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Palynology and palynofacies analysis of the Subathu Formation (early Ypresian–middle Lutetian) of Morni Hills, Haryana, India

SAMIR SARKAR[1, 2], MARCELA SVOBODOVÁ[3] AND SUMAN SARKAR[1*]

[1]Birbal Sahni Institute of Palaeosciences, 53 University Road, Lucknow 226 007, India.
[2]L–6/153, Sector–M, Aliganj, Lucknow 226 024, India.
[3]Institute of Geology of the Czech Academy of Sciences, v.v.i., Rozvojová 269, 165 00 Prague, Czech Republic.
**Corresponding author: suman.sarkar@bsip.res.in*

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ABSTRACT

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Palynofossils and sedimentary organic matter recovered from two well exposed stratigraphic sections of the Subathu Formation (early Ypresian to middle Lutetian) outcropping in the Morni Hills, Haryana (Lesser Himalayas) are evaluated to interpret the depositional environment. The Morni Hills' palynofloral assemblage consists of dinocysts, spores, pollen grains, fungal spores and ascostromata, and freshwater algae. Among these the significant palynotaxa are *Pediastrum diffusus, P. angulatus, Achomosphaera ramulifera*, *Adnatosphaeridium multispinosum*, *A. vittatum, Areoligera senonensis*, *Systematophora diversispinosum*, *Cordosphaeridium fibrospinosum*, *C. gracile*, *Glaphyrocysta exuberans*, *Homotryblium abbreviatum*, *H. pallidum*, *H. tenuispinosum*, *Hystrichokolpoma salacium*, *Hystrichosphaeridium tubiferum, Lingulodinium machaerophorum, Operculodinium centrocarpum, Thalassiphora pelagica, Lygodiumsporites lakiensis, Todisporites major, Pteridacidites* sp., *Podocarpidites couperi, Neocouperipollis brevispinosus,* etc.

Five assemblage zones along with one barren zone are recognized on the basis of restricted species and variable abundance data of the examined palynofossils. Dinoflagellate cyst associations show a remarkable change from the older to younger horizons in the present succession. Variation in the composition of the assemblages from lower to upper horizons of the present succession might have been governed by several factors, viz. change in salinity concentration, decrease in water depth, and increase in proximity to the shoreline. Different types of organic matter types were also characterized, whose relative proportions in a vertical succession in both the sections, show changing depositional environmental gradients in this area. The study indicates that the basal carbonaceous shales seem to have been deposited in a freshwater swamp environment. Later, an open lagoon followed by closed lagoon and tidal flat environments are interpreted during the progradational sequence of the regressive phase.

Key–words—Palynoflora, Facies, Subathu, Eocene, Morni Hills, Lesser Himalayas.

INTRODUCTION

THE Eocene marine sediments of the Himalayan foothills have been designated as the "Subathus" (Medlicott, 1864, 1879). The rocks of this formation developed as a discontinuous outcrop along the narrow belt in the extra–peninsular region of the Indian subcontinent extending from Jammu in the west to as far as Nepal in the southeast. In the Morni Hills of Haryana, they rest unconformably on the pre–Tertiary Tundapathar limestones (Hore, 1979). Microfossils like benthic foraminifera and ostracods have been used for the biostratigraphy of the Subathu rocks in the Morni Hills (Bagi, 1992; Mathur & Juyal, 2000). Basic palynostratigraphy and the depositional environment of the Kharak section outcropping in the Morni Hills have earlier been discussed by Sarkar and Prasad (2000a). However, the depositional history of the basal beds of the Subathu succession has mostly remained unknown due to its unfossiliferous nature. It is also not possible to date the entire outcrop of the Subathu Formation purely on the basis of floral and faunal fossils because of their sporadic occurrences limited only to certain levels of the Subathu succession pertinent to the Morni Hills.

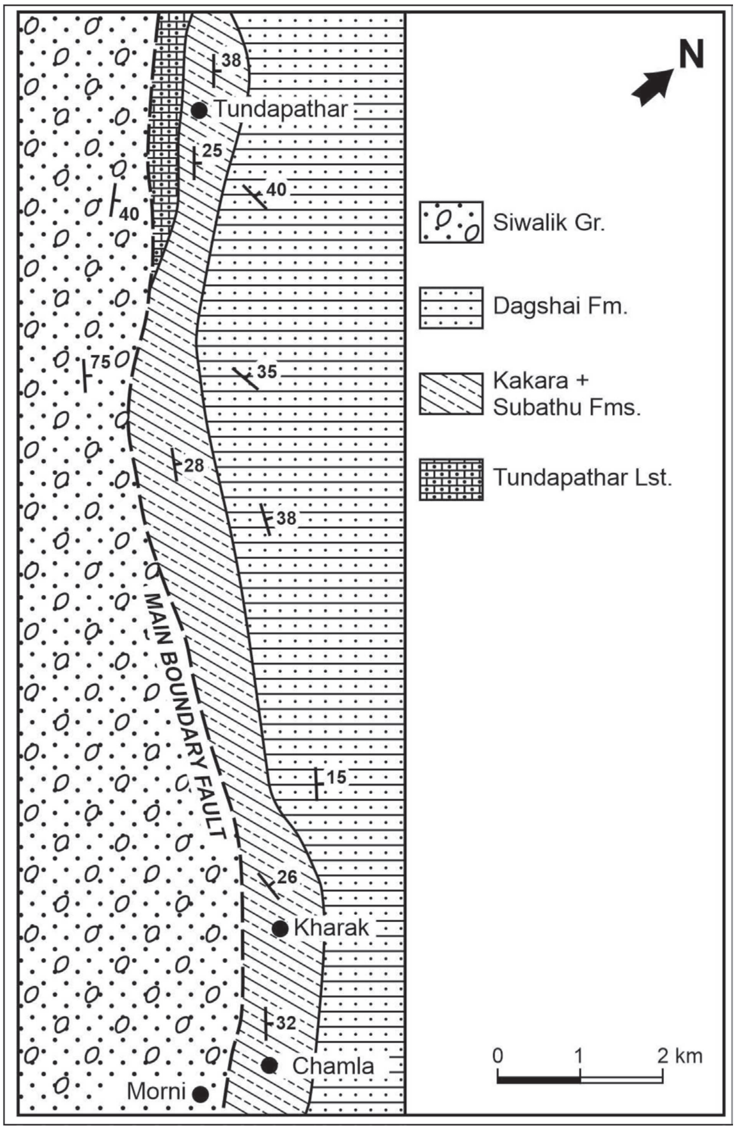


Fig. 1—Geological Map showing the study area (after Mathur & Juyal, 2000).

Moreover, the lithofacies varies considerably from place to place that is a hindrance in their correlation.

Particulate organic matter behaves as any other sedimentary grains with their own specific physical characteristics (Tyson, 1993, 1995, 2000; Huc, 1988; Aggarwal *et al.,* 2015, 2017, 2019a, b; Aggarwal, 2022). They provide information regarding their origin, transport conditions and diagenetic evolution. Palynofacies analysis has also been used extensively in the interpretation of palaeoenvironments (Burgees, 1974; Fisher, 1980; Hancock & Fisher, 1981; Parry *et al*., 1981; Sladen & Batten, 1984; Whitaker, 1984; Batten, 1996; Tripathy, 1997; Jaramillo & Oboh–Ikuenobe, 1999; Hermann *et al.,* 2012; De Wetering *et al.,* 2013; Slater & Wellman, 2015; Zarei, 2017; Mishra & Singh, 2018; Murthy *et al.,* 2019; Aggarwal *et al*., 2019a, b; Kumar *et al.,* 2021). In view of this, a detailed palynological investigation with major emphasis on the palynofacies characteristics were applied for the purpose of biostratigraphic zonation and also for the interpretation of palaeoenvironmental conditions during early Ypresian–middle Lutetian in the Morni Hills, Haryana.

GEOLOGICAL SETTING AND LOCAL STRATIGRAPHY

The Subathu Formation represents the lowermost marine sequence of the Tertiary rocks in the Morni Hills. It is overlain by the Dagshai Formation with a gradationally conformable contact (Fig. 1). The rocks of this formation rest unconformably on the Pre–Tertiary Tundapathar limestones. The general geological succession of this area (Hore, 1979) is as follows:

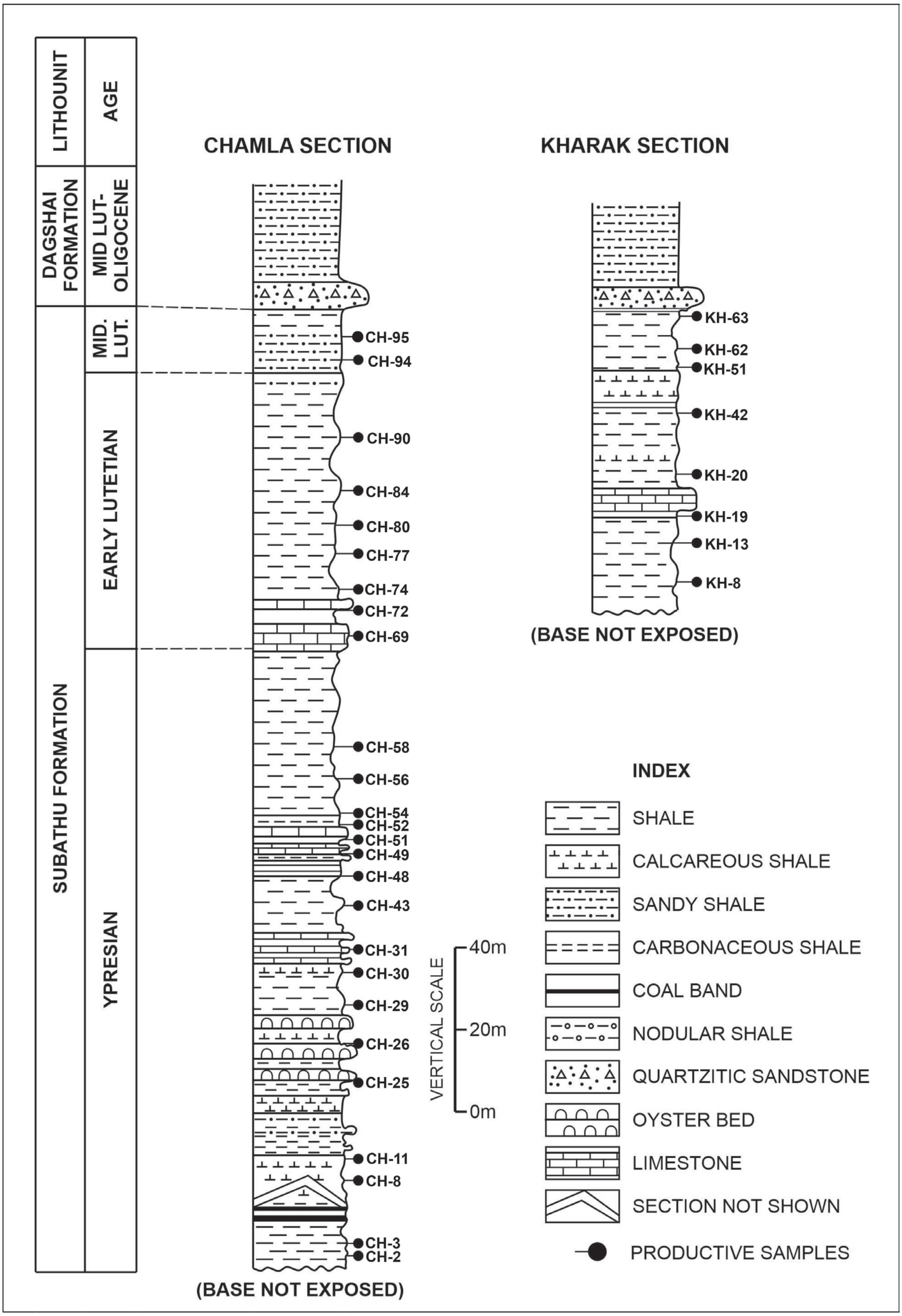


Fig. 2—Lithocolumns of the Chamla and Kharak River sections highlighting the location of the productive samples.

Subathu Group (Eocene)
——————Unconformity?——————
Tundapathar Group (Pre–Tertiary)
Thrust contact

The Tundapathar Group along with the overlying Subathu Group thrusts over the younger Nahan Group as parautochthonous unit along a major boundary fault. The basal part of the Subathu Formation is composed mainly of highly friable and calcareous black shales with pockets of calcite, pyrites and haematite nodules. The middle part is characterised by grey, olive–green splintery shales with 1–1.5 m thick band of shelly limestones. Needle shales are friable and intercalated with the bedded shales. The upper horizons mainly consist of olive green splintery shales with siltstone bands. The Subathu Formation conformably grades into the Dagshai Formation. The Subathu Formation in the Morni Hills attains a thickness of about 240 m and has a NE–SW strike with 10–20° dip to the north–west. One of the presently studied sections is the Chamla section, situated on the east bank of the Ghaggar River near the village Chamla in Haryana. The beds are overturned and show high dips due southwest. In the lower parts, the dips are highly variable. The lowest part of the profile consists of grey to black carbonaceous shales (partly phyllitic) intercalated with calcite veins and shelly limestones with oyster bands. The middle part of the sequence is quite thick and at the base, grey shales occur that show gradation into black shales towards the top. The upper horizons start with a 2 m thick carbonate build–up followed by 6 m of splintery shales. The sequence is overlain by white quartzitic sandstone and marine nodular shales of the Dagshai Formation. The other section analysed is the Kharak section, which is situated on the west bank of the river Ghaggar near the village Kharak. A 68 m thick rock sequence is exposed in this section. The contact between the Subathu and Dagshai units is overturned in this section and shows high dips varying from 75° to 80° in the S–W direction with a NW–SE trending strike (Bagi, 1992). The basal beds mainly comprise black carbonaceous shales which are overlain by grey splintery shales. White quartzitic sandstones are overlain by the red nodular beds of the Dagshai Formation.

MATERIAL AND METHODS

The present palynological investigation is based on the detailed study of 170 samples collected from two stratigraphic sections of the Subathu Formation. 34 study samples yielded diagnostic dinoflagellate assemblages associated with angiosperm pollen grains, fungal spores and conidia, algal remains and pteridophytic spores. The location of palynologically productive samples is demonstrated in Fig. 2. For the recovery of palynofossils, samples were processed by the conventional maceration technique with HCl, HF, HNO_3 and KOH. The acetolysis process was used when the palynomorphs were dark in color. Sedimentary organic matter was recovered applying standard palynological treatment with non–oxidizing acids. Quantitative estimation of each organic matter constituent was done by counting at least 200 particles. Diversity and abundance of phytoplankton with their size,

PLATE 1 ⟶

All photomicrographs are magnified ca x 500, unless otherwise mentioned. Coordinates of the specimens refer to the stage of BX–50 Olympus microscope. Scale Bar equals 40 µm.

1. *Spiniferites mirabilis* (Rossignol, 1964) Sarjeant, 1970, BSIP Slide No. 12755, coordinates 108 x 52.
2. *Diphyes colligerum* (Deflandre & Cookson, 1955) Cookson, 1965, BSIP Slide No. 12756, coordinates 37 x 93.
3. *Pentadinium laticinctum* Gerlach, 1961, BSIP Slide No. 12757, coordinates 35 x 99.
4. *Homotryblium abbreviatum* Eaton, 1976, BSIP Slide No.12758, coordinates 42 x 95.
5. *Gonyaulacysta* sp., BSIP Slide No. 12769, coordinates 56 x 103.
6. *Adnatosphaeridium vittatum* Williams & Downie, 1966, BSIP Slide No. coordinates 32 x 101.
7. *Achomosphaera multifurcata* Jain & Tandon, 1981, BSIP Slide No. 12771, coordinates 23 x 104.
8. *Lingulodinium machaeroforum* (Deflandre & Cookson, 1955) Wall, 1967, BSIP Slide No. 12769, coordinates 38 x 105.
9. *Polysphaeridium* sp., BSIP Slide No. 12774, coordinates 27 x 101.
10. *Glaphyrocysta vicina* (Eaton, 1976) Stover & Evitt, 1978, BSIP Slide No. 12755, coordinates 51 x 108.5
11. *Adnatosphaeridium* sp., BSIP Slide No. 12775, coordinates 24 x 104.
12. *Hystrichokolpoma salacia* Eaton, 1976, BSIP Slide No. 12776, coordinates 37 x 104.
13. *Spiniferites membranaceus* (Rossignol, 1964) Sarjeant, 1970, BSIP Slide No. 12768, coordinates 56 x 113.
14. *Homotryblium tenuispinosum* Davey & Williams, 1966 BSIP Slide No. 12763, coordinates 46 x 109.
15. *Neocouperipollis brevispinosus* Sarkar & Singh, 1988, BSIP Slide No. 12762, coordinates 65 x 100.
16. Angiosperm pollen type–1, BSIP Slide No. 12765, coordinates 46 x 104.
17. *Achomosphaera* sp., BSIP Slide No. 12772, coordinates 63 x 106.

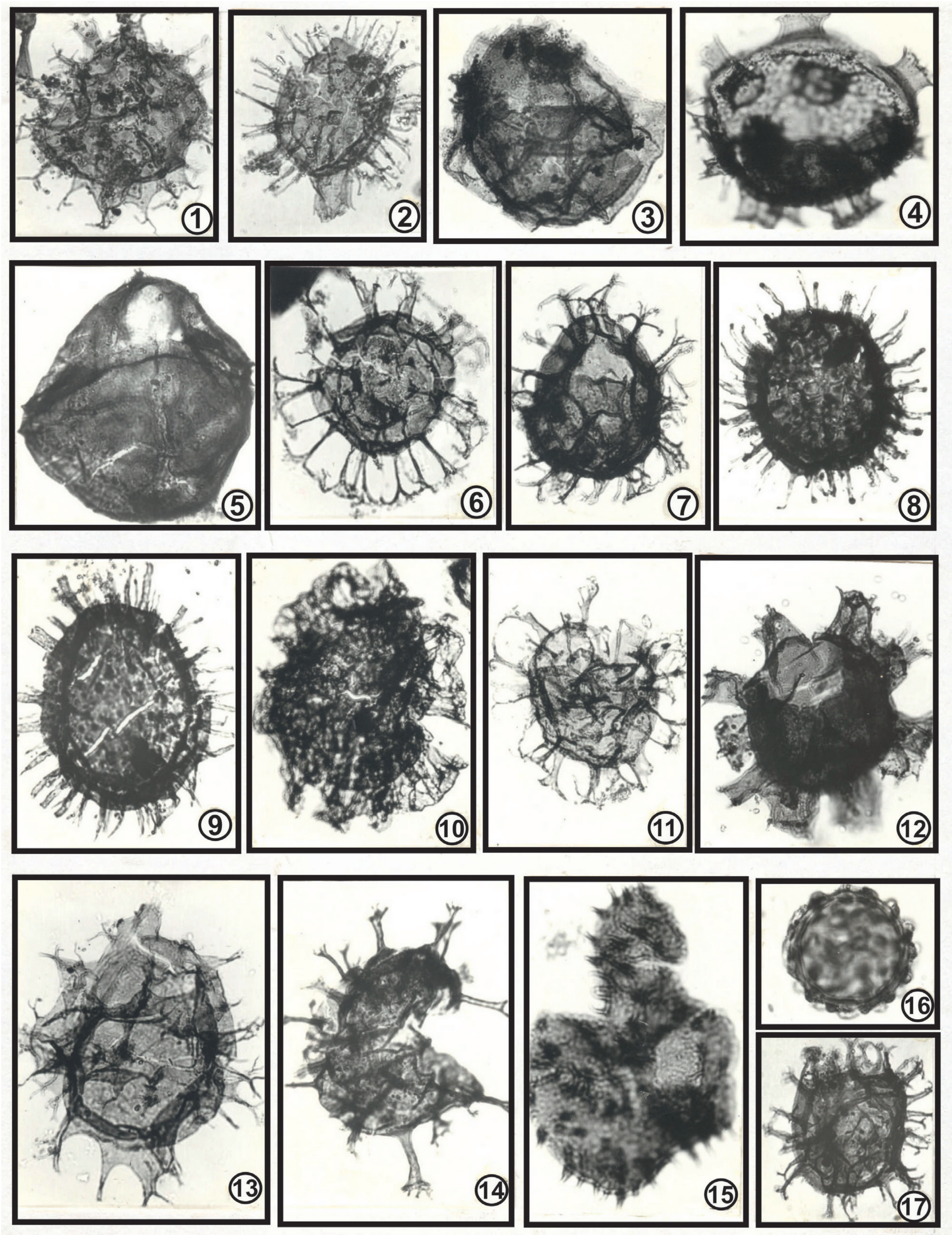


PLATE 1

Scale Bar:

shape, and degree of biodegradation are some of the important aspects considered for the characterisation of sedimentary organic matter. The slides were prepared in polyvinyl alcohol and mounted in Canada balsam. All the figured slides are housed in the Repository of the Birbal Sahni Institute of Palaeosciences, Lucknow. Dinoflagellate cyst nomenclature proposed by Williams *et al.* (1998) has been adopted in the present study.

PALYNOTAXA

A total of 26 genera and 38 species of dinoflagellate cysts are recorded in the current study with *Achomosphaera*, *Adnatosphaerdium*, *Cordosphaerdium*, *Glaphyrocysta*, *Homotryblium*, *Hystrichokolpoma* and *Thalassiphora* showing >1 species. In addition, multiple species pertinent to the genus *Pediastrum* (*P. angulatus*, *P. compactum*, *P. diffusus* and *P. wilsonii*) representing freshwater algae, along with pteridophytic spores (*Cyathidites minor*, *Dictyophyllidites dulcis, Lygodiumsporites lakiensis, Pteridacidites* sp., *Todisporites major, T. minor* and *T. dagshaiensis*), gymnosperm pollen (*Podocarpidites couperi*) and angiosperm pollen (*Neocouperipollis brevispinosum*, *N. pyrispinosus* and *Palmidites noviculatus*) are also recovered from the study material. Fungal remains corresponding to the genera *Dicellaesporites, Multicellaesporites* and *Phragmothyrites* with some acritarchs (*Veriachium mornii*) and reworked palynotaxa (*Araucariacites* sp., *Callialasporites segmentatus, C. trilobatus* and *Cicatricosisporites* sp.and few others) are the other components. Some stratigraphically significant palynofossils and palynofacies types are illustrated (Pls 1–3).

RECORDED PALYNOFLORAL ASSEMBLAGE ZONES

Well preserved palynofloral assemblages are recorded from different levels of the investigated sections. Most of the recorded dinocysts, spore and pollen grains represent long ranging taxa but some of them are good markers, indicating the Eocene age. The dinocysts recovered from the Subathu Formation in the currently studied successions are divided into 5 groups based on the evaluated range of the distribution and relative abundance of the dominant species. Quantitative details of the identified groups from the two study sections are shown in Figs 3 and 4. Environmental characteristics of these associations in oceanic conditions and water depth of the habitat are inferred from information available (Ashraf, 1979; Kothe *et al.* 1988; Sarkar & Singh, 1988; Sarkar & Prasad, 2000 a, b). The characteristics and associated species of each group and lithofacies are given below:

Zone A (Succession Interval 0–7 m)

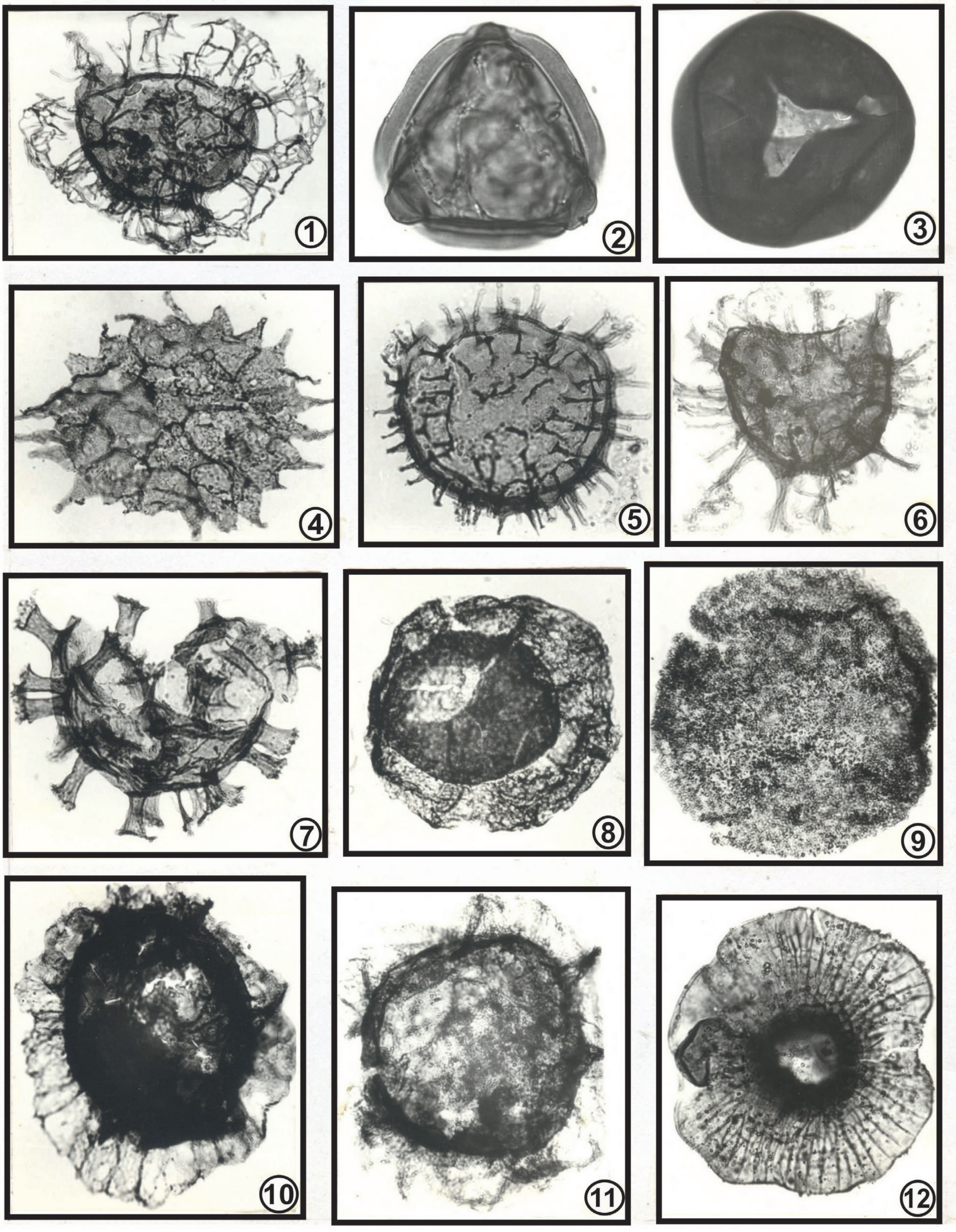
The dinocysts of this association occur mainly in the basal shale bed. The association is characterised by abundant large chorate dinocysts, viz. *Glaphyrocysta* and *Hystrichokolpoma*. In addition, *Systematophora* are commonly present. Most of the recorded species are interpreted to be mainly associated with the open marine conditions.

Lithofacies—This horizon mainly consists of shelly limestone, carbonaceous shales intercalated with thin coal beds. The lower contact could not be ascertained due to tectonically disturbed strata. The upper contact of this zone is delineated by the appearance of a black shale facies which is barren.

PLATE 2 ⟶

All photomicrographs are magnified ca x 500, unless otherwise mentioned. Coordinates of the specimens refer to the stage of BX–50 Olympus microscope. Scale Bar equals 40 µm.

1. *Adnatosphaeridium multispinosum* Williams & Downie, 1966, BSIP Slide No. 12772, coordinates 63 x 106.
2. *Pteridacidites* sp., BSIP Slide No. 12767, coordinates 53 x 97.
3. *Todisporites major* Couper, 1958, BSIP Slide No. 12766, coordinates 51 x 102.
4. *Pediastrum* sp., BSIP Slide No. 12777, coordinates 46 x 93.
5. *Polysphaeridium* sp., BSIP Slide No. 12761, coordinates 45 x 108.
6. *Fibrocysta axiale* (Eisenack, 1965) Morgenroth, 1966, BSIP Slide No. 12764, coordinates 55 x 102.
7. *Homotryblium* sp., BSIP Slide No. 12760, coordinates 60 x 111.5.
8. *Thalassiphora pelagica* (Eisenack, 1954) Eisenack & Gocht, 1960, BSIP Slide No. 12761, coordinates 45 x 110.
9. *Kallosphaeridium brevibarbatum* de Coninck, 1969, BSIP Slide No. 12773, coordinates 51 x 94.
10. *Membranilarnax pterospermoides* (O. Wetzel, 1933) Sarjeant, 1985, BSIP Slide No. 12770, coordinates 66 x 110.
11. *Cyclonephelium* sp., BSIP slide no 12761, coordinates 35 x 97.
12. *Trichothyrites setifer* (Cookson, 1947) Saxena & Misra, 1990, BSIP Slide No. 12769, coordinates 48 x 98.



Scale Bar:

PLATE 2

Significant palynofossils of this zone—*Glaphyrocysta compactum, G. exuberans, G. divaricata, Systematophora diversispinosum* and *Hystrichokolpoma cinctum.*

Barren Zone (8–22 m)

This zone mainly consists of massive black shale or splintery black shale associated with carbonate bands. 14 m thick black shale sequence is observed.

Lower contact—Black splintery shale ~5 m thick is found at the base of this zone.

Upper contact—The uppermost part of this zone is formed by black shale followed by greenish grey shale.

Lithofacies—This zone is characterised by a black shale facies, a product of euxinic environment. Euxinic conditions are most unfavourable for the preservation of the organisms and hence this zone is totally barren.

***Zone B* (Succession Interval 22–39 m)**

This zone occurred between 22–39 m of the succession. The most abundant species of the association are *Systematophora diversispinosum*, *Sentusidinium brevispinosum* and *Homotryblium abbreviatum*. They are commonly associated with *Hystrichokolpoma* spp. and *Muratodinium fimbriatum*. These forms are usually found in shallow–water environment, thus this association is thought to have thrived in habitats occurring between the low–tide mark and a water depth of ~30 m.

Lithofacies—This palynological zone mainly comprises greenish gray, thin bedded, calcareous, splintery shales with lenses of limestone. The shales are occasionally nodular.

Lower contact—Thin bedded greenish gray splintery shales overlying the black shales mark the lower contact of this zone.

Upper contact—The upper part of thin bedded shales forms the upper contact of this palynological zone.

Significant palynofossils of this zone—*Systematophora diversispinosum, Sentusidinium brevispinosum, Hystrichokol–poma salacium, Glaphyrocysta compactum* and *Muratodinium fimbriatum*.

***Zone C* (Succession Interval 39–69 m)**

This zone is characterised by the dominance of *Homotryblium* and the common occurrence of *Systematophora*. The species diversity is low with less than eight species. The genus *Homotryblium* is common and it indicates shallow marine environment in subtidal zone (depth range ~5–20 m).

Lithofacies—The olive green, calcareous splintery shales containing streaks and veins of calcite forms the base of this palynological zone.

Lower contact—Thin bedded shales gradually transit into olive green shales.

Upper contact—The percentage of *Homotryblium* decreases near the boundary of the upper part of this zone (the distance between lower and upper part is about 30 m).

Significant palynofossils of this zone—*Homotryblium tenuispinosum, H. abbreviatum, Thalassiphora pelagica* and *Systematophora diversispinosum*.

***Zone D* (Succession Interval 69–89 m)**

This palynological zone is found in the depth range 69–89 m. Dinoflagellate cysts occur sporadically in very fine gray shales. The most dominant species of this association are *Cordosphaeridium multispinosum, C. fibrospinosum* and *C. exilimurum*. They are commonly associated with *Thalassiphora pelagica*, *Todisporites major* and *Neocouperipollis* spp. This diagnostic association probably thrived in the upper sublittoral zone.

Lithofacies—The main lithounit of this zone comprises olive green calcareous splintery shales with marked increase in the carbonate contents, greenish grey splintery shales with more veins of calcite and very thin limestones.

Significant palynofossils of this zone—*Cordosphaeridium multispinosum, C. fibrospinosum, C. exilimurum, Thalassiphora pelagica, Todisporites major* and *Neocouperipollis* spp.

***Zone E* (Succession Interval 89–110 m)**

The upper part of the muddy, fine grained shale contains prominent land–derived phytoclasts and sporomorphs.

PLATE 3 ⟶

Organic matter types in the current study. (a) Opaque phytoclast; (b) Biodegraded wood/cuticles; (c) Amorphous organic matter; (d) Dinoflagellates; (e) Rootlets; (f) Fungal Body; (g) Spore; (h) Pollen Grain.

1–2. Palynofacies from upper part of the profile (Unit IV) rich in woody phytoclasts, biodegraded cuticles, tracheids and opaque phytoclasts.

3–4. Palynofacies from middle part of the profile (Units II and III) rich in dinoflagellate cysts, amorphous organic matter and brown debris.

5–6. Palynofacies from lower part of the profile (Unit I) rich in amorphous organic matter, fungal hyphae, rootlets and spore/pollen grains.

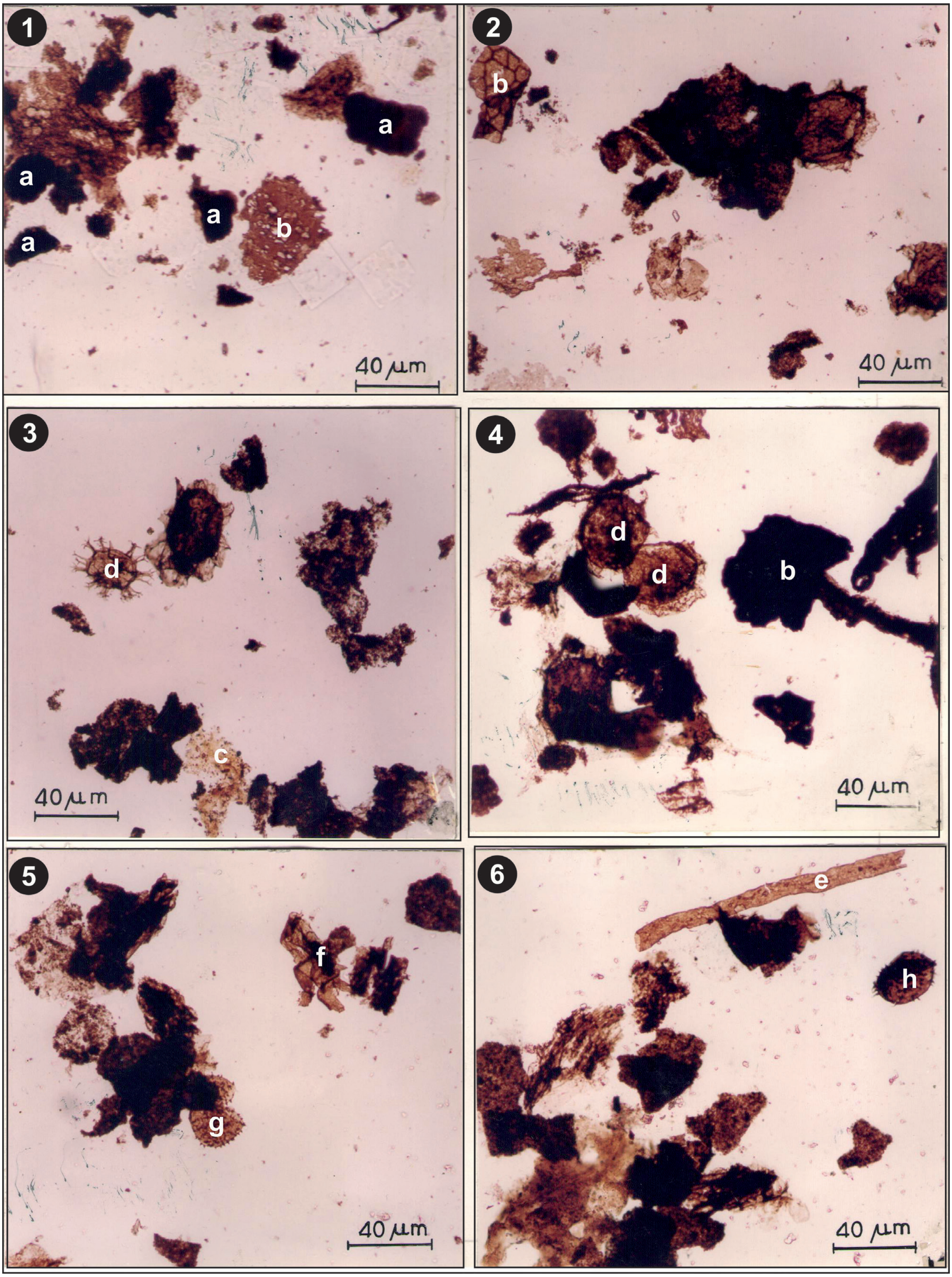


PLATE 3

Dinoflagellate cysts are diverse but *Thalassiphora* prevails as the most abundant taxon. This genus is dominant in the shallow–marine environment up to ~10 m depth. Therefore, the palaeoenvironmental conditions appear to be an embayment shallower than 10 m deep in a warm water environment.

Lithofacies—Massive to nodular pale olive–green shales with siltstone bands form the principal lithounit of this palynological zone. Shales are slightly arenaceous in composition. In the lower part of this palynological zone there are intercalations of gray shales whereas the upper part of the zone is intercalated with purple shale facies.

Significant palynofossils of this zone—*Thalassiphora pelagica, T. velata, Systematophora diversispinosum, Homotryblium tenuispinosum, H. abbreviatum, Cordosphaeridium multispinosum.*

Dinoflagellate cysts are present in all the samples except few basal samples (Sample nos. 3 and 8). Most of the species are represented by low to moderate number of specimens but some taxa show characteristic peaks in the frequency distribution at various levels. Terrestrial sporomorphs prevail in the depth of 63–85 m where marine palynofossils reach up to 20%. This interval contains the lowest number of marine species of all the studied samples. The dominance of *Homotryblium* in this interval is noteworthy. The most common taxa are *Homotryblium abbreviatum* and *H. tenuispinosum.* A diverse and abundant dinocyst assemblage is also recorded within the 68 to 76 m interval. Highest species diversity with 10–15 species per sample is recorded within this interval. *Thalassiphora pelagica* shows its highest abundance representing about 45% of the total palynoflora. *Cordosphaeridium* spp. are most abundant between 69 to 89 m of the stratigraphic section. At the top of the section there is a characteristic rise in the relative abundance of the species of *Spiniferites*. Palynofacies records comprise dinocysts, acritarchs, foraminiferal linings, spores and pollen as well as plant cuticles and other phytoclasts. It indicates a marine depositional environment. The basal samples are mostly woody in nature with some samples containing proportions of indeterminate organic fragments. The sediments are interpreted to have been deposited in near–shore conditions. Generally, the dispersed organic matter content of sediments from the neritic and marginal marine environments consists of two main components: organic matter derived from the continent (terrestrial) and the organic matter produced in the ocean such as dinoflagellate cysts and marine amorphous organic matter.

PALYNOFACIES

In the present study, only the relative proportion of different organic matter constituents and their quantitative assessments in the two measured stratigraphic sections of the Subathu Formation, viz. Kharak and Chamla of the Morni Hills are carried out to get a holistic interpretation of the depositional environment. Distribution of the relatively autochthonous fraction (dinocysts, acritarchs) depends upon the nutrient status, salinity, pH and redox state of the water column. On the contrary, the distribution of allochthonous particles like pollen, spore, and land–derived elements is mainly controlled by physical processes (wind, fluvial activity). Several schemes of palynofacies classification have been proposed (Staplin, 1969; Combaz, 1980; Masran & Pocock, 1981; Batten, 1983; Whitaker, 1984; Boulter & Riddick, 1986; Hart, 1986; Pocock *et al*., 1987). In the present study, seven organic matter types are distinguished that are briefly described below:

Black Debris—Black opaque fragments commonly designated as inertinite. It is mostly derived from the lignified tissues of higher plants. The black color is due to highly oxidizing environmental condition.

Degraded Brown Debris—Orange brown opaque debris with poorly visible cellular structure. It mostly originates from the lignified tissue of the higher plants and represents moderately oxidizing environment.

Structured Debris—The cellular structures are clearly visible. It mostly originates from cuticles of higher plant leaves. Its dominance in the shallow–marine region indicates low–energy and reducing conditions in a more proximal setting.

Yellow Debris—Translucent with or without structural details mostly originates from fresh water algal tissue. Its dominance in shallow–marine conditions indicates proximal and restricted depositional environment.

Amorphous Organic Matter—It appears as fluffy lumpy and granular mass of tissue without any finer structural details. It represents the end product of bacterial decay. It is mostly derived from the degradation of marine constituents (dinocysts and acritarchs).

Dinocyst/Acritarch—Marine microplankton.

Pollen/spore and freshwater (green) algae—Pollen and spores of terrestrial plants and freshwater alga *Pediastrum.*

On the basis of qualitative and quantitative analyses of different organic matter types in the early Ypresian–middle Lutetian sequence, the Subathu succession in the present area of investigation has been divided into four units:

Unit I—The main lithology is carbonaceous shale. Palynofacies shows dominance of terrestrial debris. The basal part (2 m) of this unit consists of well–preserved cuticles, yellow debris, rootlets and algal zygospores followed by the dominance of unsorted black debris of terrestrial origin and abundant pteridophytic spores. Dinoflagellate cysts, viz. *Kallosphaeridium* and *Systematophora* prevail only in the upper part of this unit.

Depositional Environment—Palynofacies characteristic of carbonaceous shales indicate freshwater swamp–like environment. The basal parts of carbonaceous shales deposited in the conditions with lower oxygen content while the upper

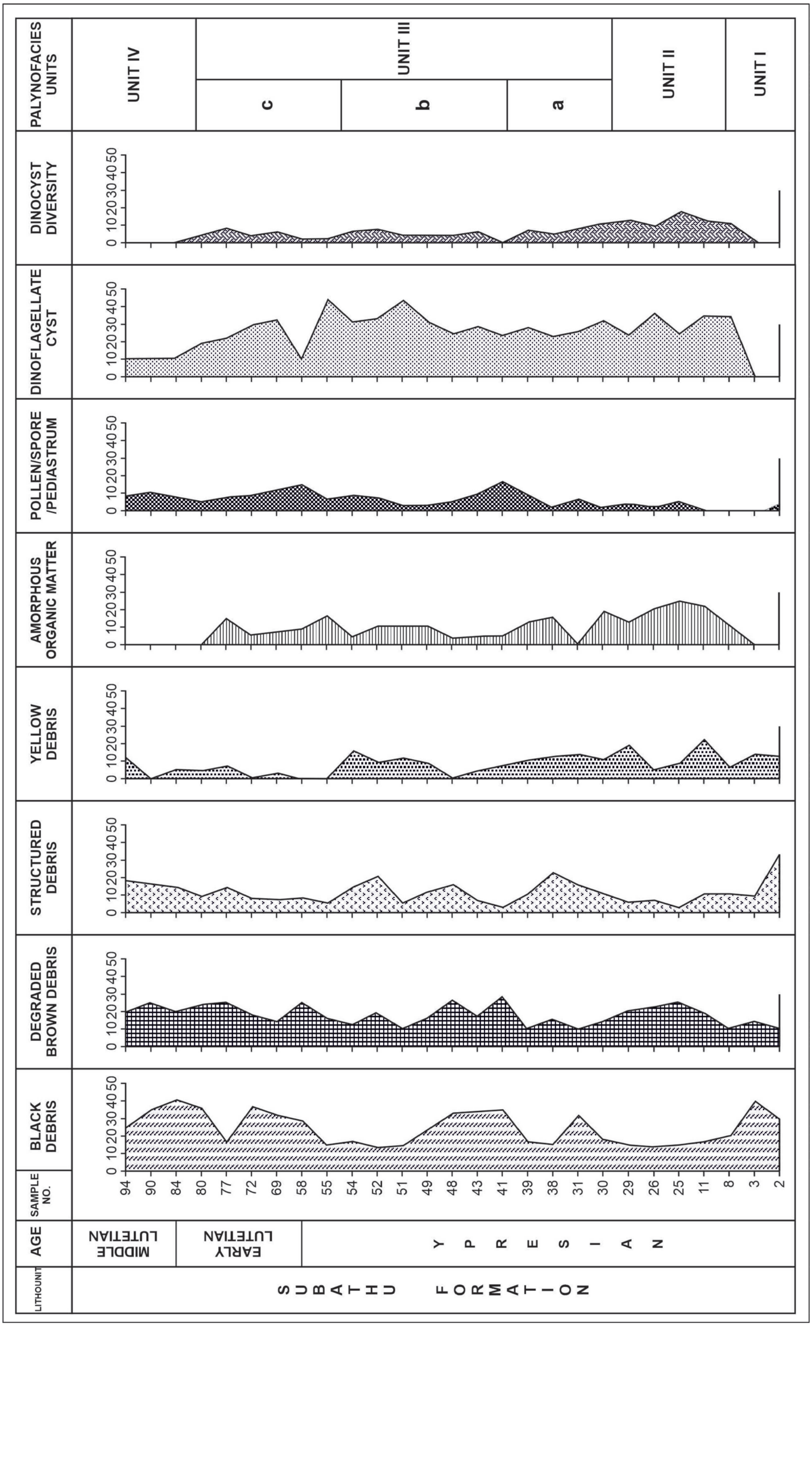


Fig. 3—Distribution of the dispersed organic matter types, dinoflagellates, pollen, spore and algal remains in the Chamla section.

part under normal oxygen conditions. Dinoflagellate cysts appear in the upper part of the section and correspond to brackish /marsh environment.

In the Kharak section, the sequence starts from the upper part of unit I, and the lower zone of unit I is completely absent. Dominance of pteridophytic spores in a sedimentary sequence indicates warm and humid climate (Rullkötter *et al*., 1982). However their abundance is considered as an erosional feature since it indicates pronounced fluvial input in to the marine system (Poumot, 1982).

Unit II—The diversity of dinoflagellate cysts as well as the amount of amorphous organic matter increases but the quantity of spores and pollen grains decrease. Black oxidized debris occur which are mostly equidimensional and blade–like forms. Marine constituents are represented by the dominance of chorate dinoflagellate taxa, i.e. *Homotryblium, Operculodinium, Achomosphaera, Glaphyrocysta,* etc.

Depositional Environment—The palynofacies characterise shallow–marine depositional conditions slightly influenced by tidal open marine environment. Presence of amorphous organic matter indicates low energy conditions and lower oxygen content in the water column. The blade shaped outline of the black debris characterises this unit. It is mostly derived from the lignified tissue of the plant material. Owing to its flat shape, its settlement on the sea floor is delayed identical to the mica flakes. Apart from the buoyancy scale, the black oxidized nature of these particles indicate their resistance to decay, hence can be transported more offshore without being further degraded. These particles have been considered as reworked debris in this unit.

Unit III—This unit is characterised by sudden influx of land–derived debris. The diversity and abundance of dinoflagellate cysts decrease. Due to altering character of the terrestrial debris, we divided this unit in three subunits.

Subunit I—This subunit shows dominance of yellow debris and freshwater alga *Pediastrum* and amorphous organic matter content, however black debris and degraded brown debris occurs in moderate quantity. Dominance of *Thalassiphora pelagica* and *Operculodinium centrocarpum* dinoflagellate cysts characterises this unit. The amorphous organic matter prevails in the Kharak section while the Chamla sequence is dominated by degraded brown debris.

Subunit II—This subunit is characterised by an increase in terrestrially derived black oxidized debris and decrease in degraded brown and yellow debris. Dinoflagellate cysts are represented by *Thalassiphora pelagica, Operculodinium centrocarpum* and common occurrence of *Aerosphaeridium arcuatum, Achomosphaera ramulifera, Adnatosphaeridium* spp. etc.

Subunit III—The basal part of this subunit is characterised by the dominance of yellow debris and *Pediastrum* with decrease in black debris and degraded brown debris. Dinoflagellate cysts are represented by *Thalassiphora pelagica, Muratodinium fimbriatum, Operculodinium centrocarpum* and *Lingulodinium macherophorum.*

Depositional Environment—The palynofacies characteristics indicates proximal and restricted type of depositional environment. Massive blooms of *Thalassiphora pelagica* is a characteristic feature of this unit. *T. pelagica* mostly dominates in low saline reducing water conditions (Kothe *et al*., 1988). The high percentage of black debris and degraded brown debris are indicative of increasing oxidizing conditions at the sediment–water interphase. Subunits I and II possibly represent open lagoonal settings. However, later on the environmental conditions become more restricted. Therefore, a closed lagoonal type of environment is envisaged for subunit III.

Unit IV—Palynofacies shows the increase of unsorted black oxidized debris, degraded brown debris and structured debris, pollen/spore and fungal elements and decrease in dinocyst taxa and complete absence of amorphous organic matter.

Depositional Environment–It indicates high oxidizing conditions due to intermittent sub–aerial exposure. Dominance of terrestrial debris indicates increased continental input. The sediments most probably deposited in tidal flat conditions.

COMPARISON OF MORNI SUBATHU (EOCENE) PALYNOFLORAL ASSEMBLAGE WITH THAT OF OTHER AREAS

Several palynological zonation schemes pertaining to the Subathu Formation have been published till date (Singh *et al*., 1978; Singh & Sarkar, 1992; Sarkar, 1997; Sarkar & Prasad, 2000a, b; Singh *et al*., 2007). It is very clear that existing zonation criteria can be applied precisely on both the sections of the Morni Hills, viz. Chamla and Kharak. Singh *et al.* (1978) divided the Subathu succession in seven cenozones and two subzones based on the data obtained from several sections of Kalka–Shimla areas of Himachal Pradesh whose age ranges from late Thanetian to Priabonian. Palynofloral data suggests that this zonation scheme is also applicable in the present area of investigation.

The samples from 2–8 m interval at the base contain marine microflora which is characteristic of the *Cyclonephelium* spp. cenozone described by Singh *et al.* (1978). The presence of *Glaphyrocysta exuberans* indicates that this interval is not older as envisaged by Singh *et al.* (1978).

The 39 to 48 m of the Chamla section is characterised by the dominance of *Homotryblium.* The dinoflagellate cyst assemblages contain several species known from the *Homotryblium* cenozone of Singh *et al.* (1978). These taxa range in age from late Ypresian to middle Lutetian. The high percentage of *Homotryblium* spp. in this horizon suggests that this interval should be referred to the *Homotryblium* cenozone of Singh *et al.* (1978). The benthic foraminifera records from this horizon also indicates a late Ypresian age (Bagi, 1992).

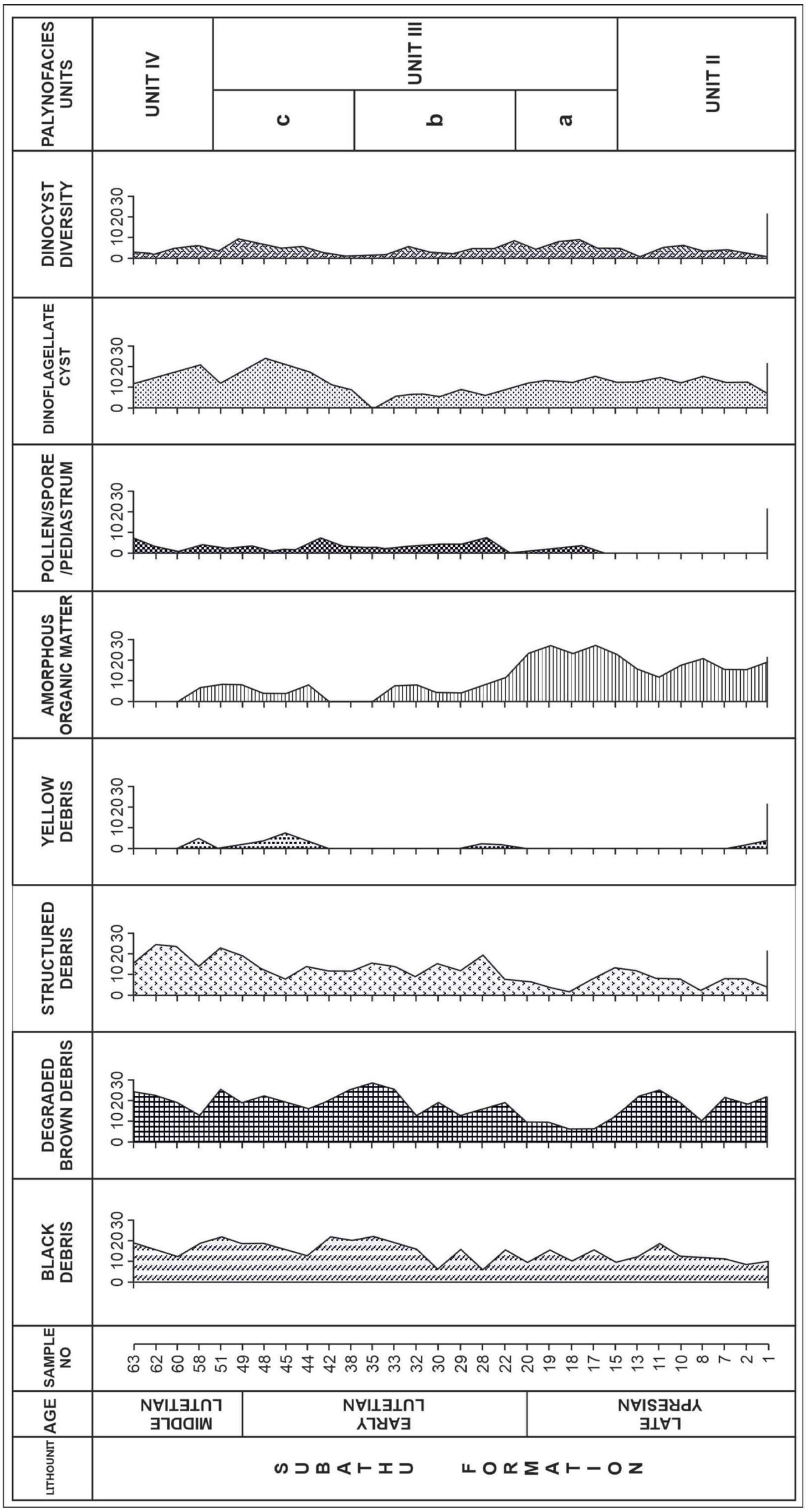


Fig. 4—Distribution of the dispersed organic matter types, dinoflagellates, pollen, spore and algal remains in the Kharak River section.

The palynoflora from 48 m to 57 m of the Chamla section is comparable with assemblages characterising *Thalassiphora* spp. as described in the Cenozone scheme by Singh *et al.* (1978). Several dinocyst taxa are common in between the two assemblages. The dinoflagellate cysts from the upper 63 m to 79 m of the section is comparable with assemblages characterising *Spiniferites* spp. from the Cenozone of Singh *et al.* (1978). Khanna (1978) envisaged that the basal beds were deposited under continental conditions prior to the invasion of the Nummulitic Sea. Present study confirms the former investigations made in the Morni Hills. The Kharak River section includes uppermost four cenozones. However, the cenozones in this section are comparatively thinner in terms of lithostratigraphy.

Khanna *et al*. (1985) recorded 23 dinoflagellate cyst species belonging to 17 genera from Subathu sediments of Jammu region. Many of the forms are common with the Morni Assemblage. The Jammu Assemblage is closely comparable with the middle part of the Morni palynofloral assemblage. The record of Eocene palynological assemblages from western India are numerous (Venkatachala & Kar, 1969; Kar, 1978; Jain & Tandon, 1982; Rao & Vimal, 1952; Sah & Kar, 1969, 1970, 1974; Koshal, 1980; Samant & Phadtare, 1997; Kar & Sharma, 2001). However, meaningful comparison is not possible due to poor presence of dinoflagellate cysts in these recorded assemblages. However, the Morni palynoflora compares very well with the 4th and 5th microplankton zones of Ratchelo–Jhadwa section of Kachchh (Jain & Tandon, 1982). The palynological assemblage reported by Kar (1978) from the Naredi Formation (Eocene) of Kachchh shows similarity with the present assemblage but restricted only to the generic level. The Subathu palynological assemblage is quite distinct from the Eocene palynological assemblages of Cauvery Basin and Bengal basin in terms of the absence of dominant angiosperm pollen grains. Many dinocyst taxa are common to the middle Eocene palynofloral assemblages, recorded from Meghalaya (Dutta & Jain, 1980; Sarkar *et al*., 2014). Palynofacies analysis of the Subathu Formation from Himachal Pradesh were carried out by several workers from time to time (Venkatachala, 1981, 1984; Berry, 1989, 1994; Berry *et al.*, 1998; Berry Misra & Pundeer, 1994; Thakur & Dogra, 2011; Panwar & Thakur, 2018; Panwar *et al*., 2021) mainly focussing on source rock palynology.

DISCUSSION

The Cenozoic sea level history of the north–west Himalayas are derived from studies of various proxies like foraminifera, ostracoda, etc. which shows that major transgression took place in the early Eocene possibly resulting due to eustatic sea level changes. Palaeontological data observed that Ypresian transgression was not only restricted to the Shimla Hills but it was widespread in occurrence. The present investigation of the Morni Hills records the late Ypresian transgression in addition to the well–known early Ypresian transgression and also demonstrates the compatibility of the results with the Eocene depositional cycles (Haq *et al*., 1987). As the sea level rose, the transgression first moved into the valleys of the palaeo–drainage system. Present investigation clearly suggests that the transgression did not influence the study area until early Ypresian. During early Eocene (~54 Ma), the expanding Subathu Sea deposited huge amount of sediments in the basin. Basal sediments (before the transgression) deposited in fluvial condition. Abundant pteridophytic spores, zygospores of Zygnemataceae and land–derived plant debris in the samples from basal beds indicate that the environment correspond to the forest wetland. Sea level rise caused environmental changes as indicated by black shale lithofacies, high Fe contents in the lithofacies as well as the presence of rich dinoflagellate assemblage indicates that tidally controlled environments developed in these areas particularly inhabited by freshwater vegetation. Active sedimentation due to continued sea level rise was occurring in the vicinity of the Morni Hills during this period. Numerous channels extended into the formerly freshwater dominated areas. These channels still received fresh water runoff. The fresh water was mixed with the invading sea water to create a brackish environment. The presence of oyster beds also indicates the existence of a brackish water environment (Bagi, 1992). Dominance of pteridophytic spores in this sedimentary sequence indicate warm and humid climate**.** However, their sudden abundance in the sequence is considered as an erosional feature (Poumot, 1982). Further, transgression corresponds to warm and humid climate which also favours high precipitation and increased run–off. Hence, the abundance of pteridophytic spores in the lower horizon indicates increased run–off which is interpreted to have resulted in high supply of adjacent terrigenous material into the depositional environment. The deposition of limestone sediments above the shales indicates maximum flooding surface which would have deposited in absence of clastics.

A relative fluctuation of sea level (transgression–regression) occurred at Morni during early Ypresian time and is indicated by brackish/open marine dinocyst assemblages, relatively high Fe and low organic contents, with the shift from black carbonaceous shales to grey shales. Following the transgression of the Subathu Sea, lithofacies marks the dominance of black shales and an anoxic environment. Most of the horizons are devoid of any fossils. According to the data obtained from the occurrence of dinoflagellate cysts, the water depth was most probably about 15–20 m in very shallow inner neritic environment. At the top, the basin was gradually filled, with the gradational regressive sequence evident in the stratigraphic section from about 18 m to 45 m.

The dinocysts/spore–pollen recovered from the Subathu Formation can be grouped into 5 associations. The *Glaphyrocysta* association is found in the carbonaceous shale beds. This association occurs in the black carbonaceous shales

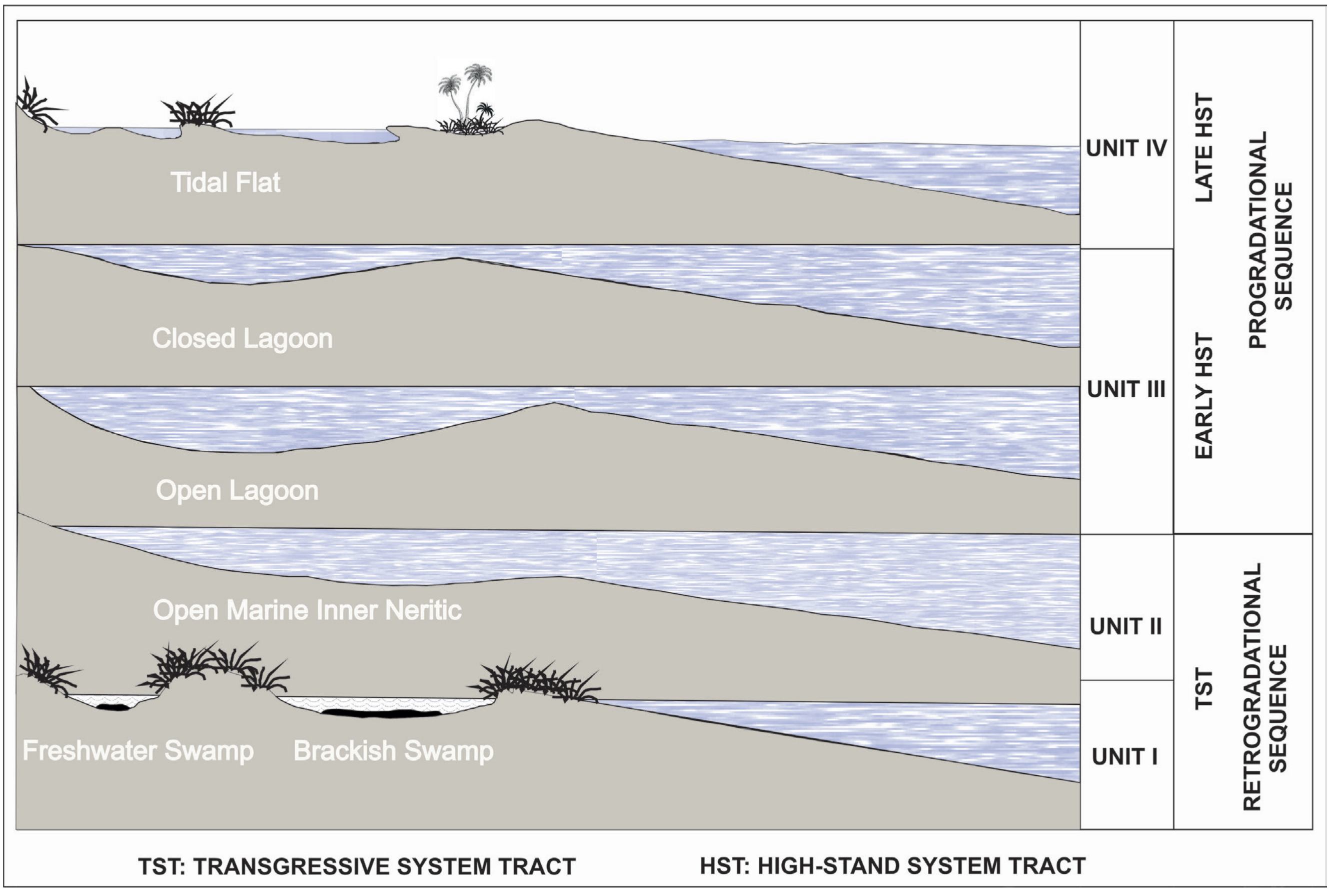


Fig. 5—A schematic figure illustrating the palaeoenvironment with changes in water depth and marine conditions in the Morni Hills.

in the Morni Hills. In grey shale sediments the *Systematophora* species association is replaced by the *Spiniferites* species association. The vertical distribution of dinocysts show that the environment changed from early Ypresian to middle Lutetian time in the Morni Hills. The change of dinocyst fossil association clearly illustrates that the water depth changed during each depositional cycle. The pattern of vertical change in both dinocyst associations and lithofacies is similar to that of the Shimla Hills. Therefore, we imply that changes in the sea level took place during the deposition of these rocks. The distribution of palynofacies, changes in water depth and marine conditions in the Morni Hills are shown in Fig. 5. The changes in both the lithofacies and dinocyst associations in the Chamla section is similar to those inferred from the stratotype section of the Subathu Formation in the Shimla Hills (Khanna *et al*., 1979; Khanna & Singh, 1981). We infer therefore that the depositional environment including water depth and marine conditions are similar in both the localities. The lower part of Chamla and Kharak sections is dated as early–late Ypresian, where there are known to have been major fluctuations in sea level caused by global sea level changes. The maximum amplitude of the sea level fluctuations inferred from dinocyst associations in the Morni Hills is nearly the same as of the global sea level rise.

CONCLUSIONS

1. The palynofloral assemblages recovered from the Subathu Formation (early Ypresian–mid Lutetian) of the Morni Hills are well diversified and consists mainly of dinoflagellate cysts, pteridophytic spores, angiosperm and gymnosperm pollen, fungal and freshwater algal remains.
2. Qualitative and quantitative analyses shows dinoflagellate cyst is most dominant (>70 percent) over other elements in the assemblage.
3. Five assemblage zones along with one barren zone are recognized on the basis of the distribution pattern of palynofossils in the Subathu successions outcropping in the Morni Hills.

4. The present palynofloral assemblages show homotaxiality with the Subathu palynofloral assemblages recorded from Himachal Pradesh and Jammu and Kashmir.
5. The carbonaceous shales of the basal part of the studied sequence in Morni Hills represents a freshwater, marshy depositional environment. Occurrences of pteridophytic spores along with large proportion of rootlets indicate in–situ characteristics of plant communities which would have contributed to the formation of carbonaceous shales in this horizon. The brackish swamp environment would have formed later on due to increased marine influence. Sea level rose further and drowned the palaeo–peat which got buried and preserved by an advancing wedge of marine sediments.
6. The relative increase in diversity of marine dinoflagellate cysts and other palynofacies parameters suggests that the deposition must have taken place in a shallow inner neritic environment. Gradual increase of terrigenous material in the vertical succession points towards gradual shallowing of the basin. On the basis of the palynofacies and palynofloral study results, the sediments first deposited in open lagoon, followed by closed lagoon and finally in a tidal flat environment.

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