters WP, Murashige T, Rangan TS & Nauer E 1972. Investigations on established virus-free *Citrus* plants through tissue culture. *In*: Price WC (Editor)—*Proc. 5th Int. Conf. Organ Citrus Virologists*: 267-271. Univ. of Florida, Gainesville, USA.

Button J & Bornman CH 1971. Development of nucellar plants from unpollinated and unfertilized ovules of Washington Navel orange in vitro *J. S. Afr. Bot.* **37**: 127-134.

Carlson S, Smith HH & Dearing RD 1972. Parasexual interspecific plant hybridization. *Proc. Natl. Acad. Sci. USA* **69** :2292-2294.

Chasan R 1992. Frontiers in fertilization. *Plant Cell* **4**: 369-372.

Chasan R 1993. Test-tube plants : The first of a new crop? *Plant Cell* **5**: 718-719.

Cheuca M-C, Cauderon Y & Tampe J 1977. Technique d'obtention d'hybrides Ble tendre x *Aegilops* par culture in vitro d'embryons immatures. *Ann. Amelior Plantes* **27:** 537-719.

Chopra RN 1958. In vitro culture of ovaries of *Althaea rosea* Cav. *In:* P. Maheshwari P (Editor)— *Modern developments in plant physiology*: 87-89. Univ. of Delhi.

Chopra RN 1962. Effect of some growth substances and calyx on fruit and seed development of *Althaea rosea* Cav. *In: Symp. Plant embryology*: 170-181. CSIR, New Delhi.

Chopra RN & Sabharwal PS 1963. In vitro culture of ovules of *Gynandropsis gynandra* (L.) Brig. and *Impatiens balsamia* L. *In:* Maheshwari P & Rangaswamy NS (Editors)—*Symp. Plant tissue and organ culture.* Int. Soc. Plant Morphologists, Delhi Univ.

Cocking EC 1972. Plant cell protoplasts—Isolation and development. *Rev. Plant Physiol.* **23:**29-50.

Collins GB, Legg PD & Kasperbater MJ 1974. Use of anther-derived haploids in *Nicotiana* : Isolation of breeding lines differing in total alkaloid content. *Crop Sci.* **14:** 77-80.

Corduan G & Spix C 1978. Anther culture of a hybrid of the genus *Hyoscyamus*: A rapid method to obtain homozygous recombinants. *In* : Alfermann AW & Reinhard E (Editors)—*Production of natural compounds by cell culture method.* : 295-302. Symp. Plant cell culture, Munich.

DeKlerk GJ 1990. How to measure somaclonal variations. *Acta bot. neerl.* **39:** 129-144.

DeMaggio AE & Wetmore RH 1961. Morphogenetic studies on the fern *Todea barbara* : Experimental embryology. *Am. J. Bot.* **48:**551-56.

Dolezel J, Novak FJ & Luzny J 1980. Embryo development and in vitro culture of *Allium cepa* and its interspecific hybrids. *Z. Pflanzenzüg* **85:** 177-184.

Eid AA, Delanghe E & Waterkyn L 1973. In vitro culture of fertilized cotton ovules: The growth of cotton embryo. *Cellule* **69:** 361-371.

Faure JE, Mogensen L, Dumas C, Lörz H & Kranz E 1993. Karyogamy after electrofusion of single egg and sperm cell protoplasts from maize; cytological evidence and time course. *Plant Cell* **5**: 747-755.

Gautheret RJ 1934. Culture du tissue cambial. *C.R. Acad. Sci. Paris* **198:** 2195-2196.

Gautheret RJ 1939. Sur la possibilite de realiser la culture indefinite des tissus de tubercules de carotte. *C.R. Acad. Sci. Paris* **208**:118-120.

George EF & Sherrington PD 1984. Plant propagation by tissue culture: Handbook and Directory of Commercial Laboratories: 88-118. England.

Goodman B 1993. A 'shotgun wedding' finally produces test-tube plants. *Science* **261**:430.

Goodsell SF 1961. Male sterility in corn by androgenesis. *Crop Sci.* **1**:227-228.

Guha Sipra & Johri BM 1966. In vitro development of ovary and ovule of *Allium cepa* L. *Phytomorphology* **16**:353-364.

Guha Sipra & Maheshwari SC 1964. In vitro production of embryos from anthers of *Datura. Nature* **204**:497.

Gulati A, Bharel S, Abidin MZ, Jain SJ & Srivastava PS 1996. In vitro micropropagation and flowering in *Artemisia annua. J. Plant Biochem. Biotechnol.* **5**:31-35.

Gupta N, Jain SK & Srivastava PS 1996. In vitro micropropagation of a multipurpose leguminous tree—*Delonix regia. Phytomorphology* **64**: 267-275.

Gupta PK, Nadgir AL, Mascarenhas AF & Jagannathan V 1980. Tissue culture of forest trees: Clonal multiplication of *Tectona grandis* L. (Teak) by tissue culture. *Plant Sci. Lett.* **17**:259-268.

Gupta PK, Mascarenhas AF & Jagannathan V 1981. Tissue culture of forest trees : Clonal propagation of mature trees of *Eucalyptus citriodora* Hook. by tissue culture. *Plant Sci. Lett.* **20**:195-201.

Haberlandt G 1902. Cultureversuche mit isolierten pflanzenzellen. *Sitzungsber, Math. Naturwiss Kl Kais Akad Wiss., Wien.* **111**: 69-92.

Haccicus B, Hausner G 1976. Ein transplanties-barer embryogener Callus aus Nucellusgenweb von *Cynanchum vincetoxicum* und die Rolle gloubularer Vorstadien in der Entwicklungsgeschichte nichtzygotischer Embryonen. *Protoplasma* **90**: 265-282.

Hannig E 1904. Zur Physiologic pflanzlicher Embryonen. I. Über die kultur von Crucifere-Embryonen ausserhalb des Embryosacks. *Bot. Ztg* **62:**45-80.

Hoffmann E 1978. Mutation and selection of haploid cell culture systems of rape and rye. *In:* Alfermann AW & Reinhard E (Editors)—*Production of natural compounds by cell culture methods*: 319-329. Int. Symp. Plant Cell Culture, Munich.

Iriving GW & Herrie HT 1949. *Antibiotics.* Chemical Publ. Co., Inc, Booklyn, USA.

Ito I 1961. In vitro culture of ovary and seed in orchids. *Ph.D. Thesis.* Kyoto Prefect Univ., Kyoto, Japan.

Ito I 1966. In vitro culture of orchids. (I) Effects of sugar, peptone, and coconut milk upon the growth of ovary of *Dendrobium mobile*. *Sci. Rep. Kyoto Prefect Univ. Agric.* **18**:38-50.

Ivanicka J & Pretova A 1980. Embryo culture and micropropagation of cherries in vitro. *Scient. Hortic.* **12**:77-82.

Johri BM 1971. Embryogenesis in tissue cultures. *In: Les Cultures de Tissue de Plantes* : 260-289. CNRS, Paris, No. 193.

Johri BM & Bajaj YPS 1963. In vitro response of the embryo of *Dendrophthoe falcata* (L.f.) Ettings. *In:* Maheshwari P & Rangaswamy NS (Editors)—*Symp plant tissue and organ culture*: 292-301. Int. Soc. Plant Morphologists, Univ. of Delhi.

Johri BM & Bhojwani SS 1965. Growth responses of mature endosperm in cultures. *Nature* **208:** 1345-1347.

Johri BM & Sehgal CB 1966. Chemical induction of polyembryony in *Anethum graveolens* L. *Naturwissenschaften* **50**:47-48.

Johri BM & Srivastava PS 1973. Morphogenesis in endosperm cultures. *Z. Pflanzenphysiol* **70:** 285-304.

Jones M 1988. Fusing plant protoplasts. *TIBTECH* **6:** 153-158.

Kanta K & Maheshwari P 1963. Intraovarian pollination in some Papaveraceae. *Phytomorphology* **13:** 230-237.

Kanta K, Rangaswamy NS & Maheshwari P 1962. Test-tube fertilization in a flowering plant. *Nature* **194:** 1214-1271.

Karp A, Wu QS, Steels SH & Jones MGK 1987. Chromosome variation in dividing protoplasts and cell suspensions of wheat. *Theor. Appl. Genet.* **74:** 140-146.

Kermicle JL 1973. Androgenesis and the indeterminate gametophyte mutation: Source of the cytoplasm. *Maize Genet. Cytol.* **17:** 655-666.

Kobayashi S 1987. Uniformity of plant regenerated from orange. protoplasts. *Theor. Appl. Genet.* **74:** 10-14.

Konar RN & Nataraja K 1965. Experimental studies in *Ranunculus sceleratus* L. in vitro. *Acta bot. Neerl.* **18:** 680-699.

Konar RN & Nataraja K 1969. In vitro control of floral morphogenesis in *Ranunculus sceleratus* L. *Phytomorphology* **14:** 558-563.

Kranz E & Dresselhaus T 1996. In vitro fertilization with isolated higher plant gametes. *Trends Plant Sci. Rev.* **1**: 82-89.

Kranz E & Lörz H 1990. In vitro fertilization of single, isolated gametes, transmission of cytoplasmic organelles and cell reconstitution of maize (*Zea mays* L.) : *In:* Nijkamp HJJ, Van der Plas LHW & Van Aartrijk (Editors)—*Progress in plant cellular and molecular biology*. VII. 24-29. Kluwer Academic Publishers, Dordercht (Netherlands).

Kranz E & Lörz H 1993. In vitro fertilization with isolated, single gametes results in zygotic embryogenesis and fertile maize plants. *Plant Cell* **5:** 739-746.

Kranz E & Lörz H 1994. In vitro fertilization of maize by single egg and sperm cell protoplast fusion mediated by high calcium and high pH. *Zygote* **2**:125-128.

Kranz E, Bautor J & Lörz H 1991. Electrofusion-mediated transmission of cytoplasmic organelles through the in vitro fertilization process, fusion of sperm cells with synergids and central cells, and cell reconstitution in maize. *Sex Plant Reprod.* **4:** 17-21.

Laibach F 1925. Das Taubwerden von Bastardsamen und die kunstliche Aufzucht fruh absterbender bastardembryonen. *Z. Bot.* **17:** 417-459.

Laibach F & Kribben FJ 1949. Der Einfluss von Wuchsstoft auf die Bildung Mannlicher und Weiblicher Buten bei eier Monozischen Pflanze (*Cucumis sativus* L). *Ber. dtsch Bot. Ges.* **62:** 53-55.

LaRue CD 1942. The rooting of flowers in culture. *Bull. Torrey bot. Club* **69**: 332-341.

LaRue CD 1947. Growth and regeneration of the endosperm of maize in culture. *Am. J. Bot.* **34:** 585-568.

LaRue CD 1954. Studies on growth and regeneration in gametophytes and sporophytes of gymnosperms. *Brookhaven Symp. Biol.* **6:** 187-208.

Maheshwaran G & Williams EG 1987. Uniformity of plants regenerated by direct somatic embryogenesis from zygotic embryos of *Trifolium repens*. *Ann. Bot. (London)* **59:** 93-97.

Maheshwari Nirmala 1958. In vitro culture of excised ovules of *Papaver somniferum*. *Science* **127:** 342.

Maheshwari P & Kanta K 1964. Control of fertilization. *In:* Linskens HF (Editor)—*Pollen physiology and fertilization:* 187-194. North-Holland Publ., Amsterdam.

Maheshwari P & Lal M 1961. In vitro culture of excised ovules of *Papaver somniferum* L. *Phytomorphology* **11** : 307-314.

Maheshwari P & Rangaswamy NS 1965. Embryology in relation to physiology and genetics. *In:* Preston RD (Editor)—*Advances in Botanical Research* **2:** 219-321. Academic Press, London.

Maliga P, Sz-Breznovits A & Marton L 1973. Streptomycin-resistant plants from callus culture of haploid tobacco. *Nature (New Biol.)* **244**: 29-30.

Mantell SH, Matthews JA & Mckee RA 1985. *Principles of plant biotechnology-An introduction of genetic engineering in plants.* Blackwell Sci. Pub. Oxford, London, Edinburg.

Masuda K, Koda Y & Okazawa Y 1978. Callus formation and embryogenesis of endosperm tissue of parsley seed cultured on hormone-free medium. *Physiol. Plantarum* **41:** 135-138.

Mauney JR 1961. The culture in vitro of immature cotton embryos. *Bot. Gaz.* **122:** 205-209.

Melchers G 1977. Microbial techniques in somatic hybridization by fusion of protoplasts. *In:* Brinkley BR & Porter KR (Editors)—*Int. Cell Biol. 1976-1977:* 207-215. Rockfeller Univ. Press, Boston, Mass, USA.

Melchers G, Sacristan MD & Holder AA 1978. Somatic hybrid plants of potato and tomato regenerated from fused protoplasts. *Carlsberg Res. Commun.* **43**: 203-218.

Mitra GC & Chaturvedi HC 1972. Embryoids and complete plants from unpollinated ovaries and from ovules of in vivo-grown emasculated flower buds of *Citrus* spp. *Bull Torrey bot. Club* **99:** 184-189.

Mu S, Liu S, Zhou Y, Qian N, Zhang P, Xie H, Zhang F & Yan Z 1977. Induction of callus from apple endosperm and differentiation of the endosperm plantlet. *Sci. sin.* **20:**370-377.

Mullins MG & Srinivasan C 1976. Somatic embryos and plantlets from an ancient clone of the grapevine (cv. Cabernet-sauvignon) by apomixis in vitro. *J. Exp. Bot.* **27**: 1022-1030.

Murashige T & Skoog F 1962. A revised medium for rapid growth and bioassays with tobacco tissue cultures. *Physiol. Plantarum* **15:** 473-497

Nag KK & Johri BM 1971 Morphogenic studies on endosperm of some parasitic angiosperms. *Phytomorphology* **21**: 202-208.

Nakajima T 1962. Physiological studies of seed development, especially embryonic growth and endosperm development. *Univ. Osaka Prefect* ser. B **13**: 13-48.

Nakano H, Tashiro T & Maeda E 1975. Plant differentiation in callus tissue induced from immature endosperm of *Oryza sativa*. *Z. Pflanzenphysiol.* **76**: 444-449.

Nickell LG 1952. Stimulation of plant growth by antibiotics. *Proc. Soc. Exp. Biol. Med.* **80**: 615.

Nitsch JP 1951. Growth and development in vitro of excised ovaries. *Am. J. Bot.* **38**: 556-576.

Nitsch JP 1969. Experimental androgenesis in *Nicotiana*. *Phytomorphology* **19:** 389-404.

Nobècourt P 1937. Cultures en serie de tissue Vegetaux sur milieu artificiel. *C.R. Seanc. Soc. Bid.* **205** : 521.523.

North C 1975. Embryo culture as an aid to breeding in *Lilium*. *Acta Hortic.* **47**: 187-191.

O'Connel MA, Hosticka LP & Hanson MR 1986. Examination of genome stability in cultured *Lycopersicon*. *Plant Cell Rep.* **5:** 276-279.

Phillips R, Arnott SM & Kaplan SE 1981. Antibiotics in plant tissue culture: Rifampicin activity controls bacterial contaminants without effecting the growth of short-term explant cultures of *Helianthus tuberosus*. *Plant Sci. Lett.* **21**: 235-240.

Pickering RA & Thomas HM 1979. Crosses between tetraploid barley and diploid rye. *Plant Sci. Lett.* **16:** 291-296.

Power JB, Cummins SE & Cocking EC 1970. Fusion of isolated plant protoplasts. *Nature* **225:** 1016-1018.

Prakash J & Pierik RLM (Editors) 1993. *Plant biotechnology: Commercial prospects and problems*: 1-289. Oxford & IBH Publ Co. Pvt Ltd., New Delhi.

Purohit M, Pande D, Datta A & Srivastava PS 1995. In vitro flowering and high xanthotoxin in *Ammi majus* L. *J. Plant Biochem. Biotechnol.* **4:** 73-76.

Purohit SS 1994. *Microbiology: Fundamentals and applications*. Agro Botanical Publ., Bikaner (India).

Quak F 1977. Meristem culture and virus-free plants. *In:* Reinert J & Bajaj YPS (Editors)—*Applied and fundamental aspects of plant cell, tissue and organ culture:* 598-600. Springer-Verlag, Berlin.

Rangan TS *1982*. Ovary, ovule and nucellus culture. *In:* Johri BM (Editor)—*Experimental embryology of vascular plants:* 105-130. Springer-Verlag, Berlin, Heidelberg, New York.

Rangan TS & Rangaswamy NS 1968. Morphogenic investigations on parasitic angiosperms. I. *Cistanche tubulosa* (Orobanchaceae). *Can. J. Bot.* **46:** 263-266.

Rangaswamy NS 1958. In vitro culture of nucellus and embryos of *Citrus*. *In:* Maheshwari P (Editor)—*Proc. Symp. Modern developments in plant physiology:* 104-106. Univ Delhi.

Rangaswamy NS & Shivanna KR 1971. Overcoming self-incompatibility in *Petunia axillaris* (Lam.) BSP.II. Placental pollination in vitro *J. Indian bot. Soc.* **50A**: 286-296.

Rangaswamy NS & Shivanna KR 1975. Nucellus culture of two cucurbits - *Luffa cylindrica* and *Trichosanthes anguina*. *Ann. Bot. (London)* **39**: 139-196.

Rao PS 1965. The in vitro fertilization and seed formation in *Nicotiana rustica* L. *Phyton (Hungary)* **2:** 183-196.

Rau MA 1956. Studies on the growth in vitro of excised ovaries- I, Influence of colchicine on the embryo and endosperm in *Phlox drummondi* Hock. *Phytomorphology* **6:** 90-96.

Ravishankar GA & Venkataraman LV 1993. Role of plant cell culture in food biotechnology: Current trends, limitations and future prospects. *In.* Prakash J & Pierik RLM (Editors)—*Plant biotechnology: Commercial prospects and problems*: 255-274. Oxford & IBH Publ Co. Pvt. Ltd, New Delhi.

Razdan MK 1995. *An introduction to plant tissue culture*. Oxford & IBH Publ Co. Pvt. Ltd., New Delhi.

Russell SD 1992. Double fertilization. *Int. Rev. Cytol.* **140:** 357-388.

Sachar RC & Kanta K1958. Influence of growth substances on artificially cultured ovaries of *Tropaeolum majus* L. *Phytomorphology* **8:** 202-218.

Sachar RC & Kapoor M 1959. In vitro culture of ovules of *Zephyranthes*. *Phytomorphology* **9:** 147-156.

Sehgal CB 1972. In vitro induction of polyembryony in *Ammi majus* L. *Curr. Sci.* **41:** 263-264.

Sharma'DR, Chowdhury JB, Ahuja V & Dankhar BS 1980. Interspecific hybridization in genus *Solanum*— A cross between *S. melongena* and *S. khasianum* through embryo culture. *Z. Pflanzenzütg* **985**: 248-253.

Shekhawat NS, Johri BM & Srivastava PS 1995. Morphogenesis and plant tissue culture. *In:* Johri BM (Editor)—*Botany in India: History and Progress:* 307-356. Oxford & IBH Publ. Co. Pvt Ltd, New Delhi.

Shivanna KR 1965. In vitro fertilization and seed formation in *Petunia violacea* Lindl. *Phytomorphology* **15:** 183-185.

Siddiqui SA 1964. In vitro culture of ovules of *Nicotiana tobacum* L. var. NP **31**. *Naturwissenschaften* **51:** 517.

Skoog F & Miller CO 1975. Chemical regulation of growth and organ formation in plant tissues cultured in vitro. *Symp. Soc. Exp. Biol.* **11:** 118-131.

Srivastava PS 1971. In vitro induction of triploid roots and shoots from mature endosperm of *Jatropha panduraefolia*. *Z.Pflanzenphysiol.* **66:** 93-96.

Srivastava PS 1973. Formation of triploid 'plantlets' in endosperm cultures of *Putranjiva roxburghii*. *Z. Pflanzenphysiol* **69:** 270-273.

Srivastava PS & Johri BM 1978. Pollen embryogenesis. *J. Palynol.* **23-24**: 83-99.

Srivastava PS & Steinhauer A 1981a. Isozymes in differentiating shoot bud cultures of *Betula pendula* Roth. *Z. Pflanzenphysiol.* **103**: 341-346.

Srivastava PS & Steinhauer A 1981b. Regeneration of birch plants from catkin tissue cultures. *Plant Sci. Lett.* **22:** 379-386.

Srivastava PS, Purohit M, Pande D & Datta A 1993. Phenotypic variation and alkaloid content in the androgenic plantlets of *Datura innoxia*. *Phytomorphology* **43:** 209-216.

Stewart JMD 1981. In vitro fertilization and embryo rescue. *Environ Exp. Bot.* **21**: 301-315.

Stoltz LP 1977. Growth regulator effects on growth and development of excised mature *Iris* embryo in vitro. *Hortic. Sci.* **12:** 495-496.

Taira T & Larter EN 1978. Factors influencing development of wheat-rye hybrid embryos in vitro. *Crop Sci.* **18:** 348-350.

Tamiya H 1959. Process of growth of *Chlorella* studied by the technique of synchronous culture. *In: Symp. Algology*: 1-10. New Delhi.

Thorpe TA 1980. Organogenesis in vitro: Structural, physiological and biochemical aspects. *In:* Vasil IK (Editor)—*Perspective in plant cell and tissue culture*. *Suppl II A*: 71-111. Academic Press, New York.

Tukey HB 1938. Growth patterns of plants developed from immature embryos in artificial culture. *Bot. Gaz.* **99**: 630-665.

Tulecke W 1957. The pollen of *Ginkgo biloba:* In vitro culture and tissue formation. *Am. J. Bot.* **44:** 602-608.

Uchimiya H, Kameya T & Takahashi N 1971. In vitro culture of unfertilized ovules in *Solanum melongena* and ovaries in *Zea mays*. *Japan J. Breed.* **21**: 247-250.

Umiel N & Goldner R 1976. Effects of streptomycin on diploid tobacco callus cultures and the isolation of resistant mutants. *Protoplasma* **89:** 83-89.

Vasil IK (Editor) 1980. International Review of Cytology. Suppl II A. *Perspectives in plant cell tissue culture*. Academic Press, New York.

Vasil IK & Nitsch C 1975. Experimental production of haploids and their uses. *Z. Pflanzenphysiol.* **76:** 191-212.

Vasil Vimla & Hildebrandt AC 1965. Differentiation of tobacco plants from single isolated cells in microculture. *Science* **150:** 189-192.

Wernicke W, Harms CT, Lörz H & Thomas E 1978. Selective enrichment of embryogenic microspore populations. *Naturwissenschaften* **65:** 540-541.

White PR 1932. Plant tissue culture: A preliminary report of results obtained in the culturing of certain plant meristems. *Arch. Exp. Zellforsch. besconders Gewebeztich* **12:** 602-620.

White PR 1939. Controlled differentiation in a plant tissue culture. *Bull. Torrey Bot. Club* **66:** 507-513.

White PR 1954. *The cultivation of animal and plant cells.* Ronald Press, New York.

Zamski E & Umiel N 1978. Streptomycin resistance in tobacco. II. Effects of the drug on the ultrastructure of plastids and mitochondria in callus cultures. *Z.Pflanzenphysiol.* **88**: 317-325.

Zenkteler M 1970. Test-tube fertilization of ovules in *Melandrium album* Mill with pollen grains of *Datura stramonium* L. *Experientia* **26**: 661-662.

Zenkteler M 1990 . In vitro fertilization and wide hybridization in higher plants. *Crit. Rev. Plant Sci.* **9**: 267-279.