
Fossil dinoflagellates : an emerging tool in Indian biostratigraphy

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Jain KP, Garg R & Khowaja-Ateequzzaman 1992. Fossil dinoflagellates : an emerging tool in Indian biostratigraphy. *Palaeobotanist* 40 : 420-428.

The total span of fossil dinoflagellate research in India stretches within the last three decades. Two distinct phases of this study are recognised, the phase of *Reconnaissance and Understanding* (1961-70) and the phase of *Establishment and Refinement* (1971-1990). The significance of dinoflagellate cysts in resolving various biostratigraphic problems of Mesozoic and Cenozoic sedimentary sequences is discussed citing specific examples from Indian basins. Recent approaches towards achieving biostratigraphic precision through integration with smaller planktonic and larger benthonic foraminifera, ammonites, and calcareous nannoplankton, are specifically highlighted focusing the potential of dinoflagellate cysts to resolve the time boundaries. A review of the previous literature has revealed that wrong identifications, especially of marker taxa, have led to major errors in age determination of sedimentary sequences. A few cases are exemplified. An appeal has been made to fellow palynologists to be careful in presenting geological and palynological data to maintain the viability and potential of this group of microfossils in biostratigraphy.

Key-words—Dinoflagellate cysts, Biostratigraphy, Triassic-Miocene, India.

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सारांश

अशिमत घूर्णीकशाभपुटीयों : भारतीय जैवस्तरविन्यास में इनका बढ़ता महत्व

कृष्ण प्रसाद जैन, राहुल गर्ग एवं खोवाजा-अतीक़ुज़्ज़ामाँ

पिछले तीन दशकों में भारत में घूर्णीकशाभपुटीयों पर अनुसन्धान हुआ है। इस अध्ययन की दो स्पष्ट अवस्थायें सुनिश्चित की गई हैं। पहली अवस्था (1961-70) आवीक्षण एवं समझने वाली तथा दूसरी (1971-90) अनुसन्धान स्थापन एवं बारीकी से अध्ययन करने से सम्बद्ध है। भारतीय द्रोणीयों से विशिष्ट उदाहरण देते हुए मध्यजीवी एवं नूतनजीवी अवसादी अनुक्रमों की विभिन्न जैवस्तरिक समस्याओं को सुलझाने में घूर्णीकशाभपुटीयों के महत्व की विवेचना की गई है। छोटे प्लवकी एवं बड़े बेन्थोनी फ़ोरामिनीफ़रों, अमोनाइटों तथा चूनामय पराप्लवकों के माध्यम से आधुनिक विधियों से जैवस्तरिक अध्ययन करने पर विशेष बल दिया गया है। घूर्णीकशाभपुटीयों से काल-सीमा सम्बन्धी समस्यायें सुलझाने में भी अत्यन्त सहायता मिली है। पुराने साहित्य के अध्ययन से व्यक्त हुआ है कि त्रुटिपूर्ण अभिनिर्धारण, विशेषतया सूचक वर्गों का, से अवसादी अनुक्रमों के आयु-निर्धारण में भारी त्रुटियाँ हुई हैं। इस हेतु कुछ उदाहरण भी प्रस्तुत किये गये हैं। अतः परागणुविदों से पुनर्विचार-प्रार्थना की गई है कि सूक्ष्मजीवाश्मों के इस समूह का जैवस्तरविन्यास में उपयोग करते समय अत्यन्त सावधानी से काम लें।

DINOFAGELLATES constitute a major part of phytoplankton food chain and are conspicuous among the primary producers in the oceans, next to diatoms. Their production is mainly controlled by the factors of incident effective radiation, temperature, salinity, major and minor nutrients and hydrodynamics in the photic zone. The productivity is generally inversely proportional to depth under normal photic conditions, highest productivity shall indicate relatively shallowest compensation depth (1-90 m). Apart from open sea, dinoflagellates also

occur in lakes, marshes and estuaries. The true affinities of dinoflagellates to plant or animal has now been resolved and are accepted as plants (Algae), placed under the Division Pyrrhophyta (from the Greek *Pyrrhos* means flame coloured, and *Phyta*, means plants) constituting four classes, viz., the Ebriophyceae, the Ellobiophyceae, the Desmophyceae, and the Dinophyceae.

Dinoflagellates are microscopic organisms ranging in size between 5-200 μm , unicellular, mostly planktonic and autotrophic (photosynthetic), having a biflagellate stage in the life cycle, the unique flagellar movement derived the name dinoflagellate from the Greek *dinos*, means whirling and Latin *Flagellatus*, means whip or scourge; the nucleus is large and combines the features of both prokaryotes and eukaryotes, hence are termed to possess a mesokaryotic nucleus (Dodge, 1965).

It is now accepted that only the resting cyst stage, in the life cycle of dinoflagellates, after release of the protoplasm during excystment, is preserved as fossil. Not all species of living dinoflagellates produce cysts and therefore the fossil records represent only a small fraction of the whole group, mainly represented by three orders viz., Dinophysiales, Gymnodiniales and Peridinales, of the class Dinophyceae.

True dinoflagellate cysts through geological time are known from Late Triassic onwards, though two doubtful earlier records are known, one each, from Late Silurian of Tunisia (Calandra, 1964; Sarjeant, 1978) and Permian and Early Triassic of Canada (Jansonius, 1962). The dinoflagellate affinity of Late Silurian species, *Arpylorus antiquus* Calandra 1964 has been widely discussed by Bujak and Williams (1981, p. 2083) concluding that, "... in our present state of knowledge it seems preferable to keep an open mind on the question of whether or not *Arpylorus* is a dinoflagellate".

A synthesis of global dinoflagellate cyst records through time reveals that the evolution in this group of plants was moderately rapid that has made them a significant tool for biostratigraphy. Further, greater biostratigraphic resolution has been achieved through integration of dinoflagellate cyst data with standard zones of calcareous nannoplankton, planktonic foraminifera, ammonite, and larger benthonic foraminifera.

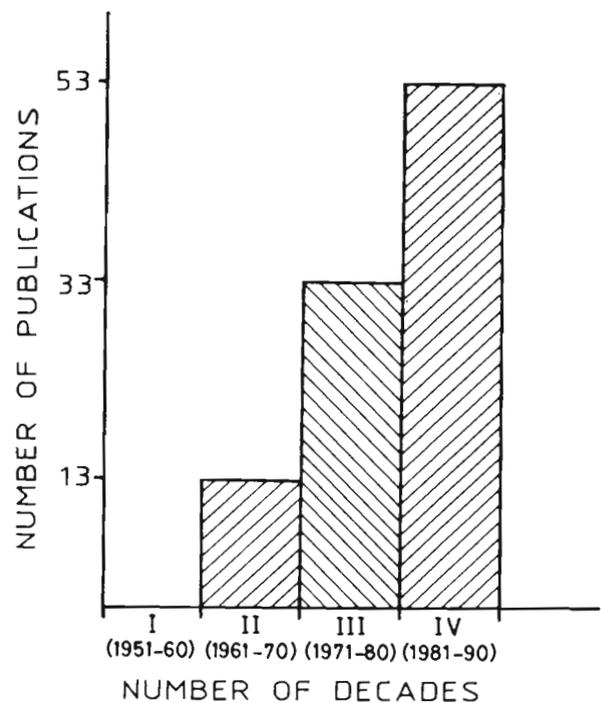
FOSSIL DINOFLAGELLATE STUDY IN INDIA

The history of fossil dinoflagellates in India stretches within a span of last three decades (1961-1990). A perusal of literature demonstrates that papers published between 1961-1970 (Bakshi, 1962; Biswas, 1962; Mathur, 1964; Varma & Dangwal, 1964; Rawat, 1967, 1968; Banerjee & Misra, 1968; Venkatachala & Kar, 1968; Jain & Subbaraman, 1969; Salujha, Srivastava & Rawat, 1969; Srivastava & Banerjee, 1969; Deb, 1970; Sah, Kar & Singh, 1970) are either brief reports with illustrations or records of incomplete assemblages with or without precise geological data. These are not of much

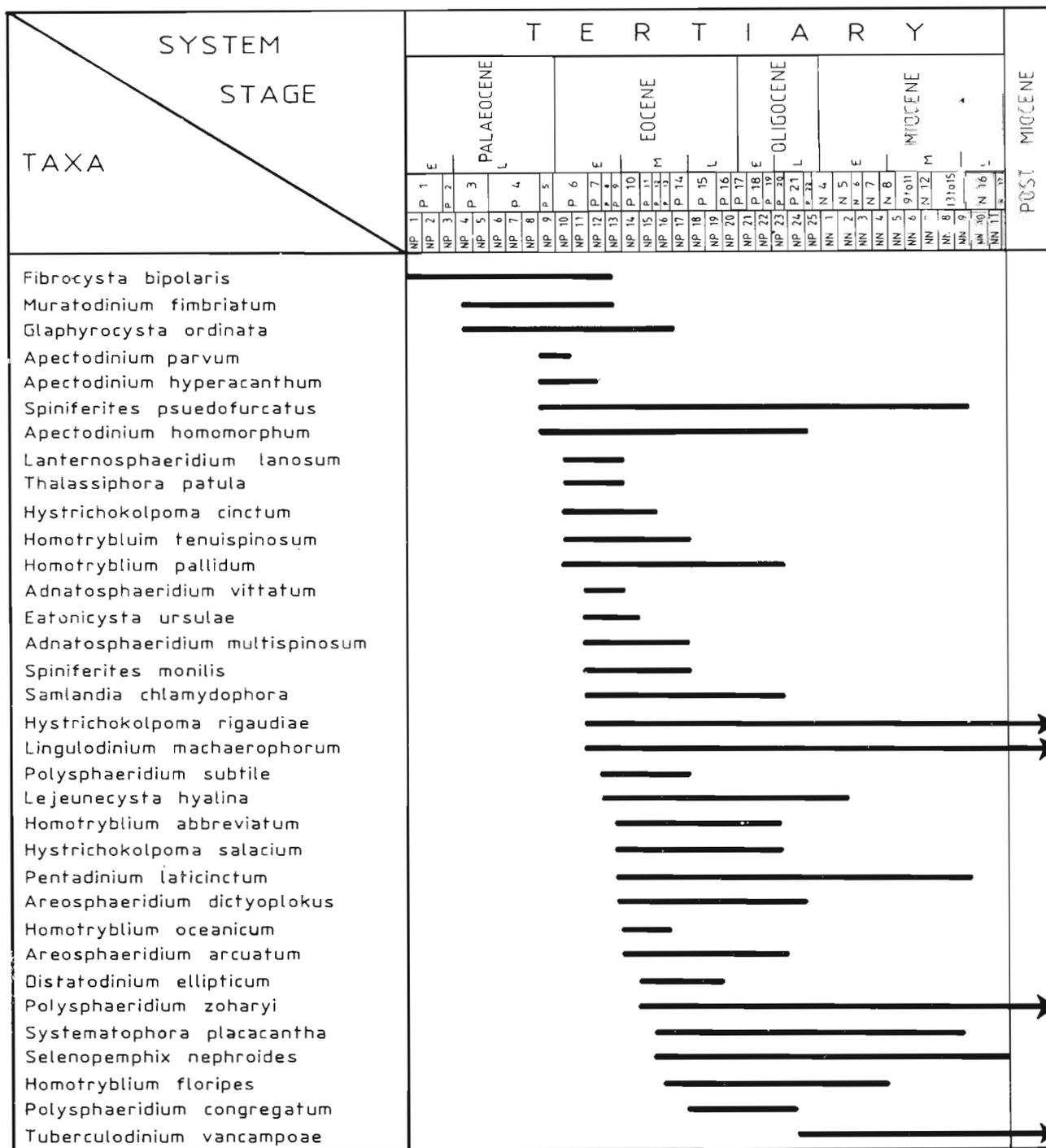
biostratigraphic consequence except indicating dinoflagellate cyst productive horizons.

Such a phase is normal and significant for any new group of fossils that serves to bring it in the main stream of subsequent biostratigraphic studies. This period is considered here as a phase of *Reconnaissance and Understanding*.

The next two decades (1971-80 & 1981-90) marked sharp rise in the number of publications (Text-figure 1) and greater interest in describing more or less complete taxonomic accounts establishing age, biozones and environment of deposition (Dutta & Jain, 1980; Jain, 1977, 1978; Jain & Dutta, 1978; Jain & Garg, 1986b; Jain *et al.*, 1986; Jain *et al.*, 1975; Jain & Taugourdeau-Lantz, 1973; Kar, 1979, 1985; Khanna *et al.*, 1985; Khanna & Singh, 1981a, b, c; Khanna *et al.*, 1981; Kumar, 1986a, b; Mehrotra & Sarjeant, 1986, 1987, 1990; Sarkar & Singh, 1988; Sharma & Sarjeant, 1987; Sharma & Mehrotra, 1984; Singh *et al.*, 1979; Singh & Tripathi, 1987; Tripathi & Singh, 1984). The last decade, in particular, has been a further advanced step towards precision biostratigraphy utilizing the concept of high resolution through direct correlation or integration with other plankton and invertebrate fossil data (Jain & Tandon, 1981; Jain *et al.*, 1984; Jain & Garg, 1986a). We define this period in India as a phase of *Establishment and Refinement*,



Text-figure 1—Bar diagram showing number of publications dealing with fossil dinoflagellates from India during the last four decades (1951-1990).



Text-figure 2

corresponding to the Modern Period (1961 to date) of fossil dinoflagellate study in other parts of the world (Sarjeant, 1974).

BIOSTRATIGRAPHIC POTENTIAL OF DINOFLAGELLATE CYSTS

Dating, biozonation, correlation, and the

environment of deposition of marine sedimentary sequences of India are primarily based on invertebrate mega- and micro-faunas, viz., ammonites, larger benthonic and smaller planktonic foraminifera, which have greater precision due to their wide geographical distribution and rapid evolution. Dinoflagellates, unlike terrestrial spores and pollen, are indigenous to marine environment

controlling their distribution and life cycle and are thus equally significant. Non-availability of invertebrate fossil evidences in several cases especially in paralic or shallow shelf sequences, considerably widen the scope of these organic-walled micro-fossils in biostratigraphic studies.

Known global stratigraphic ranges of some selected Jurassic, Cretaceous and Tertiary dinoflagellate cyst taxa recorded from the Indian sediments indicate their biostratigraphic potential (Text-figure 2). Some examples are discussed below.

The Triassic dinoflagellate cyst records from India are rare (Lukose & Misra, 1980; Sharma & Mehrotra, 1984; Sharma & Sarjeant, 1987) reported only from a subsurface and a surface sequence of Rajasthan and Andaman Islands respectively. The dinoflagellate cysts reported from Rajasthan (Well Shumarwali Talai no. 2 at a depth between 3060-3262 m) as *Gonyaulacysta* spp. (probably *Rhaetogonyaulax* spp. in Kumar, 1990, p. 251) needs critical restudy to precisely date the samples. The occurrence of dinoflagellate cysts taxa, viz., *Heibergella asymmetrica* Bujak & Fischer 1976, *H. salebrosacea* Bujak & Fisher 1976, *Nannoceratopsis dictyambonis* Riding 1974, *Rhaetogonyaulax rhaetica* (Sarjeant) Loeblich & Loeblich 1968 and *Sverdrupiella mutabilis* Bujak & Fisher 1976, in the Andaman Island samples led Sharma and Sarjeant (1987, p. 259) to suggest Late Triassic (Late Carnian-Rhaetic) age. But Kumar (1990, p. 251-252) opined that the entire Late Triassic assemblage is reworked from the Tenasserim Shan massif where the marine Napeng beds of Rhaetic age are present and are most likely the source of the Late Triassic dinoflagellate cysts reported from the Baratang Formation, Andaman Islands. He also pointed out the absence of Late Triassic sediments in the area.

The marine Jurassic rocks in India are mainly confined to its western and northern margins. Thick, almost continuous successions are exposed in Kutch, Jaisalmer and Tethys Himalayan basins and have been known to geologists for over a century due to their rich invertebrate fauna specially the ammonites. A comprehensive study of dinoflagellate cysts from Spiti Shale (Formation), Malla Johar area, Tethys Himalaya revealed their biozonational potential (Jain *et al.*, 1984). The dinoflagellate cyst recovery is restricted within the 160 m thick middle part of Spiti Shale sequence (Jain *et al.*, 1984, fig. 3; p. 77). It has been divided into five Microplankton Assemblage zones A, B, C, D and E in stratigraphic order. The dinoflagellate cyst data has been integrated with ammonite zones (Jai Krishna *et al.*, 1982, fig. 2) assigning an age extending from Oxfordian-Kimmeridgian to early Upper Tithonian.

Recently Helby *et al.* (1988) suggested correspondence between the Microplankton Assemblage zones B and C of Jain *et al.* (1984) and the Australian dinoflagellate *Dingodinium jurassicum* and *Pseudoceratium iebiense* zones of Helby *et al.* (1987) assigned to Middle to Late Tithonian and latest Tithonian to basal Berriasian ages respectively. The *Dingodinium jurassicum* Oppel Zone (Helby *et al.*, 1987) is defined by the youngest occurrence of *Omatia montgomeryi* and oldest occurrence of *Pseudoceratium iebiense* having several significant accessory forms, of which *Dingodinium jurassicum* is dominant. These constituents alongwith others of this zone are absent in Spiti Shale Assemblage Zone B. Rather, *Pseudoceratium spitiensis* and *Omatia montgomeryi* appear late in the Assemblage zones C and E respectively. However, predominance of *O. montgomeryi* in the youngest Assemblage Zone E of Jain *et al.* (1984) in the Spiti Shale was perhaps not noted by Helby *et al.* (1988) as their *O. montgomeryi* zone, defined by the total range of the nominate species, is older to *D. jurassicum* and *P. iebiense* zones and dated to be Lower Tithonian. As such, their correlation of zones B and C of Spiti Shale with younger Australian zones is not tenable. Moreover, the Microplankton Assemblage Zone B is characterised by the presence of *Wanaea clathrata*, which can be compared with *W. clathrata* Acme Zone, having its youngest occurrence up to basal Kimmeridgian (Helby *et al.*, 1987, p. 29). According to Dr Robin Helby (Personal communication), occurrence of *W. clathrata* with Lower Tithonian *Torquatisphinctes-Aulacosphinctoides* Assemblage zone documented in Spiti Shale by Jain *et al.* (1984), has recently been observed in Indonesia and New Zealand also.

In Kutch Basin the dinoflagellate cysts are known from a part of Jhuran Formation (Jain *et al.*, 1986) ranging in age from Upper Oxfordian to Kimmeridgian extending up to *P. pectinatus* Zone (*sensu anglico*), probably equivalent to latest Early Tithonian. Kumar (1987) reported some dinoflagellate cyst taxa from the Jhurio Formation of Kutch assigning Bathonian-Callovian age. This assemblage does not contain age marker taxa, viz., *Nannoceratopsis* spp. and *Wanaea* spp. and hence its age remains open to question (Garg *et al.*, 1988, p. 255). However, detailed dinoflagellate cyst studies may be of great significance to date the sediments older than Oxfordian in Kutch.

With the growing significance of magnetostratigraphy to resolve the Cretaceous-Tertiary Boundary (KTB) problem in different sections over the globe, it has been generally agreed

that the KTB in both marine and terrestrial sections falls within the reversed polarity interval between anomalies 29 and 30 (i.e. Chron C29 R) and the age of 65 Ma is estimated in marine strata (Berggren *et al.*, 1985, p. 149). Through geochemical analysis significant occurrence of the iridium rich clay layer has been recognised to mark the biostratigraphically determined KTB in some marine sections (Alvarez *et al.*, 1979, 1980; Smit, 1982).

The global reconstruction of microfloral and microfaunal changes or extinctions across the KTB are mainly based on some established sections, viz., El kef (Tunisia), Stevns Klint (Denmark), Caravaca (Spain), etc. The dinoflagellate cysts, calcareous nannoplankton and planktonic foraminifera are variously discussed to define the extinction levels.

In India, high iridium values (12 ppb) have been reported in a 1.5 cm thick yellowish brown clay layer exposed in Um Sohrengkew section, Meghalaya, showing global nature of iridium enrichment (Bhandari *et al.*, 1987). This iridium rich clay layer marks the K/T biostratigraphic boundary mainly based on planktonic foraminifera (Pandey, 1981, 1990; Pandey & Ravindran, 1988). The extinction level of dinoflagellate cyst genus *Dinogymnium* corresponds with the calcareous nannoplankton species *Micula prinsii* showing their last occurrence just below the clay layer. The Early Danian in the sequence is recognised above the clay layer by the FAD of marker dinoflagellate cyst taxa, i.e., *Danea californica* and *Kenleyia* spp. (Jain, 1991, p. 699).

The biostratigraphic significance of *Apectodinium homomorphum* plexus (sensu Harland, 1979) to mark the latest Palaeocene and Early Eocene has global recognition. Recently Powell (1988) has modified the earlier concept of Costa *et al.* (1978) that *Wetzeliiella astra* equates to the base of calcareous nannoplankton zone NP10, is doubtful but the highest occurrence of *Apectodinium augustum* must be taken to delineate the Palaeocene/Eocene boundary in central North Sea, which ends at the top of NP9 zone. Powell (1988, p. 336) is of the opinion that the base of the range of the genus *Apectodinium* lies within *A. augustum* Interval Biozone. In those instances where it is recognizable, we may refer this event to the "Base *Apectodinium* datum".

In Cauvery Basin and South Shillong Plateau, *Apectodinium* plexus is well represented (Jain & Garg, 1986b; Dutta & Jain, 1980) dating the sedimentary sequences to be Late Palaeocene equivalent to the NP9 Zone. The subsurface sequence from the former basin has calcareous nannoplankton control having *Discoaster*

multiradiatus (Jain *et al.*, 1983), though *A. augustum* and *Wetzeliiella astra* have not been reported. The significance of *A. summissum* along with *A. parvum* and *A. hyperacanthum* has been given due importance. A perusal of dinoflagellate cyst literature reveals the presence of *Apectodinium* in the subsurface of Krishna-Godavari Basin (Mehrotra & Sarjeant, 1987) and Subathu Formation exposed in the Jammu area (Khanna *et al.*, 1985). The forms documented by Mehrotra and Sarjeant (1987; pl. 4, fig. 2; pl. 5, figs 2, 3) from K-G Basin are misidentified as *Fibrocysta* and should belong to *Apectodinium*.

The Late Palaeocene marine sequences in India, with special reference to Palaeocene-Eocene boundary, are defined through planktonic foraminiferal stratigraphy following approximately the same datum of *Morozovella velascoensis* disappearance. In Indian basins *M. velascoensis* is not evenly distributed and therefore another species *M. oclusa* nearest to *M. velascoensis* is used to demarcate P/E boundary (Pandey & Ravindran, 1988, p. 14). The common presence of *Apectodinium homomorphum* plexus is therefore extremely useful to mark the latest Palaeocene datum in India.

Jain and Tandon (1981) for the first time attempted to integrate the dinoflagellate cyst data with larger benthonic foraminifera generated from Jhadwa-Baranda section of Harudi Formation in south-western Kutch. They divided this sequence into five informal microplankton zones, concluding Middle Eocene (Lutetian) age for the sequence which has close correspondence with those of larger Foraminifera. Apart from similar age conclusions, their palaeoenvironmental interpretations are also the same. Recently Jain and Garg (1991) pointed out the significance of *Eatonicysta ursulae* occurring in *Nummulites beaumonti* Zone of Tandon (1976) which also supports Lutetian age for this zone.

Apart from the above discussed biozonational schemes and their direct correlation with invertebrate faunal evidences, several other biozonational schemes have also been proposed solely based on dinoflagellate cysts (Singh *et al.*, 1979; Khanna *et al.*, 1981; Mathur, 1986; Sarkar & Singh, 1988). Mathur (1986) proposed three zones for a subsurface sequence representing the Kalol Formation in Cambay Basin, Gujarat, assessing Middle Eocene (Lutetian-Bartonian) age. He listed 49 species within a 250 m thick bore-core sequence without any illustrations. A critical comparison with other Middle Eocene dinoflagellate cyst assemblages described from Kutch and South Shillong Plateau (Jain & Tandon, 1981; Dutta & Jain, 1980) suggests more of generic than specific similarity. A detailed

taxonomical account with illustrations of dinoflagellate cysts from Kalol Formation in future would be of great help to define Middle Eocene key taxa.

Stratigraphic significance of *Tuberculodinium vancampoae* (Deflandre & Cookson) Wall 1967 is well established on global context having its oldest record from P21/NP25 zones of Late Oligocene age (Williams & Bujak, 1985, p. 903, fig. 19). In India this species has been reported from different sedimentary basins, viz., Kutch (Kar, 1979, 1985; Jain, 1980; Jain & Garg, 1991); Kerala (Jain, personal comm.) and South Shillong Plateau (Saxena & Rao, 1984; Jain & Garg, 1990). Besides, *T. vancampoae* has also been recorded from the Early Miocene sediments of Kerala coast and Bhuban Formation, South Shillong Plateau and from unclassified Miocene sediments of Khari Nadi Formation, Kutch (Saxena *et al.*, 1986; Saxena & Rao, 1984; Kar, 1985).

So far, we have dealt with the prospective side of the work carried out showing how the study of fossil dinoflagellates in last two decades have gained ground to figure itself at par with other marine micropalaeontological parameters to resolve the biostratigraphic problems. It would be unjust if we drop the curtain at this stage without focusing the retrospective side that 'ails' dinoflagellate studies in India, minimising its biostratigraphic potential.

It has now become imperative to update the stratigraphic and geographic distribution of published taxa through revisions of misidentified ones, which can otherwise minimise the potential of these fossils in biostratigraphy (Jain, 1982; Jain & Garg, 1982, 1983, 1986a, 1990a, 1990b). From the following case histories it would be evident how misidentification of one or more significant taxa in a dinoflagellate cyst assemblage can lead to a totally different age conclusion.

Mehrotra and Sinha (1979, 1981) discovered microplankton from Sangchamalla Formation (Upper Flysch) of Malla Johar area in the Tethyan zone of Kumaon Himalaya. They concluded Upper Cretaceous to Middle Eocene or probably Upper Eocene age range for this Formation. They based their age conclusions on the presence of following taxa, viz., *Areosphaeridium diktyoplokus* (Klumpp) Eaton 1971, *A. arcuatum* Eaton 1971, *Hystrichokolpoma unispinum* Williams & Downie 1960, *Deflandrea speciosa* Alberti 1959, *Homotryblum tenuispinosum* Davey & Williams 1960, *Cordosphaeridium exilimurum* Davey & Williams 1966, *Cleistosphaeridium disjunctum* Davey *et al.* 1966, *Adnatosphaeridium* sp. and *Odontochitina cribropoda* Deflandre & Cookson 1955. Later, Jain and Garg (1986a) revised and

reassessed this dinoflagellate cyst assemblage concluding that there is a total absence of *Areosphaeridium*, *Diphys*, *Deflandrea*, *Homotryblum*, *Adnatosphaeridium*, *Hystrichokolpoma* species and *Cordosphaeridium exilimurum*. Instead it contains *Oligosphaeridium complex*, *O. pulcherrimum*, *Cordosphaeridium inodes*, *Coronifera oceanica*, *Hystrichosphaerina schindewolfi*, *Odontochitina cribropoda*, *Endoceratium ludbrookiae*, *Cleistosphaeridium* sp. and *Gonyaulacysta* sp. The taxonomic reassessment led them to conclude an Upper Cretaceous age for the Sangchamalla Formation not extending to Middle or Upper Eocene.

Kar (1979, 1985) documented Tertiary dinocyst assemblages from Kutch, which required major revisions due to wrong identifications (Jain & Garg, 1991). Such documentations not only pollute the dinocyst literature but more significantly lead to confusion in inter- or intra-basinal comparisons and dating of the assemblage.

Likewise, a restudy of the type and figured slides of dinocyst assemblages described from subsurface of Krishna-Godavari Basin by Mehrotra and Sarjeant (1987) has revealed predominance of *Apectodinium* species at 2,703-2,706 m and 3,621-3,624 m depths. Its misidentification as *Fibrocysta* has led them to conclude Maastrichtian and Palaeocene ages for the above two bore-core samples, respectively. A critical reassessment of these dinocyst assemblages is therefore imperative for precise dating of inter- and supra-trappean sediments of the K-G basin.

It is, therefore, obligatory on the part of a micropalaeobotanist to religiously follow and maintain the basic norms of this study, viz., geological field setting and position of samples in a litholog; careful chemical processing of the rock samples avoiding any chance of contamination or loss of any organic-walled or biogenic microfossil, faithful description of morphotypes based on several specimens; sincere efforts to identify a particular morphotype, to be attributed to a new or an already existing taxon by comparing it well with the known allied genera and species. These aspects form the basis for an effective statistical analysis to achieve precision in biostratigraphic, palaeobiogeographic and palaeoecologic interpretations.

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