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Revision and reassessment of a dinoflagellate cyst assemblage from Sangchamalla Formation (Upper Flysch), Malla Johar area, Kumaon Himalaya, India

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ABSTRACT

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A dinoflagellate cyst assemblage described by Mehrotra and Sinha (1981) from the Sangchamalla Formation (Upper Flysch) of Malla Johar area in the Tethyan zone of higher Kumaon Himalaya is critically re-evaluated.

The taxonomic revision of the assemblage on its face value indicates total absence of *Areosphaeridium dictyoplokus* (Klumpp) Eaton, *A. arcuatum* Eaton, *Homotryblium tenuispinosum* Davey & Williams, *Hystrichokolpoma unispinum* Williams & Downie, *Diphyes colligerum* (Deflandre & Cookson) Davey & Williams and *Deflandrea speciosa* Alberti based on which a Lower Tertiary age was assigned by Mehrotra and Sinha (1981). Instead it is characterised by the predominance of *Oligosphaeridium* with common occurrence of *Coronifera, Gonyaulacysta, Hystrichosphaerina, Tityrosphaeridium* and *Cordosphaeridium*. A new species, viz., *Hystrichosphaeridium himalayaensis* proposed by Mehrotra and Sinha (1981) is treated as a junior synonym of *Oligosphaeridium complex* (White) Davey & Williams.

The revised dinocyst assemblage is devoid of exclusive Tertiary taxa and indicates an Upper Cretaceous age. Possibility of Lower Cretaceous reworking in the 'Upper Flysch' assemblage is suggested. The occurrence of dinocysts in the deep oceanic environment of the 'Upper Flysch' sediments is considered to be most probably due to transportation from shallower regions through sedimentary processes.

Key-words—Palynology, Dinoflagellates, Sangchamalla Formation, Upper Cretaceous (India).

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सारांश

कुमायूँ हिमालय (भारत) में मल्ला-जोहर क्षेत्र के संगचामल्ला शैल-समूह से उपलब्ध घूर्णीकशाभ पुटी समुच्चय का संशोधन एवं पुनर्मूल्यांकन

कृष्ण प्रसाद जैन एवं राहुल गर्ग

उच्चतर कुमाऊँ हिमालय के टैथीय मंडल में मल्ला-जोहर क्षेत्र के संगचामल्ला शैल-समूह (उपरि फ्लिश) से महरोत्रा एवं सिन्हा (1981) द्वारा वर्णित एक घूर्णीकशाभ पुटी समुच्चय का समीक्षात्मक मूल्यांकन किया गया है।

इस समुच्चय के वर्गीकरणिक संशोधन से एँरिओस्फ़ेयरीडियम् डिक्टियोप्लोकस (क्लम्प) ईटन, एँ. आर्कुएटम् ईटन, होमोट्राइब्लियम् टेनुइस्पाइनोसम् डावे व विलियम्स, हिस्ट्रीकोकॉल्पोमा यूनीस्पाइनम् विलियम्स व डाऊनी, डाइफ़िस कॉलिजेरम् (डिफ्लान्ड्रे व कुक्सन) डावे व विलियम्स एवं डिफ्लान्ड्रीआ स्पेसिओसा ॲल्बर्टाई की पूर्ण अनुपस्थिति व्यक्त होती है जिनके आधार पर महरोत्रा एवं सिन्हा ने इसकी अधरि तृतीयक आयु निश्चित की थी। अतः इसके बजाय यह समुच्चय ओलिगोस्फ़ेयरीडियम् की पूर्वबाहुल्यता के साथ-साथ कोरोनिफ़ेरा, गोनीओलासिस्टा, हिस्ट्रीकोस्फ़ेयरीना, ?टिटॉयरोस्फ़ेयरीडियम् एवं कोर्डोस्फ़ेयरीडियम् की सामान्य उपस्थिति से अभिलक्षणित है। महरोत्रा एवं सिन्हा द्वारा प्रस्तावित हिस्ट्रीकोस्फ़ेयरीडियम् हिमालयेन्सिस नामक एक नवजाति को ओलिगोस्फ़ेयरीडियम् कॉम्प्लेक्स (व्हाइट) डावे व विलियम्स के कनिष्ठ पर्यायनाम के रूप में प्रयुक्त किया गया है।

यह संशोधित घूर्णीकशाभ पुटी समुच्चय वर्जनकारी तृतीयक युगीन वर्गकों से विहीन है तथा उपरि क्रीटेशी आयु इंगित करती है। उपरि फ्लिश समुच्चय में अधरि क्रीटेशी की संभावना प्रस्तावित की गई है। उपरि फ्लिश अवसादों के गहरे समुद्री वातावरण में घूर्णीकशाभ पुटीयों की उपस्थिति सम्भवतया अवसादीय प्रक्रियाओं द्वारा छिछले क्षेत्रों से वहन के कारण मानी गई है।

INTRODUCTION

RECENTLY Mehrotra and Sinha (1978, 1981) described dinoflagellate cysts from the Sangchamalla Formation (Upper Flysch of Heim and Gansser, 1939) which forms the uppermost part of the Tethyan sequence exposed in the Malla Johar area, Kumaon Himalaya, Uttar Pradesh. They assigned an Upper Cretaceous to Middle Eocene or ?Upper Eocene age to this succession on dinocyst evidence. However, based on the other microplankton evidences, an Upper Cretaceous age has been assigned to the 'Upper Flysch' sediments by most of the workers (Kalia, in Shah & Sinha, 1974; Mamgain & Sastry, 1975; Sastry & Mamgain, 1977; Jain *et al.*, 1978; Garg *et al.*, 1981). Only the uppermost part of the 'Upper Flysch' (the Balcha Dhura Formation of Kumar *et al.*, 1977) has been considered to be Lower-Middle Palaeocene in age based on planktonic foraminifera (Singh *et al.*, 1981).

The occurrence of dinocysts in the 'Upper Flysch' sediments further led Mehrotra and Sinha (1978, 1981) to visualise a shallow marine depositional environment within the flysch sedimentation cycle. This also does not conform with the known deep water depositional framework of this part of the Tethyan sequence (Heim & Gansser, 1939; Mamgain & Sastry, 1975; Kumar *et al.*, 1977). In the present note, a critical reassessment of the dinoflagellate cyst assemblage described by Mehrotra and Sinha (1981) is made to resolve these discrepancies of age and palaeoenvironment of the 'Upper Flysch' succession.

STRATIGRAPHIC STATUS AND AGE OF 'UPPER FLYSCH'

The term 'Upper Flysch' was introduced by von Kraft (1902) for a thick sedimentary sequence of shales, sandstones, limestones and 'tuffs', overlying the Giumal Sandstone and overlain by the Exotic Blocks'. The term was retained by Heim and Gansser (1939) who mentioned that the uppermost unit of this succession forming the crest of Balcha Dhura, are not 'tuffs' but are red and green alternations of chert, with thiner cherty or shaly layers, rich in radiolarians. Kumar *et al.* (1972) named the 'Upper Flysch' succession as Flysch Series. They pointed out that the topmost units are actually basic volcanic rocks (spilite and associated serpentinite) and are neither 'tuffs' nor alternations of sandstones, shales and radiolarian cherts. These basic rocks were termed 'Balcha Dhura Volcanics' by Kumar *et al.* (1972). Shah and Sinha (1974) subsequently proposed a new name Sangchamalla Formation for the 'Upper Flysch' succession lying between Giumal Sandstone and the 'Exotic Blocks', with a remark that "the name 'Upper Flysch' used by Gansser has no significance".

Kumar *et al.* (1977) carried out a comprehensive study of the Malla Johar succession, providing a revised lithostratigraphic scheme alongwith measured lithologs and details of sedimentary structures, trace fossils, palaeocurrents and depositional environment of the entire sequence. They preferred to subdivide the 'Upper Flysch' succession into two formations, eg. Jhangu and Balcha Dhura formations. The Jhangu Formation is represented by a thick sequence of dark coloured shales and graywacke, typical flysch sediments, with associated calcareous sandstone, foraminiferal limestone, radiolarian chert and red and green clays. The younger Balcha Dhura Formation (renamed after 'Balcha Dhura Volcanics' of Kumar *et al.*, 1972) is represented by the topmost ophiolite succession consisting of basic and ultrabasic volcanic rocks and associated with red and green shales and radiolarian cherts.

Heim and Gansser (1939) assigned an Upper Cretaceous (post-Albian) age to the 'Upper Flysch' succession. Later Kalia (1972, in Shah & Sinha, 1974), Mamgain and Sastry (1975) and Sastry and Mamgain (1977) supported Upper Cretaceous (Upper Cenomanian-Turonian to Maestrichtian) dating of these sediments based on the planktonic foraminiferal evidences. Subsequent study on planktonic foraminifera from the upper part of the Balcha Dhura Formation, representing the topmost part of the 'Upper Flysch', however, led Singh *et al.* (1981) to suggest Lower-Middle Palaeocene age for the studied horizon.

Since 1978, the authors have also been engaged to work out the Upper Jurassic-Cretaceous biostratigraphy of the sedimentary sequence exposed in Malla Johar area, Kumaon Himalaya. The studied microplankton include Jurassic dinocysts from Spiti Shale and Cretaceous radiolarians from Giumal Sandstone, Jhangu Formation and Balcha Dhura Formation (Jain *et al.*, 1978, 1984; Garg *et al.*, 1981). Based on thin section study of radiolarian assemblages from Jhangu Formation and Balcha Dhura Formation, Jain *et al.* (1978) and Garg *et al.* (1981) favoured an Upper Cretaceous age for these sediments. Incidentally, the planktonic foraminiferal fauna from Balcha Dhura Formation studied by Singh *et al.* (1981) was recovered from a slightly younger horizon than the samples which yielded the radiolarian assemblage (see Singh *et al.*, 1981, p. 384). Singh *et al.* (1981, p. 385) remarked that the discrepancy in age as suggested by radiolarians (Upper Cretaceous) and planktonic foraminifers (Palaeocene) could be deceptive as the succession consists of alternate cherts and calcareous shales in association with volcanic rocks. They further suggested that the Cretaceous-Palaeocene boundary may be sharp in the area, which can only be deciphered accurately by closer sampling of the deep sea deposits of the Balcha Dhura Formation.

Mention must be made of the views expressed by Kumar *et al.* (1977) and Singh *et al.* (1981) who, on stratigraphic grounds, expressed that the possibility of the 'Upper Flysch' succession extending into Upper

Palaeocene or even Eocene could not be totally ruled out. It was considered surprising by them that a thick sequence of more than 500 m could have been deposited under constantly deep water environment beyond continental slope within a relatively short span of time during Upper Cretaceous, mainly Maestrichtian, as the lowermost units of Jhangu Formation yielded nannoplankton indicative of Campanian-Maestrichtian boundary (Jafar in Kumar *et al.*, 1977, p. 419). However, definite microfossil evidences from the top of Balcha Dhura Formation, just underlying the 'Exotic Blocks' to date do not suggest an age younger than Lower-Middle Palaeocene.

All these evidences, thus, support Upper Cretaceous age for the major part of Heim and Gansser's 'Upper Flysch' succession and Early-Middle Palaeocene age for the topmost part of the ophiolite succession. However, Mehrotra and Sinha (1981, p. 159), on the basis of certain dinoflagellate cysts, proposed Palaeocene to Middle Eocene or Upper Eocene (?) age for the major part of the 'Upper Flysch' and suggested Upper Cretaceous age only for the lowermost part of the succession.

In order to resolve this age controversy as well as to check the accountability of the reported dinocyst assemblages vis-a-vis other microplankton assemblages (planktonic foraminifers and rediolarians) recorded from the same succession, we thought it best to reassess the identifications of the dinocyst taxa documented by Mehrotra and Sinha (1981, pls. 1-3) as some striking discrepancies were noticed in their identifications. This is also desirable in view of the fact that if age determination of the studied succession based on one evidence is believed to be true, the other evidences suggesting some different age have to be reviewed and logically explained within the known sedimentation and tectonic framework.

DINOFLAGELLATE CYSTS FROM THE 'UPPER FLYSCH'

Out of the four major units of the Sangchamalla Formation recognised by Shah and Sinha (1974), dinocysts have been reported by Mehrotra and Sinha (1981) from nearly all the stratigraphic levels except the basal 50 m dark greenish shale containing a few graywacke bands. The overlying 70 m thick purple marly shale with bands of foraminiferal ooze yielded abundant dinocysts, viz., *Odontochitina cribropoda* and *Systematophora schindewolfi* and has been assigned an Upper Cretaceous age. The succeeding 650 m thick unit represented by greenish graywacke and dark shales with bands of radiolarian cherts towards the top, is also found to be quite rich in dinoflagellate cysts. The dinocysts were recovered by Mehrotra and Sinha (1981) from ten samples representing different levels of this unit. Based on the predominance of *Oligosphaeridium complex*, *O. pulcherrimum*, *Cordosphaeridium exilimurum*, *Diphyes colligerum*, and the first appearance of *Areosphaeridium diktyoplokus*, *A. arcuatum* and *Homotryblium tenuispinosum*, a Palaeocene to Lower Eocene age is assigned to this unit by Mehrotra and Sinha (1981, p. 159). The topmost 300 m thick sequence consisting of greenish shales with bands of chocolate sandstone and dark grey radiolarian cherts is also found to be palynologically productive. Predominance of *Areosphaeridium diktyoplokus*, *A. arcuatum*, *Homotryblium tenuispinosum* and absence of *Hystrichokolpoma unispinum* together with rarity of *Oligosphaeridium complex* and *O. pulcherrimum*, further led them to suggest Middle Eocene to Upper Eocene (?) age for this uppermost part of the Sangchamalla Formation. Thus, Sangchamalla Formation was considered by Mehrotra and Sinha (1978, 1981) to range in age from the Upper Cretaceous to Middle or ?Upper Eocene. Mehrotra and Sinha (1981) identified the following dinocysts:

* *Hystrichosphaeridium himalayaensis* Mehrotra & Sinha, 1981; pl. 152, p. 1, figs 7-9.
* *Areosphaeridium diktyoplokus* (Klumpp) Eaton, in Mehrotra & Sinha, 1981; p. 152, pl. 2, fig. 1.
* *A. arcuatum* Eaton, 1971; in Mehrotra & Sinha, 1981; p. 152, pl. 2, fig. 2.
* *Hystrichokolpoma unispinum* Williams & Downie, 1966, in Mehrotra & Sinha, 1981; p. 152, pl. 2, fig. 9.
  Oligosphaeridium complex (White) Davey & Williams, 1966, in Mehrotra & Sinha, 1981; p. 152, pl. 1, figs 1, 2.
  O. pulcherrimum (Deflandre & Cookson) Davey & Williams, 1966, in Mehrotra & Sinha, 1981; p. 152, pl. 1, figs 3-5.
* *Oligosphaeridium* sp., in Mehrotra & Sinha, 1981; p. 153, p. 1, fig. 6.
  Gonyaulacysta sp., in Mehrotra & Sinha, 1981; p. 153, pl. 3, figs 5, 6.
* *Deflandrea speciosa* Alberti, 1959, in Mehrotra & Sinha, 1981; p. 153, pl. 3, fig. 9.
* *Homotryblium tenuispinosum* Davey & Williams, 1966, in Mehrotra & Sinha, 1981; p. 153, pl. 2, figs 3-5.
* *Cordosphaeridium exilimurum* Davey & Williams, 1966, in Mehrotra & Sinha, 1981; p. 153, pl. 2, fig. 6.
* *C. sangchamallai* sp. nov. Mehrotra & Sinha, 1981; p. 153, pl. 2, figs 7, 8.
* *Systematophora schindewolfi* (Alberti) Neale & Sarjeant, 1962; in Mehrotra & Sinha, 1981; p. 153, pl. 3, fig. 4.
* *Diphyes colligerum* (Deflandre & Cookson) Davey & Williams, 1966 in Mehrotra & Sinha, 1981; p. 153, pl. 3, fig. 2.
* *Cleistosphaeridium disjunctum* Davey *et al.*, 1966, in Mehrotra & Sinha, 1981; p. 154, pl. 3, fig. 1.
* *Adnatosphaeridium* sp., in Mehrotra & Sinha, 1981; p. 154, pl. 3, fig. 3.
* *Odontochitina cribropoda* Deflandre & Cookson, 1955, in Mehrotra & Sinha, 1981; p. 154, pl. 3, figs 7, 8.

The dinocyst taxa marked by an asterisk in the above list need a proper reallocation and are discussed.

TAXONOMIC REMARKS

Our interpretations presented here are solely based upon the face value of illustrations and descriptions provided by Mehrotra and Sinha (1981). Repository of the type material is not given by the authors and the slides were not available for restudy. The plate and figure numbers cited in this present paper refer to Mehrotra and Sinha (1981).

1. *Hystrichosphaeridium himalayensis* Mehrotra & Sinha (1981) is considered to be a junior synonym of *Oligosphaeridium complex* (white) Davey *et al.* (1966). The holotype of this species illustrated by Mehrotra & Sinha (1981, pl. 1, fig. 7) is a poorly preserved specimen showing presence of a process-free paracingular area, an apical archaeopyle and intratabular tubiform processes which are distally expanded with aculeate terminations. These characters suggest its placement under *Oligosphaeridium complex* rather than *Hystrichosphaeridium* which differs from *Oligosphaeridium* in having paracingular processes. The paratype illustrated in Pl. 1, fig. 8 differs from the holotype in having greater number of processes which are relatively shorter and broader, and a few processes with trifurcate distal ends; the archaeopyle is not clearly marked. Hence, this specimen is tentatively referred here to *Achomosphaera*.

2. *Areosphaeridium diktyoplokus* (Klumpp) Eaton (1971) is distinguished by its solid, fibrous intratabular processes with stems of variable length and breadth terminating in a broad, net-like distal platform which is circular to polygonal in outline with irregular to entire margin. The development of distal platform is not a uniform all round expansion of stem but a broad, blunt bifurcation (Eaton, 1971, p. 359). Based on restudy of the type material, Sarjeant (1981, p. 114) noted that the distinctive clypeate distal terminations of the processes of both holotype and paratype have irregular, not entire, margins.

The Sangchamalla specimen referred to *A. diktyoplokus* by Mehrotra and Sinha (1981, pl. 2, fig. 1) does not show the characteristic process termination of this species. Instead, it shows gradual funnel-like distal expansion of the processes giving an indication that lumen is extending into the stem which apparently seems to be hollow. The distal terminations of processes have distinctly spinose margins. Illustrations of *A. diktyoplokus* provided by Eaton (1971) and Sarjeant (1981) do not show spinose margins of the distal platform. The Sangchamalla form shows closer affinity with *Oligosphaeridium* which differs from *Areosphaeridium* in having non-fibrous, hollow, tubiform processes and lacks the characteristic distal terminations. Although the non-fibrous and hollow nature of the process stem are not clearly discernible in the poorly preserved Sangchamalla specimen, the fenestrated funnel-like distal terminations of the long, slender processes with spinose margins, alongwith process-free paracingular zone and apical archaeopyle suggest its placement under *Oligosphaeridium pulcherrimum* (Deflandre & Cookson) Davey & Williams, 1966.

3. *Areosphaeridium arcuatum* Eaton was considered by Sarjeant (1981, p. 115) as a junior synonym of *Areosphaeridium dictyostilum* (Menendez) Sarjeant. However, this was rejected by Lentin and Williams (1981) maintaining *A. arcuatum* as proposed by Eaton (1971).

A. arcuatum is characterised by intratabular processes having solid, fibrous stems which are distally expanded and bifurcate (licrate). The bifurcations are of variable length and have denticulate or irregular distal margin, sometimes with a net-like structure.

The poorly preserved Sangchamalla specimen referred to *A. arcuatum* by Mehrotra and Sinha (1981, pl. 2, fig. 2) shows a process free paracingular area, apical archaeopyle and apparently hollow processes with gradual funnel-like distal expansions showing development of lumen, and aculeate distal margins. These features clearly suggest *Oligosphaeridium complex* affinity.

4. The specimens referred to *Homotryblium tenuispinosum* Davey & Williams (1966) by Mehrotra and Sinha (1981, pl. 2, figs 3-5) include two different morphotypes. Two specimens (figs 3, 4) belong to *Oligosphaeridium complex* due to smaller number of slender and hollow tubular processes with distinctly aculeate distal ends, an apparently process free paracingular area and an apical archaeopyle. The third specimen (fig. 5) shows broader and apparently fibrous processes and does not show any resemblance to the figs 3 and 4 of the same Plate. It, however, appears to be similar to the other three specimens illustrated in pl. 2, figs 7-9 as discussed below.

5. The dinocyst specimens referred to *Homotryblium tenuispinosum* (pl. 2, fig. 5), *Cordosphaeridium sangchamallai* (pl. 2, figs 7, 8) and *Hystrichokolpoma unispinum* (pl. 2, fig. 9) are poorly preserved and distorted.

Cordosphaeridium sangchamallai Mehrotra & Sinha (1981) is stated to differ from *C. inodes* only in the slightly smaller size range of the cyst and the processes. This is, however, not a significant character for the creation of a new species. The holotype of *C. sangchamallai* (Mehrotra & Sinha, 1981, pl. 2, fig. 7) shows a process free paracingular area and fibrous, tubular processes. These characters suggest its placement under *Cordosphaeridium* sensu Sarjeant (1981). Though Mehrotra and Sinha (1981) mention the archaeopyle to be apical and haplotabular, it is not clearly marked in the illustrated specimens. Should the archaeopyle prove to

be precingular, these specimens may be assigned to *Cordosphaeridium inodes*.

The forms illustrated in pl. 2, figs 5 and 9, referred to as *Homotryblium tenuispinosum* and *Hystrichokolpoma unispinum* respectively, show close resemblance to figs 7 and 8 of the same plate in having tubular, apparently fibrous and hollow, intratabular processes with slightly expanded distal ends. These forms are also referred to *Cordosphaeridium* for the present.

6. The dinocyst specimen referred to *Cordosphaeridium exilimurum* by Mehrotra and Sinha (1981, pl. 2, fig. 6) is poorly preserved and distorted. In a recent study, Sarjeant (1981) observed that the holotype of *C. exilimurum* displays the presence of paracingular processes and is, therefore, not assignable to *Cordosphaeridium* as emended therein. He suggested its alternative placement under *Hystrichosphaerina* or *Plethysyrinx* depending upon the apical or precingular archaeopyle type respectively. Jain and Garg (1985) preferred to place this species questionably under *Tityrosphaeridium* due to the apparent absence of trabecular interconnection between processes. The 'Upper Flysch' forms having greater number of broad and fibrous processes are tentatively placed under *?Tityrosphaeridium exilimurum*.

7. *Diphyes colligerum* (Deflandre & Cookson) Davey & Williams (1966) is differentiated from *Coronifera* Cookson & Eisenack emend. Davey (1974) in having apical archaeopyle rather than precingular, found in the latter. The Sangchamalla specimen (Pl. 3, fig. 2) shows the presence of precingular archaeopyle and compares very closely to *Coronifera oceanica* described from the Lower Albian of Dalmiapuram Formation (Jain, 1977a, pl. 2, figs 18-22).

8. *Deflandrea speciosa* Alberti (1959), in Mehrotra and Sinha (1981, pl. 3, fig. 9), is characterised by a distinct apical archaeopyle with three horns—one apical, one postcingular and one antapical—suggesting affinity with *Endoceratium ludbrookiae* (Cookson & Eisenack), Loeblich & Loeblich (1968) rather than *Deflandrea* which has intercalary archaeopyle and one apical and two antapical horns.

9. Davey *et al.* (1966, pp. 169-170) instituted the species, *Cleistosphaeridium disjunctum* with a remark that the regular arrangement of processes seen in the specimen is not a typical feature of the genus and therefore made a provisional allocation to *Cleistosphaeridium*. Later Reid (1974, p. 591) considered that species to be a junior synonym of *Lingulodinium machaerophorum* (Deflandre & Cookson) Wall (1967).

The illustration of Mehrotra and Sinha (1981, p. 158, pl. 3, fig. 1) shows a badly preserved specimen which indicates the presence of an apical archaeopyle. It can be referred to *?Cleistosphaeridium* but not to *Lingulodinium machaerophorum*.

10. Alberti (1961, p. 60; pl. 10, figs 1-3, 6, 7) described *Hystrichosphaerina schindewolfi*, the type species of the genus, from the Turonian sediments of Germany. Later, Neale and Sarjeant (1962, p. 455) by implication transferred this species to *Systematophora*. Stover and Evitt (1978, pp. 57-58) and Davey (1982, p. 20) maintained the original status of this species. The Malla Johar specimens assigned to *Systematophora schindewolfi* by Mehrotra and Sinha (1981, pl. 3, fig. 4) should, therefore, be attributed to *Hystrichosphaerina schindewolfi*.

11. The specimen described as *Adnatosphaeridium* sp. and considered to represent a new species of the genus by Mehrotra and Sinha (1981, p. 154, pl. 3, fig. 3) does not show the process form of *Adnatosphaeridium*. It shows two different types of few intratabular processes and lacks interconnecting trabecular development. Position of archaeopyle, though mentioned to be 'apical' haplotabular by Mehrotra and Sinha (1981, p. 154), is not clearly marked in the illustrated specimen. It is referred here to as Dinocyst type A.

Checklist of revised dinocyst assemblages:

1. *O. complex* (Pl. 1, figs 1, 2, 4, 7 & 9; Pl. II, figs 2-4)
2. *O. pulcherrimum* (Pl. I, figs 3, 5, 6; Pl. II, fig. 1)
3. *?Achomosphaera* sp. (Pl. I, fig. 8)
4. *?Tityrosphaeridium exilimurum* (Pl. II, fig. 6)
5. *Cordosphaeridium inodes* (Pl. II, figs 7-8)
6. *Cordosphaeridium* sp. (Pl. II, figs 5, 9)
7. *Coronifera oceanica* (Pl. III, fig. 2)
8. *Hystrichosphaerina schindewolfi* (Pl. III, fig. 4)
9. *Odontochitina cribropoda* (Pl. III, figs 7, 8).
10. *Endoceratium ludbrookiae* (Pl. III, fig. 9)
11. *?Cleistosphaeridium* sp. (Pl. III, fig. 1)
12. *Gonyaulacysta* sp. (Pl. III, figs 5, 6)
13. Dinocyst type A (Pl. III, fig. 3)

AGE OF THE DINOCYST ASSEMBLAGE

The revised Upper Flysch dinocyst assemblage discussed above suggests total absence of Tertiary dinocyst taxa, identified and recorded by Mehrotra and Sinha (1981), viz., *Areosphaeridium diktyoplokus, A. arcuatum, Homotryblium tenuispinosum, Hystrichokolpoma unispinum, Deflandrea speciosa* and *Cleistosphaeridium disjunctum*. It further shows the absence of *Diphyes colligerum*, an Upper Cretaceous-Tertiary form. On the contrary, it has been noted that *Odontochitina cribropoda* and *Hystrichosphaerina schindewolfi* are restricted to the lowermost part of the Sangchamalla Formation, whereas the younger assemblages are characterised by the abundance of *Oligosphaeridium complex* and *O. pulcherrimum*, which occur in association with *?Tityrosphaeridium exilimurum, Cordosphaeridium* sp. and *Coronifera oceanica*. The stratigraphic position of the remaining

species, viz., *Endoceratium ludbrookiae* (identified as *Deflandrea speciosa* by Mehrotra & Sinha, 1981), *Gonyaulacysta* sp., *Cleistosphaeridium* sp. and Dinocyst type A in the studied sequence, has not been provided by Mehrotra and Sinha (1978, 1981). However, from their explanations of plates it appears that *E. ludbrookiae* (recorded as *Deflandrea speciosa*) comes from the same sample (No. 6828/76/6) from which species like '*Hystrichokolpoma unispinum*', (*Cordosphaeridium* sp.), '*Areosphaeridium diktyoplokus*' (*Oligosphaeridium pulcherrimum*), occurring in the topmost levels of the Sangchamalla Formation, are recorded. In our opinion, *Endoceratium* is most likely reworked from the older sediments in this area. The occurrence of *Endoceratium ludbrookiae* is quite intriguing as it has a restricted geologic range from Albian to Early Cenomanian (Millioud, 1975). The planktonic foraminifera indicate Turonian-Maestrichtian age for the 'Upper Flysch' succession.

The typical Upper Cretaceous marker dinocyst genus, *Dinogymnium*, is absent in the described dinocyst assemblages of 'Upper Flysch' sediments, though this is well represented in the Campanian-Maestrichtian sediments of Assam, southern India and other parts of the world (Jain *et al.*, 1975; Jain, 1977, 1977a).

In our opinion the dinocyst assemblage recorded from the 'Upper Flysch' succession primarily consists of Cretaceous taxa with *Cordosphaeridium* and ?*Tityrosphaeridium* as the only Upper Cretaceous elements extending into Lower Tertiary. The known stratigraphic ranges of the above mentioned taxa clearly reflect as Upper Cretaceous aspect.

For reasons discussed above, the proposal of Mehrotra and Sinha (1981) that the age of the Sangchamalla Formation does not restrict to Upper Cretaceous but extends from Upper Cretaceous to ?Upper Eocene, is not acceptable.

DEPOSITIONAL ENVIRONMENT OF 'UPPER FLYSCH' AND DINOCYSTS

Heim and Gansser (1939) and Mamgain and Sastry (1975) considered the 'Upper Flysch' to be deep water open sea deposits. However, Mehrotra and Sinha (1981, p. 160) visualised the predominance of dinocysts in the Upper Flysch sequence as an indication of shallow marine depositional environment within the flysch sedimentational cycle. They further inferred that the flysch graben with loaded sediments experienced pulsational vertical movements with shallowing and deepening of the basin.

Based on the lithology, sedimentary structures, trace fossils and microplankton evidences, it has now been well established by Kumar *et al.* (1977) that the Giumal Sandstone is a deposit of continental margin, mainly the continental slope, and the overlying 'Upper Flysch' succession (Jhangu Formation) was laid down in still deeper environment in a rapidly sinking basin. Further, according to Kumar *et al.* (1977, pp. 420, 431), the uppermost part of the 'Upper Flysh' represents an ophiolite succession, developed during the last phase of sedimentation when submarine fissures appeared leading to outpouring of the basic and ultrabasic lavas. These volcanic rocks occur interbedded with deep sea clays, radiolarian cherts and foraminiferal oozes in the Balcha Dhura Formation.

It is thus quite obvious that in such a sedimentation and tectonic framework, mere occurrence of dinocysts cannot be taken to indicate occurrence of a shallow marine environment within a 'pulsationally sinking and rising flysch basin' as surmised by Mehrotra and Sinha (1981). Any explanation put forward to account for the occurrence of dinocysts in the 'Upper Flysch' succession should logically conform with the palaeoenvironmental model visualised by Kumar *et al.* (1977). According to Mehrotra and Sinha (1981, p. 151), dinocysts are mostly recovered from purple, green and black shales while arenaceous and calcareous lithologies are barren. The recorded assemblage represents an open sea assemblage due to the abundance of chorate cysts. Occurrence of dinocysts in these deep sea 'Upper Flysch' sediments can be attributed to two processes. These dinocysts might have accumulated through direct settling from the euphotic zone to the deep sea basin where these were ultimately deposited alongwith clay/silt size sediments. Equally significant may be the role of turbidity currents which might have periodically transported dinocysts with fine terrigenous clastics that were being laid down contemporaneously at the shallower regimes of the basin. Before drawing any inferences, it is, however, desirable to have a look at the known distribution of dinoflagellate cysts in the surface sediments of the present day oceans.

In modern sediments, fairly rich assemblages of dinoflagellate cysts are recorded from abyssal plain in western Carribean by Wall (1967) and continental slope of South Africa by Davey (1971). Dinocysts have been recorded throughout the Atlantic from ocean trench to intertidal sediments (Williams, 1971; Reid & Harland, 1977, p. 155). Occurrence of dinocysts in deep sea 'red clays' is also known (Williams, 1971, p. 239). Wall (1967) considered direct settling of cysts from the euphotic zone as the main cause for accumulation of dinocysts in Yacatan Basin lutites from two sediment cores at depths of over 4,000 m in the Carribean. Redeposition of neritic sediments, which contain a far greater number of dinocysts, is thought to be a less likely cause in view of the small amount of reworking of microplankton noted in these lutites. Wall (1967) has, nevertheless, suggested further investigation of 'possibly disturbing influence' of turbidity currents on composition of deep sea

microplankton assemblages. Davey (1971)noted the richness of dinocysts in continental slope and shelf sediments of South Africa in areas within the zone of current mixing in surface waters and with very little turbulence. This, according to Davey (1971), would have allowed rapid settling and concentration of dinocysts acting as fine grained sedimentary particles. Though dinocysts are recorded from a variety of lithologies in modern sediments, it has generally been found that cysts are selectively concentrated in fine grained sediments and appear to act as fine silt particles (Wall, 1971; Dale, 1976).

It is true that palaeoenvironmental interpretations of older dinocyst assemblages shall remain only tentative till more information is gathered about the biocoenosis and thanotocoenosis of Recent dinoflagellates and their cysts in the modern sediments. In spite of this, it would not be preposterous to attribute the occurrence of dinocysts in deep sea 'Upper Flysch' sediments of Malla Johar to direct settling from surface waters as well as to the periodic influence of turbidity currents. It is to be noted that low density and low energy turbidity currents were periodically operative during the deposition of Giumal Sandstone and Jhangu Formation (Kumar *et al.*, 1977). Association of turbidite sequences, dark coloured shales and oozes which occur interstratified in the Jhangu Formation, is attributed by Kumar *et al.* (1977, p. 431) to quick changes in the supply of material from land and minor fluctuations in the basin depth. The latter remained almost throughout near the continental margin on or beyond the continental slope. The dinocysts might have been brought down periodically to the deeper regimes of the basin through turbidity currents alongwith fine terrigenous clastics from the shelf areas. This also lends some credence to our contention that reworking of Lower Cretaceous dinocysts might have taken place.

It is also interesting to note that Mamgain and Sastry (1975) and Sastry and Mamgain (1977) reported the occurrence of pteridophytic spores and angiospermous and gymnospermous pollen grains in the 'Upper Flysch' sediments. They considered the occurrence of these land derived microfloral elements in deep water open sea deposits as only indicating proximity of the coast and presence of near shore vegetation.

It is, therefore, considered that the dinoflagellate cysts recovered from the 'Upper Flysch' were most probably brought down in a deeper environment near the continental margin through transportation from shallower regions by some sedimentary processes and were subsequently deposited there.

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