Palynology of Middle Siwalik sediments (Late Miocene) from Bagh Rao, Uttar Pradesh

Samir Sarkar, Ananta P. Bhattacharya & H. P. Singh

A Late Miocene palynofloral assemblage, recovered from the Siwalik sediments exposed at Bagh Rao in Uttar Pradesh, has been studied. It contains a variety of spores, pollen grains and algal and fungal remains. Based on palynofloral analysis two distinct palynological zones A and B are established. The presence of Botryococcus, Pediastrum, Zygnema, Azolla and Nymphaea indicates fresh water environment during the deposition of Zone A sediments. Zone B lacks the presence of aquatic elements. However, it shows the abundance of montane elements, viz., Pinus, Podocarpus and Tsuga in addition to the pollen of Peceae, Asteraceae and Acacia. The sediments of Zone B appear to have been deposited in much drier conditions than that of Zone A. The overall palaeobotanical evidences point out the prevalence of low land rainforests under warm humid climate in the area of investigation.

Key-words—Palynology, Freshwater elements, Montane elements, Middle Siwalik, Late Miocene (India).

Samir Sarkar, Ananta P. Bhattacharya & H. P. Singh. Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow 226 007. India.

THE Siwalik Group (Miocene-Pliocene) of rocks form an important succession in the Tertiary strata of the Indian subcontinent. These continental deposits were laid down in the fore deep on the southern side of the rising Himalaya all along the sub-Himalayan range of India, Nepal and Pakistan. The Siwalik sediments attracted the attention of palaeontologists because of their rich vertebrate fauna.

However, palynological information available from these sediments is very scanty as most of the investigated samples from these areas have been found to be barren or with very few palynofossils (Badgley & Behrensmeyer, 1980; Ranga Rao et al., 1981). During palynological investigation of the Lower Tertiary formations of north-western Himalaya, the present author’s have processed few Siwalik samples containing well-preserved palynofossils of Late Miocene at Bagh Rao, northern India (Text-figure 1). Considering its potential to reveal palaeoclimatic and palaeoecological information in the sub-Himalayan region during the Neogene Period a detailed palynological study of this area was undertaken.

Therefore, the present study is aimed to record palynofossils from the Middle Siwalik sediments (Late Miocene) exposed at Bagh Rao and also to evaluate their bearing on palaeofloristics, palaeoclimatic, and palaeoenvironments. Available contemporary palynological data has also been used to assist in identification of stratigraphically and ecologically significant palynotaxa.
MATERIAL AND METHODS

The material for the present study was collected from the Siwalik sequence exposed along the Bagh Rao near Hardwar. The samples consist of clay, siltstone, silty shale and carbonaceous shale which occur as thin intercalations in the thick sequence of sandstone. Of the 17 samples macerated, only 7 samples yielded rich palynoassemblages. The palynofossils were recovered from the samples by employing the conventional technique of maceration. HCl, HF, HNO3 and KOH reagents were used to complete the process. Palynofossils have been recorded only from thin intercalated clay partings between the thick sandstones. This situation is quite normal with the Siwalik strata. In case of poorly yielding samples heavy liquid floatation technique using Potassium-Cadmium-Iodide solution was employed for better recovery of palynofossils. Slides were prepared in polyvinyl alcohol and mounted in Canada balsam. Three hundred palynofossil per sample were counted for quantitative analysis.

LIST OF PALYNOFOSSILS RECORDED

A check-list containing well known palynotaxa but without description has been given. Selected palynofossils have been commented upon, wherever necessary. Palynotaxa are arranged alphabetically with in the categories, viz., algal and fungal remains, pteridophytic spores, gymnospermous and angiospermous pollen and Incertae sedis.

A. Algal remains

1. Botryococcus braunii Kützing 1840 (Pl. 1, fig. 8)
2. Pediasirium compactum Singh & Khanna 1978 (Pl. 1, fig. 2)
3. Spirogyra zygospore (Pl. 1, fig. 10)
   Remarks—Several specimens closely comparable to the zygospores of Spirogyra have been recovered. The specimens are ellipsoidal in outline with a size-range from 80 x 100 to 95 x 110 μm. Each specimen is characterised by having a longitudinal furrow. The wall is very thin with laevigate to infrapunctate ornamentation.
4. Zygnema zygospore (Pl. 1, fig. 5)
   Remarks—Zygospores are quadrate, most of them are crumpled, with size range from 55-65 to 100-115 μm. The walls are very thin and finely pitted. A circular depression with a very hyaline wall has been noticed in most of the specimens. These zygospores closely compare with those of extant genus Zygnema of Zygnemaceae (Randhawa, 1959).
B. Fungal remains

5. Callimothallus assamicus Kar, Singh & Sah 1970
6. Inapertispores circularis Sheffy & Dilcher 1971
7. Inapertispores ovalis Sheffy & Dilcher 1971
8. Multicellaesporites sp.
10. Phragmothyrites eocaenica Edwards 1922

C. Pteridophytic spores

11. Azolla microspores (Pl. 1, fig. 9)
   Remarks—Only a few microspores of the genus *Azolla* have been studied. They are mostly embedded in the spongy massula. Massulae are circular to subcircular with size varying from 130 to 140 μm. Microspores possess a distinct trilete mark with laesurae extending up to the equator.
12. Azolla megaspore Type-1 (Pl. 1, fig. 13)
   Remarks—The present specimen has long conical column. Perispore is slightly lamellated and the upper part is foveolate. The oval-shaped megaspore has a trilete mark with thick and sinuous laesurae. Megaspore wall has foveate ornamentation. Floats are spongy in nature. These specimens are comparable with *Azolla veillii* (Dijkstra) Jain & Hall 1969 except in having smaller size range. Megaspore length varies from 200 to 250 μm including the float.
13. Azolla megaspore Type-2 (Pl. 2, fig. 19)
   Remarks—Several specimens of *Azolla* megaspore Type-2 have been recorded in the present assemblage but most of them are broken. Megaspores with the float have been found rarely. The perispore surface has an even texture and appears foveolate uniformly. Some small excrescences are present on the lower side. Triradiate crests are prominent. Floats are nine in number, arranged in two rows, three larger ones are present at the apical side whereas six smaller ones are present below them. Few verrucae have also been noticed on the floats. The present megaspore specimens resemble those of modern *Azolla nilotica*.
15. Cyathidites australis Couper 1953
16. Foveosporites canalis Balme 1957 (Pl. 2, fig. 1)
17. Intrapunctisporites intrapunctis Krutzsch 1959 (Pl. 2, fig. 21)
18. Leptolepidites verrucatus Couper 1953 (Pl. 2, fig. 2)
19. Leptolepidites sp. (Pl. 2, fig. 3)
20. Lycopodiumsporites parvireticulatus Sah & Dutta 1966 (Pl. 1, fig. 11)
21. Lycopodiumsporites sp. (Pl. 1, fig. 4)
   Remarks—The specimens ascribed to *Lycopodiumsporites* sp. are very similar to those described as *Lycopodium amnotidites* by Hopkins (1969) from the Eocene Kitsilano Formation of British Columbia, Canada. Reticulations are well-developed on the distal surface and equatorial areas of the proximal surface.
22. Lygodiumsporites eocenicus Dutta & Sah 1970 (Pl. 2, fig. 16)
23. Monolites sp. (Pl. 2, fig. 6)
24. Osmundacidites sp.
25. Podocarpidaesporites sp. (Pl. 1, fig. 1)
   Remarks—These specimens are very similar to those described by Sah (1967) from the Miocene sediments of Burundi as *Podocarpidaesporites* sp. except in having scabrate ornamentation pattern.
26. Polypodiisporites ornatus Sah 1967 (Pl. 1, fig. 3).
27. Pteridacidites sp. (Pl. 2, fig. 4)
28. Striatriletes multicus_ratus Kar & Saxena 1981 (Pl. 2, fig. 17)
29. Striatriletes paucicus_ratus Kar 1985
30. Striatriletes susannae (Van der Hammen) Kar 1979 (Pl. 3, fig. 5)
31. Triletes sp. (Pl. 1, fig. 12)
   Remarks—Only a few specimens have been recorded in this assemblage. Morphologically these specimens closely compare with osmundaceous microspores. Sah (1967) has recorded *Triletes morleyi* Couper 1953 from Rusizi Valley, Burundi, which is very similar except in having verrucose ornamentation and a smaller size. The present specimens range from 150-160 μm in diameter.

D. Gymnospermous pollen

32. Abiespollenites cognatus Kar 1985 (Pl. 2, fig. 23)
33. Cedripites miocenicus Krutzsch 1971 (Pl. 2, fig. 10)
34. Pinuspollenites cretus Kar 1985 (Pl. 2, fig. 11)
35. Podocarpidaesporites khasiensis Dutta & Sah 1970 (Pl. 2, fig. 7)
36. Tsugaepollenites velatus Kar 1985 (Pl. 2, fig. 15)

E. Angiospermous pollen

37. Compositoipollenites serratus Sah 1967
38. Dicotetradites sp. (Pl. 2, fig. 13)
39. Granustephanocolpites sp.
40. Impatiensidites brevicolpus Sah 1967 (Pl. 2, fig. 22)
41. Jacobipollenites magnificus Ramanujam 1966
42. Liliacidites perforatus Pocknall 1982
43. Liliacidites sp.
44. Malvacearumpollis grandis Sah 1967
45. Malvacearumpollis sp. A (Pl. 2, fig. 18)
46. *Malvacearumpollis* sp. B (Pl. 2, fig. 12).

**Remarks**—In these specimens pores are not very clearly visible. Morphological characters show more affinity towards the family Convolvulaceae rather than Malvaceae.

47. *Montoporopollenites gramineoides* Meyer 1956

48. *Monosulcites* sp. (Pl. 3, fig. 10)

49. *Nymphaeacidites* sp.

50. *Nyssapollenites thompsonicus* Traverse 1955

51. *Polypolpites pedaliaceoides* Sah 1967 (Pl. 2, fig. 8)

52. *Tricolpites* sp. (Pl. 2, fig. 14)

**F. Incertae-sedis**

53. Spore Type-1 (Pl. 2, fig. 14)

**Description**—Miospore subtriangular, size 45 × 75 μm. Trilete, Y-rays prominent, laevaeae thin, sinuous, bordered by thick labrum. Exine 3 μm thick, ornamentation granulose, ill-developed meshes observed on the distal surface.

**Remarks**—Only a single specimen has been recovered.

54. Spore Type-2 (Pl. 2, fig. 5)

**Description**—Miospore oval-shaped, inaperturate, size range 42 to 47 μm in diameter, peripheral region transparent, about 4 μm thick. Exine thin, ornamentation curvilinear, coarse-meshes about 5 to 6 μm in diameter, low projecting papillae observed on the comers of rectangular meshes.

**Remarks**—The overall morphology indicates a bryophytic affinity for these miospores.

55. Angiosperm pollen Type-1 (Pl. 2, fig. 24)

**Description**—Pollen grain oval-shaped, size 38 × 58 μm. Tricolpate, colpi long, extending more than 2/3 of the longer axis. Exine thin, ornamentation very finely granulose, appearing finely reticulate under low magnification.

56. Angiosperm pollen Type-2 (Pl. 1, fig. 7)

**Description**—Pollen grains oval-shaped, size range 64 × 80 μm. Polyporate, 5 pores clearly visible. Exine very thin, ornamentation finely granulose, grana simulating reticulate pattern.

**DISCUSSION**

**Palynofloral composition**

The Bagh Rao palynoflora consists of pteridophytic spores, gymnospermous and angiospermous pollen grains, and algal and fungal remains. In all, 43 genera and 56 species have been recorded. A few forms have been described under *Incertae sedis*. Pteridophytic spores and algal remains generally predominate as compared to gymnospermous and angiospermous pollen grains. A few miospores with bryophytic affinity have also been recorded.

The algal forms represented by four genera, viz., *Booyrococcus*, *Pediastrum*, *Zygnema* and *Spirogyra* are found in the lower horizon of the stratigraphic sequence. Among these, zygospores of the members of *Zygnemaceae* are most common, whereas the colonial alga *Pediastrum* of the family Hydrodictyaceae and *Booyrococcus* of family Xanthophyceae are relatively less represented. Qualitative representation of the fungal palynofossils is noteworthy throughout the whole sequence, although their numerical occurrence is rather low. Among the fungal remains microthyriaceous members are well represented by *Phragmothyrleites eocaenica*, *Callimothallus assamicus* and *Notothyrites amorbus*.

Several trilete miospores having close affinity with those of the bryophytic spores of Ricciaceae have been encountered. Pteridophytic spores represented by 14 genera and 19 species constitute one of the most important botanical group in this assemblage. Palynofossils assignable to the following eight families—*Cytaceae*, *Schizaceae*, *Parkeriaceae*, *Polypodiaceae*, *Lycopodiaceae*, *Osmundaceae*, *Adiantaceae*, and *Azollaceae* have been identified. Gymnosperm pollen grains are represented by only two families, viz., *Pinaceae* and *Podocarpaceae*. The Bagh Rao assemblage contains 12 genera and 15 species of angiospermous pollen grains.

**PLATE 1**

(All photomicrographs are magnified Ca × 500, unless otherwise mentioned)

1. *Polypodiaceaspores* sp.; Slide no. BSIP 8435, Coordinates 57.5 × 96.

2. *Ptychaspis compactum* Singh & Khanna; Slide no. BSIP 8435, Coordinates 28 × 101.5.

3. *Polypodiisporites ornatus* Sah; Slide no. BSIP 8436; coordinates 36 × 99.9.

4. *Lycopodiumspores* sp.; Slide no. BSIP 8434; coordinates 50 × 108.

5. *Zygospore of Zygnema*; Slide no. BSIP 8436; coordinates 38.5 × 101.5.


7. *Angiosperm pollen Type-2*; Slide no. BSIP 8436, coordinates 61 × 97.5.

8. *Booyrococcus bratanii* Kutzing.; Slide no. BSIP 8446, coordinates 47 × 96.5.


11. *Lycopodiumspores parvireticulata* Sah & Dutta; Slide no. BSIP 8445, coordinates 38.2 × 108.

12. *Trieles* sp.; Slide no. BSIP 8435, coordinates 62.5 × 100.5.

13. *Azolla megaspore Type-1*; Slide no. BSIP 8435, coordinates 29 × 108.8.
Out of these, 3 genera and 4 species belong to monocotyledons and 9 genera and 11 species to dicotyledons. Angiosperm families, viz., Asteraceae, Malvaceae, Balsaminaceae, Cruciferae, Pedaliaceae, Lentibulariaceae and Nymphaeaceae are dicotyledonous, whereas Sparganiaceae, Poaceae and Liliaceae are monocotyledonous.

Quantitative representation of spores-pollen of different botanical groups in the assemblage is as follows: pteridophytic spores 39 per cent, gymnospermous pollen 25 per cent, angiospermous pollen grains 20 per cent and algal and fungal remains 16 per cent. Among the pteridophytic spores some of the significant forms are Striatritles spp. (33%), Lycopodiumsporites spp. (15%), Polypodiaceasporites sp. (12%), and Azolla megaspores and microspores (11%). Tsugaepollenites velatus (55%) is the most common element among the gymnospermous pollen grains. The other genera Pinuspollenites and Abiespollenites have 24 per cent and 20 per cent representation respectively. Among the angiospermous pollen grains Monoporopollenites (23%) and Malvaeaearumpollis (20%) are the most common, while the percentage of other genera are generally less than 8 per cent.

Distributional analysis of the Bagh Rao palynofoflora reveals the presence of two palynological zones A and B (Text-figure 2) in the Middle Siwalik sequence. Dominance of pteridophytic elements has been noticed in the basal part of the palynological Zone A. Angiospermous pollen grains, although conspicuous by their presence, are much less in quantity. Gymnospermous pollen grains are infrequently represented in this palynological zone. Striatritles spp. are the most common palynofofls of this assemblage zone. Abundant occurrence of Botryococcus and Pediasstrum in some horizon is noteworthy. The other common genera in this palynological zone are Lycopodiumsporites, Polypodiisporites, Azolla micro-and megaspores, zygospores of Zygmena, Jacobipollenites, Liliacaites and Nymphaeacidites.

Pinuspollenites and Tsugaepollenites are the most significant elements of Zone B. Some of the other genera abundantly present in this Zone are Abiespollenites, Monoporopollenites, Malvaeaearumpollis, Lycopodiumsporites, Striatritles and Polypodiaceasporites. The frequency of Striatritles is low in comparison to that in the palynological Zone A. The algal elements are completely absent in this zone. A marked palynofloral change has been noticed in the upper part of the sequence which is 225 metre thick. Cold loving upland elements, viz., Pinuspollenites, Tsugaepollenites and Abiespollenites are copiously represented in this horizon.

Several palynotaxa, viz., Jacobipollenites magnificus, Impatiensidites brevicolpus, Polypolpis pedaliaceoides, Compositopollenites serratii, Malvaeaearumpollis grandis and microspores of Azolla have been recorded for the first time from Middle Siwalik sediments. The known botanical affinities of some of the significant Bagh Rao palynofofls and their preferable habitats are given in Table 1.

### Palynofloral comparison

The present palynofoflora has been compared with other Middle Siwalik palynofoflor assemblages recorded
from India and Nepal in order to evaluate its palynological status. Middle Siwalik sediments in most of the investigated areas (Text-figure 3) have yielded palynofossils of low diversity dominated by bisaccate pollen and polypodiaceous spores. Palynofloral assemblages recorded by Banerjee (1968), Nandi (1972, 1975), Saxena et al. (1984) and Singh and Sarkar (1984) compare very well with those encountered in the present investigation. Several palynotaxa are in common between these assemblages. The Raxaul Middle Siwalik palynofloral assemblage (Lukose, 1969) is also closely comparable to those palynofossils recovered from the Bagh Rao in their dominance of Pinus pollen and pteridophytic spores. However, the absence of angiosperm pollen of Myricaceae, Juglandaceae and Moraceae in these sediments is noteworthy. This may be due to the fact that the sediments might have been derived from two different geographic regions.

Middle Siwalik palynofloral assemblages recorded from Chepang-Chinji section, east of Nepal Ganj (Mathur,
Text-figure 3—The areas of comparative palynological study—A, Katwalta-Chiani (Mathur, 1984); B, Barara-Dagwani; Malnu-Salwana (Mathur, 1984); C, Bhakra-Nangal (Banerjee, 1968; Saxena et al., 1984); Ramshahr (Singh & Sarkar, 1984); D, Jawalamukhi (Nandi, 1979); E, Puranpur (Mathur, 1984); F, Mohand (Nandi, 1972); G, Raxaul (Lukose, 1969); H, Chepang-Chinji (Mathur, 1984); I, Surai khola (Sarkar, 1990) are shown.

PLATE 2

(All photomicrographs are magnified ca × 500, unless otherwise mentioned)

1. Foveosporites canalis Balmc; Slide no. BSIP 8435; coordinates 14 x 42.
2. Leptolepidites verrucatus Couper; Slide no. BSIP 8432; coordinates 96 x 35.5.
3. Leptolepidites sp.; Slide no. BSIP 8433; coordinates 27 x 109.
4. Pteridacolpites sp.; Slide no. BSIP 8438; coordinates 44.5 x 104.5.
5. Spore Type-2; Slide no. BSIP 8434; coordinates 35.8 x 94.5.
6. Monolites sp.; Slide no. BSIP 8449; coordinates 48 x 101.
7. Podocarpadites khasiensis Dutta & Sah; Slide no. BSIP 8430; coordinates 52 x 105.5.
8. Polycotylites pedataceoides Sah; Slide no. BSIP 8435; coordinates 53.2 x 103.
9. Spore Type-1; Slide no. BSIP 8435; coordinates 42.5 x 95.5.
10. Cedrampites micocnemus Krutzsch; Slide no. BSIP 8436; coordinates 43 x 98.
11. Pinuspollinates creatus Kar; Slide no. BSIP 8430; coordinates 66 x 99.
12. Maluscearumpollis sp. B.; Slide no. BSIP 8434; coordinates 65 x 110.5.
13. Dicoeluradites sp.; Slide no. BSIP 8439; coordinates 65 x 110.5.
14. Tricolpites sp.; Slide no. BSIP 8445; coordinates 41 x 99.
15. Tsugaepollenites velatus Kar; Slide no. BSIP 8430; coordinates 55 x 108.5.
16. Lycopodiumspores eocenicus Dutta & Sah; Slide no. BSIP 8440; coordinates 36 x 99.9.
17. Streitites multisestatus Kar & Saxena; Slide no. BSIP 8441; coordinates 53 x 96.
18. Maluscearumpollis sp. A.; Slide no. BSIP 8434; coordinates 48.2 x 101.6.
19. Azolla megaspore Type-2 (Ca x 250); Slide no. BSIP 8435; coordinates 47 x 99.5.
20. Monosulcites sp.; Slide no. BSIP 8442; coordinates 37 x 106.
21. Intrapunctispores intrapunctis Krutzsch; Slide no. BSIP 8431; coordinates 50.5 x 98.9.
22. Impatiensspores brevicolpus Sah; Slide no. BSIP 8436; coordinates 51 x 101.8.
23. Abiespollenites cognatus Kar; Slide no. BSIP 8436; coordinates 54.5 x 101.5.
24. Angiosperm pollen Type-1; Slide no. BSIP 8442; coordinates 43.5 x 105.5.
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1-104. Narosa Publishing House, genera of vascular plants: on the available palaeobotanical evidences (both micro-

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The Bagh Raopalynoflora assemblage (Table 1) comprises palynotaxa having affinities with those families which are distributed mainly in the tropical and subtropical region, excepting some gymnosperms. Based on the available palaeobotanical evidences (both micro-

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