Palynology and palaeoenvironment of Lower Tertiary sediments around Garkhal, Himachal Pradesh, India

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A rich palynoflora consisting of dinoflagellate cysts, spores and pollen has been recovered from four measured sections of Subathu Formation (Upper Palaeocene?- Eocene) exposed in the Garkhal area, Punjab Basin, Himachal Pradesh. Five palynological zones of the Subathu Formation represented in Kalka-Shimla and Banethi-Bagthan areas have been identified in the Garkhal sections and correlated. The environment of the deposition has been deduced to be shallow marine. However, evidence for the existence of a tidal flat environment has been indicated around Garkhal. The study also throws light on species diversity in different environments. The distributional pattern of palynofossils in south- eastern and north-western parts of the basin has been analysed and interpreted. Palynofossils indicate the prevalence of a tropical climate during the deposition of Subathu sediments in this area.

Key-words—Palynostratigraphy, palaeoenvironment, Upper Palaeocene? - Eocene, Punjab Basin, India.

INTRODUCTION

THE Lower Tertiary rocks of Himachal Pradesh consists of three formations, viz., Subathu, Dagshai and Kasauli in ascending order of stratigraphy. The Subathu Formation has already been extensively worked out in the Shimla hills for palynostratigraphical studies. However, its north-western extent in Garkhal area has not received much attention.

The objectives of the present study were: (1) to establish palynological succession in Garkhal area, (2) to correlate different measured sections, (3) to understand the distribution of species diversity in response to different environments of deposition and (4) to review the status of accrued results in the context of already published information from Shimla hills.

GEOLOGICAL SETTING

The Lower Tertiary rocks in the Shimla hills overlie the pre-Tertiary rocks of Simla Slates. The geology of this area was worked out in detail by Chaudhuri (1968), and Raiverman and Raman (1971). Chaudhuri (1968) recognised three formations in the Palaeogene succession which in order of superposition are Subathu, Dagshai and Kasauli. The Subathu Formation (Upper Palaeocene to Upper Eocene), in general, consists of limestones at the base followed by alternating bands of carbonaceous shales. Pale-olive shale facies of the middle part are more arenaceous at the upper levels. This formation grades conformably into the overlying Dagshai Formation which consists of mostly purple facies having fine-grained sandstones, siltstones, claystones and mottled shales. The Dagshai Formation conformably grades into the Kasauli Formation which consists of mainly micaceous sandstones.

The Palaeogene rocks depict repetition of strata at several places in Himachal Pradesh. Pilgrim and West (1928) and Batra (1989) believe that this is due to isoclinal folding of the strata. However, Raiverman and Raman (1971) view it as an intertonguing facies relationship of a single lithostratigraphic unit, the Subathu Group. Several major folds, viz., Garkhal syncline, Sanwar anticline, Anje syncline and Kuthar anticline are present in this region. The geological map of this area after Bhatia (1982) is given in Text-figure 2.

STRATIGRAPHY

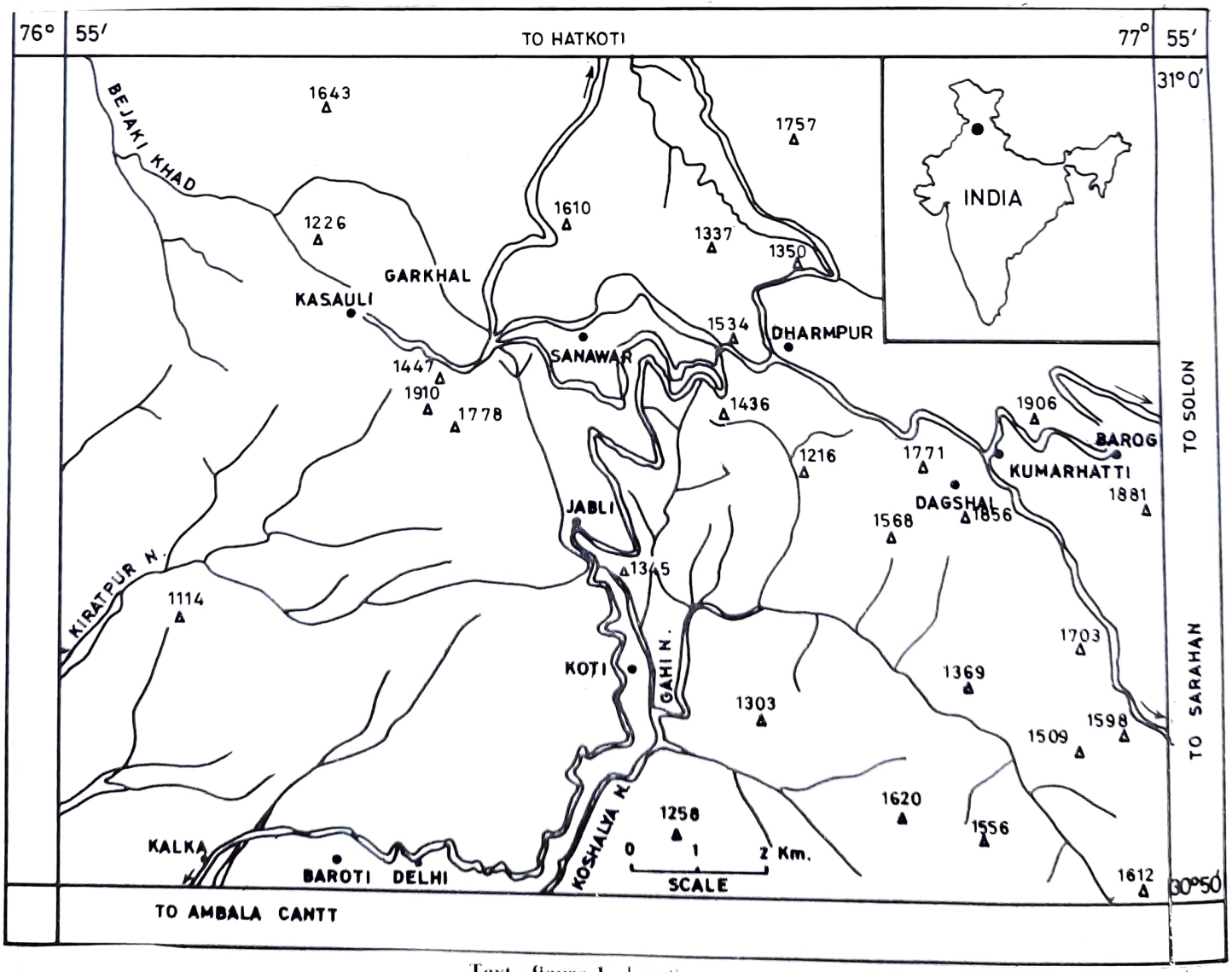
Garkhal area (Text-fig. 3) is situated about 20 km

north-west of Dharampur and represents the north-western flank of the Punjab Basin (Text-fig. 1). Sample location and lithological details are given in Text-fig. 3. Stratigraphically located rock samples were collected for palynological studies from four measured sections, viz., (A) Garkhal-Khetpal Marg (road) Section, (B) Dharampur-Kasauli Road Section, (C) Garkhal-Lawrence School Road Section and (D) Garkhal-Kasauli Brewary Road Section in the Garkhal area.

A.. *Garkhal–Khetpal Marg (road) Section*—This section is exposed on the Garkhal-Khetpal Marg located at a distance of about one km from the junction of Garkhal market. It exposes about 129 m thick sequence of Subathu Formation. The lowermost part of the section is characterised by splintery shale and the uppermost grey purple shale is overlain by the Dagshai Formation. Intercalations of argillaceous siltstone and limestone have been noticed at different levels. Forty four samples were collected, of which 20 samples have yielded well preserved palynofossils.

B. *Dharampur–Kasauli Road Section*—The section is exposed on Dharampur-Kasauli Road at a distance of about 12 km from Dharampur. About 81 m of Subathu Formation is exposed. Alternating sequence of shales and siltstones are present. The upper part of this section is highly arenaceous. The shales are mostly purple in colour and are irregularly laminated. Total 25 samples were collected, of which 14 proved to be productive.

C. *Garkhal–Lawrence School Road Section*—This section is exposed between Garkhal market and Lawrence School and represents the western limb of the Garkhal syncline. It exposes about 59 m of Subathu sediments. The rocks are dipping up to 60^0 towards N-W direction. This section is mainly composed of green shales and silts. The shales are generally arenaceous in nature. The upper part of this section is characterised by purple shale which is overlain by purplish, fine-grained massive sandstone. Various sedimentary and structural features, viz., cross bedding, ripple mark, flute cast, and load casts have also been noticed in this section. 26 samples were collected, of which 12 proved productive. Preservation of



Text - figure 1. Location map.

palynofossils is reasonably good.

D. *Garkhal–Kasauli Brewary Road Section*—This section is exposed on a road running between the Garkhal market and Kasauli Brewary. Only 12 m of Subathu Formation is exposed. Black shales are predominant. Five samples were collected, of which 3 samples are productive.

PREVIOUS PALYNOLOGICAL STUDIES

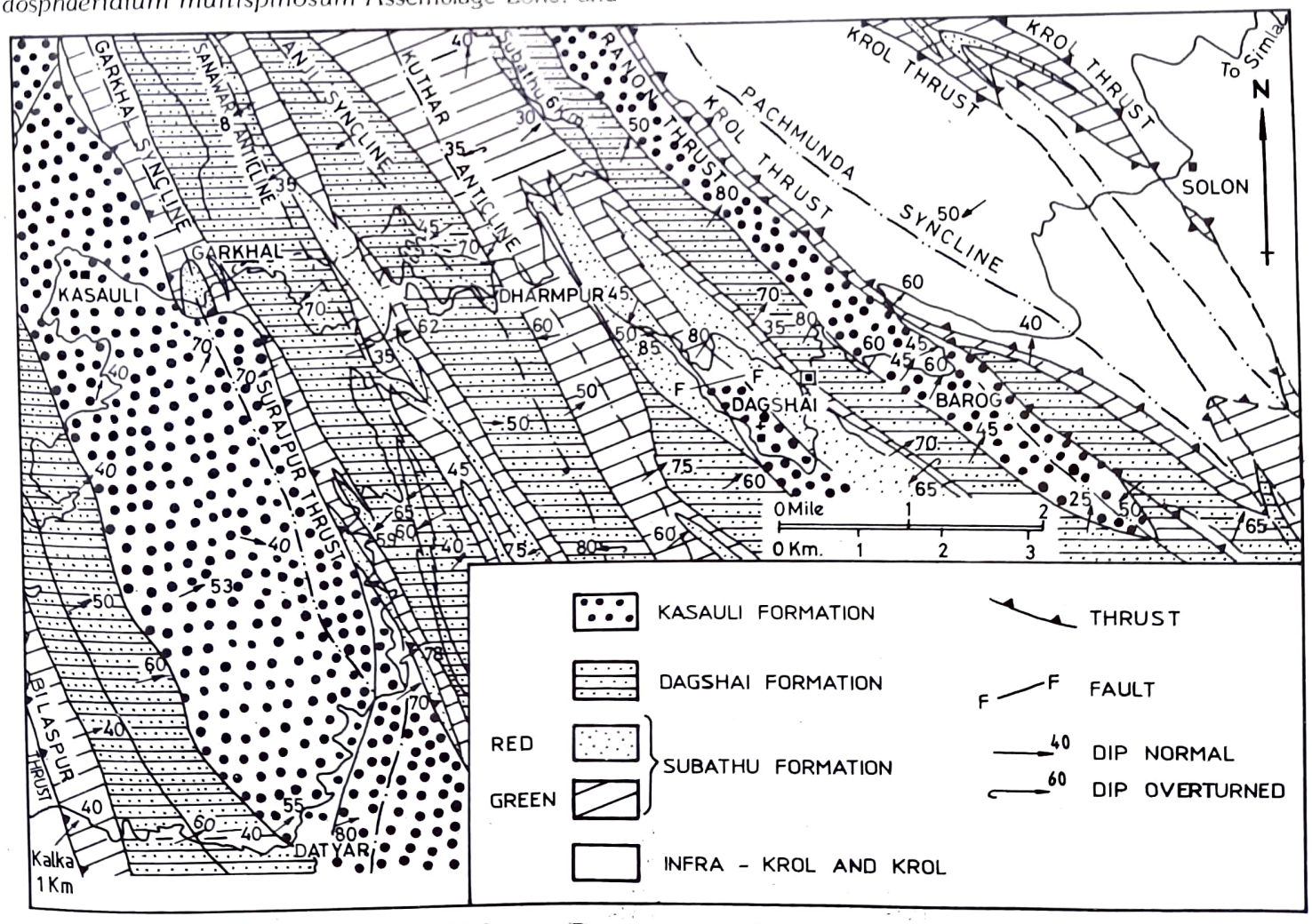
Mathur (1963, 1964, 1965) was the first to report the occurrence of palynofossils, viz., *Pediastrum*, *Botryococcus* and some other hystrichosphaerids from the Subathu rocks of Shimla hills. Subsequently, Salujha *et al.* (1969) carried out palynological investigations in this area and described a rich palynological assemblage consisting of hystrichosphaerids, spores and pollen. Singh *et al.* (1979) established seven palynological zones in the Subathu Formation at its type locality, the Subathu town, viz., (1) *Cyclonephelium* spp. Assemblage Zone, (2) Barren Zone, (3) *Cleistosphaeridium* spp. Assemblage Zone, (4) *Homotryblium* spp. Assemblage Zone, (5) *Hexagonifera* spp. Assemblage Zone, (6) *Cordosphaeridium multispinosum* Assemblage Zone, and (7) *Todisporites* spp. Assemblage Zone in ascending order. Later Singh and Sarkar (1987a,b) and Sarkar and Singh (1988) traced lateral persistence of these assemblage zones in widely separated areas of Shimla hills. Recently, Sarkar (1991) has recorded Eocene palynofossils from the Kakara Series of Lesser Himalaya. Some significant palynological contributions on palaeoenvironmental interpretations on the Subathu sediments of Shimla hills have been made by Khanna (1979), Singh and Khanna (1978, 1980), Khanna and Singh (1981) and Sarkar and Singh (1988).

METHODOLOGY

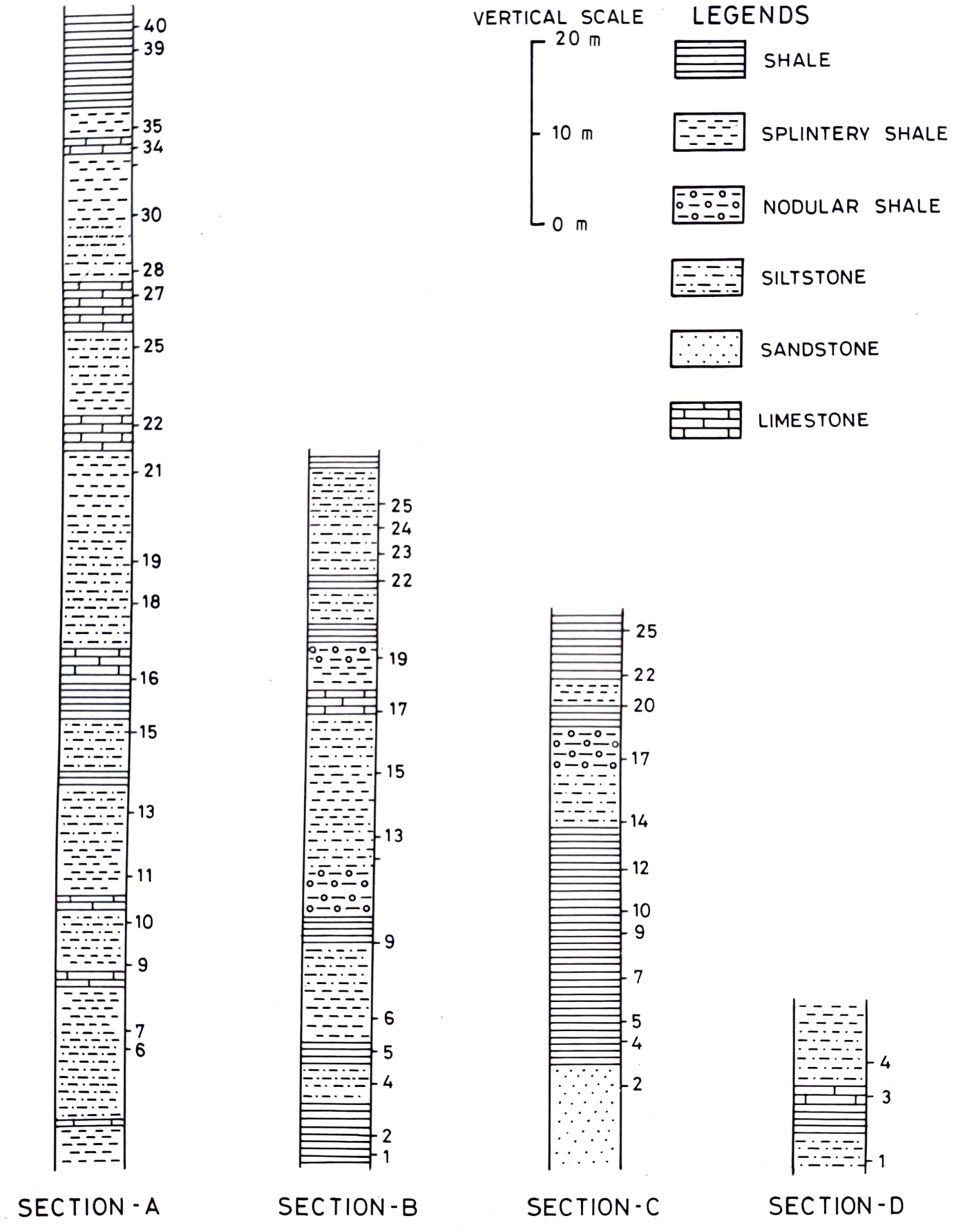
All the samples were processed by conventional technique of maceration with HCL, HF, HNO_3 and KOH. Acetolysis of palynofossils was done in the event they were not clear.

For quantitative estimation of the palynoflora two hundred palynofossils were counted per sample. All the slides of the figured specimens are housed in the repository of Birbal Sahni Institute of Palaeobotany, Lucknow.

Some ecologically significant palynofossils have been



Text - figure 2. Geological map of Garkhal area (after Bhatia, 1982).



Text -figure 3. Lithology and stratigraphic position of the productive samples in Garkhal area.
Section - A. Garkhal-Khetpal Marg Road Section.
Section - B. Dharampur-Kasauli Road Section.
Section - C. Garkhal-Lawrence School Road Section.
Section - D. Garkhal-Kasauli Brewary Road Section.

illustrated (Plate 1).

CHECK LIST OF GARKHAL PALYNOFOSSILS

A. Fresh water algae

Pediastrum angulatus Singh & Khanna 1978
Pediastrum compactum Singh & Khanna 1978
Pediastrum diffussus Singh & Khanna 1978
Pediastrum radiatus Sarkar & Singh 1988

B. Dinoflagellate cysts

Achomosphaera ramulifera (Deflandre) Evitt 1963
Adnatosphaeridium multispinosum Williams & Downie 1966
Amphorosphaeridium multispinosum Davy & Williams) Sarjeant 1981
Amphorosphaeridium sp.
Areoligera sp.
Areosphaeridium sp.
Cleistosphaeridium brevispinosum Jain & Millepied 1975
C. diversispinosum Davey *et al* 1966
Cleistosphaeridium sp.
Cordosphaeridium fibrospinosum Davey & Williams 1966
Cyclonephelium compactum (Deflandre & Cookson) 1955
Diphyes colligerum (Deflandre & Cookson) Goodman & Witmer 1985
Gonyaulacysta sp.
Glaphyrocysta retiintexta (Cookson) Stover & Evitt 1978
G. exuberans (Deflandre & Cookson) Stover & Evitt 1978
Homotryblium abbreviatum Eaton 1976
H. floripes (Deflandre & Cookson) Stover 1975
H. pallidum Davey & Williams 1966
H. tenuispinosum Davey & Williams 1966
Hystrichokolpoma salacium Eaton 1976
Lingulodinium machaerophorum (Deflandre & Cookson) Wall 1967
Operculodinium centrocarpum (Deflandre & Cookson) Wall 1967
Polysphaeridium subtile (Davey & Williams) Bujak *et al.* 1980
Samlandia chlamydophora Eisenack 1954
Sentusidinium sp.
Spiniferites ramosus (Ehrenberg) Loeblich & Loeblich 1966
Thalassiphora patula (Williams & Downie) Stover & Evitt 1978
T. pelagica (Eisenack) Eisenack & Gocht 1960

C. Pteridophytic spores

Cyathidites australis Couper 1953
Todisporites major Couper 1958
Lygodiumsporites sp.
Dictyophyllidites sp.

D. Gymnospermous pollen

Araucariacidites sp.
Podocarpidites couperi Sarkar & Singh 1988
P. decorus Sarkar & Singh 1988

E. Angiospermous pollen

Neocouperipollis brevispinosus (Venkatachala & Kar) Sarkar & Singh 1978

F. Fungal remains

Frasnacritetrus sp.
Multicellaesporites sp.

PALYNOLOGICAL ANALYSIS AND BIOSTRATIGRAPHY

Palynological analysis of the Garkhal-Khetpal Marg Section reveals the presence of a diverse dinoflagellate cyst assemblage along with fresh water alga *Pediastrum*. Samples from the lower part of the section up to 12 m are unproductive whereas the upper part is dominated by different species of *Pediastrum* alongwith *Podocarpidites* spp. *Todisporites* sp. and *Thalassiphora* spp. The middle part of the profile shows high species diversity. The quantitative occurrence (25-40%) of the following dinocysts is considered significant: *Adnatosphaeridium multispinosum, Homotryblium abbreviatum, H. pallidum, Hystrichokolpoma salacium, Thalassiphora pelagica* and *Cleistosphaeridium diversispinosum*. Most of the samples contain *Spiniferites ramosus, Achomosphaera ramulifera, Diphyes colligerum* and *Glaphyrocysta exuberans*. In addition to dinocysts a few ill-preserved pteridophytic spores and fungal spores and conidia have also been observed.

Palynological zones of Singh *et al.* (1979), viz., (1) *Barren* Zone, (2) *Cleistosphaeridium* spp. Assemblage Zone, (3) *Homotryblium* spp. Assemblage Zone and (4) *Thalassiphora* spp. Assemblage Zone have been identified in this section (Text-fig.5). Sample from 12 m to 34 m above the Barren Zone contain a dinocyst assemblage which is characteristic of *Cleistosphaeridium* spp. Assemblage Zone of Singh *et al.* (1979). Predominance of *Cleistosphaeridium diversispinosum* along with *Adnatosphaeridium multispinosum* and *Operculodinium centrocarpum* is a noteworthy feature of this horizon. The overlying sediments from 34 m to 84 m are characterised by the rich representation of *Homotryblium abbreviatum* and *H. pallidum* together with *Spiniferites*

sp. This part of the succession is comparable to the *Homotryblium* spp. Assemblage Zone of Singh et al. (1979). The *Hexagonifera* spp. Assemblage Zone, *Cordosphaeridium multispinosum* Assemblage Zone and the topmost *Todisporites* spp. Assemblage Zone could not be traced in this section. The abundance of *Hystrichokolpoma salacium* at 92 m level is a striking feature. Singh *et al.* (1979) recognized *Hystrichokolpoma granulata* subzone in the Subathu succession at Jabli due to its acme in the lower level and lack of its lateral persistence elsewhere. The vertical distribution of *Hystrichokolpoma* spp. in Garkhal is very much restricted. *Thalassiphora patula*, *T. pelagica* and *Operculodinium centrocarpum* are dominant in the upper part of the section. The overall composition of the assemblage shows affinity with the *Thalassiphora* spp. Assemblage Zone (Sarkar & Singh, 1988). The abundance of *Pediastrum* spp. in this horizon indicates the existence of fresh water channels in the nearby area.

The Dharampur-Kasauli palynofloral assemblage is diverse in nature and possesses both marine and terrestrial elements. The most abundant forms are : *Homotryblium pallidum, H. tenuispinosum, Cordosphaeridium fibrospinosum, Thalassiphora pelagica, T. patula, Cleistosphaeridium* sp., *Glaphyrocysta* sp., *Podocarpidites decorus* and *Neocouperipollis brevispinosus*. The peak point of *Homotryblium* spp. reaches at 14 m level. However, the middle part of the sequence shows well pronounced species diversity. Quantitative rise of terrestrial elements is visible at the upper part of the section. Sporadic presence of fungal spores and conidia has been observed in many samples.

The Dharampur-Kasauli Subathu succession is assigned to three palynological assemblage zones, viz., *Homotryblium* spp. Assemblage Zone, *Cordosphaeridium* spp. Assemblage Zone and *Thalassiphora* spp. Assemblage Zone in stratigraphic order (Text-fig. 5). The other palnological zones of Singh *et al.* (1979) have not been identified in this succession. *Gonyaulacysta* is very common in Dharampur Section (Khanna, 1978) but here its quantitative representation is very poor. The occurrence of terrestrial elements, viz., *Neocouperipollis brevispinosus* and *Lygodiumsporites* spp. has also been noticed in many samples from the upper part of the section. The same road exposes part of the Subathu succession near Jhamta. Here the dinocyst assemblage mainly consists of *Cyclonephelium* spp. and *Glaphyrocysta* sp. Most likely the Jhamta assemblage represents the lowermost horizon of the Subathu succession in Dharampur-Kasauli Road Section.

The Garkhal-Lawrence School Road Section palynofloral assemblage possesses a distinct dinocyst assemblage dominated by *Spiniferites ramosus, Operculodinium centrocarpum, Polysphaeridium subtile* and *Lingulodinium machaerophorum*. It has been noticed that the spinose dinocysts predominate the other forms. The lower part of the section also contains *Thalassiphora* spp. The species diversity is rather poor. A few samples (sample nos. 20, 22) from the upper part of the section have yielded palynofossils which are rich in ter-

Plate 1

(All photomicrographs are magnified ca x 500; coordinates of specimens in slides refer to the stage of Leitz laborlux K/D microscope no. 060733).

1. *Pediastrum angulatus* Singh & Khanna 1978; slide no. BSIP 10413; coordinates : 46, x 106.
2. *Pediastrum radiatus* Sarkar & Singh 1988; slide no. BSIP 10413; coordinates : 46, 99.
3. *Operculodinium centrocarpum* (Deflandre & Cookson) Wall 1967; slide no. BSIP 10416; coordinates : 64, x 104.
4. *Adnatosphaeridium multispinosum* Williams & Downie 1966; slide no. BSIP 10413; coordinates : 54, x 102.
5. *Achomosphaera ramulifera* (Deflandre) Evitt 1963; slide no BSIP 10418; coordinates : 42, x 96.
6. *Spiniferites ramosus* (Ehrenberg) Loeblich & Loeblich 1966; slide no. BSIP 10418; coordinates : 36.5, x 110.
7. *Homotryblium abbreviatum* Eaton 1976; slide no. BSIP 10419; coordinates : 32, x 95.
8. *Thalassiphora patula* (Williams & Downie) Stover & Evitt. 1978; slide no. BSIP 10414; coordinates : 47, x 107.
9. *Cordosphaeridium fibrospinosum* Davey & Williams 1966; slide no. BSIP 10421; coordinates : 46, x 106.
10. *Glaphyrocysta retiintexta* (Cookson) Stover & Evitt 1978; slide no. BSIP 10414; coordinates : 36.5, x 110.
11. *Amphorosphaeridium* sp. slide no. BSIP 10416; coordinates : 41, x 109.
12. *Cyclonephelium* sp.; slide no. BSIP 10418; coordinates: 38, x 104.
13. 14. *Hystrichokolpoma salacium* Eaton 1976; slide no. BSIP 10418; coordinates : 62, x 96.5.
15. *Homotryblium pallidum* Davey & Williams 1966; slide no. BSIP 10419; coordinates : 54, x 96.
16. *Cleistosphaeridium flexuosum* (Davey *et al*) Sarkar & Singh 1989; slide no. BSIP 10418; coordinates. 62, x 99.
17. *Cyclonephelium compactum* Deflandre & Cookson 1955; slide no. BSIP 10414; coordinates : 49, x 100.5.
18. *Cleistosphaeridium diversispinosum* Davey *et al.* 1966; slide no. BSIP 10415; coordinates : 31, x 97.
19. *Areosphaeridium* sp. slide no. BSIP 10320; coordinates: 46, x 107.5.
20. *Thalassiphora pelagica* (Eisenack) Eisenack & Gócht 1960; slide no. BSIP 10414; coordinates : 49, x 195.5.

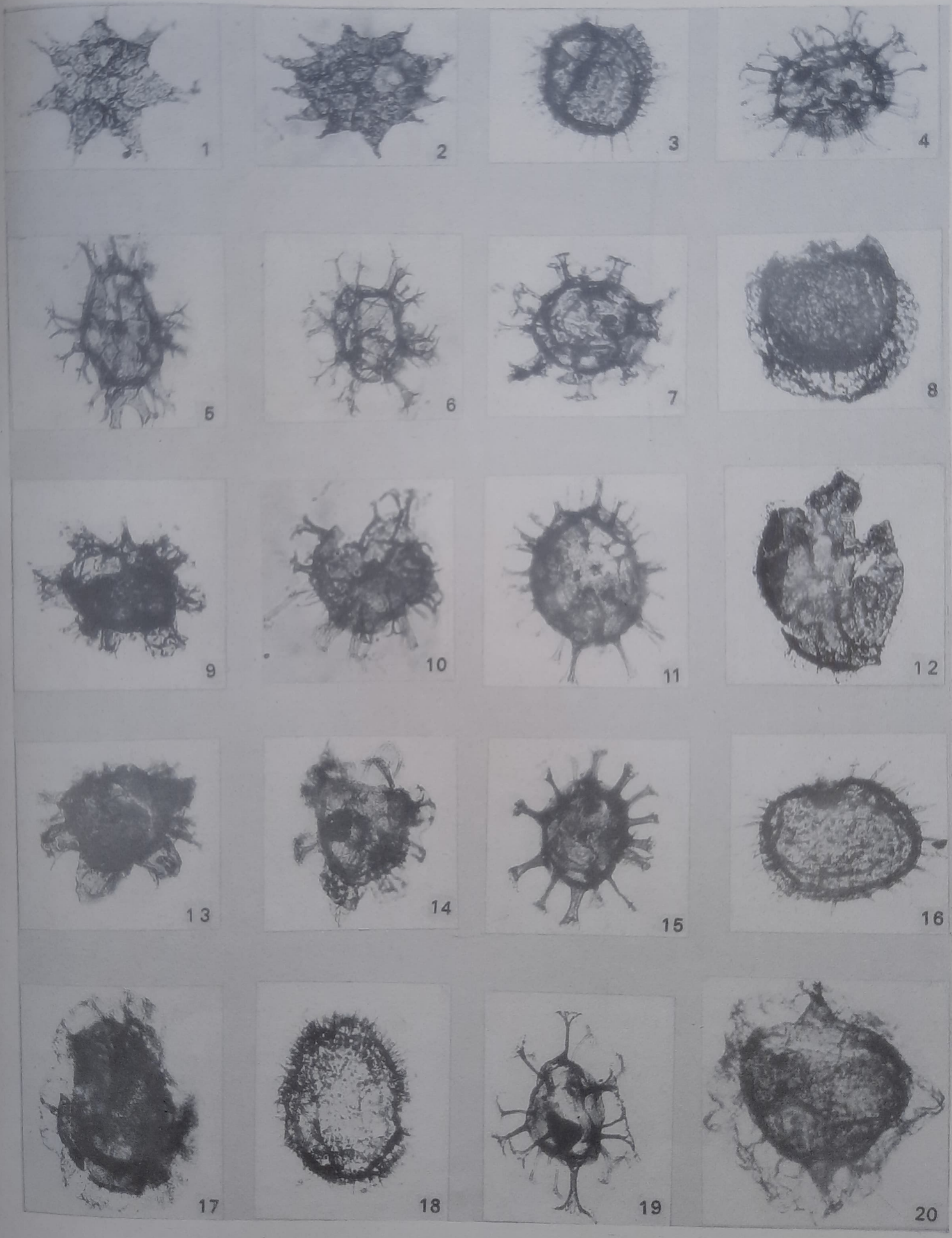
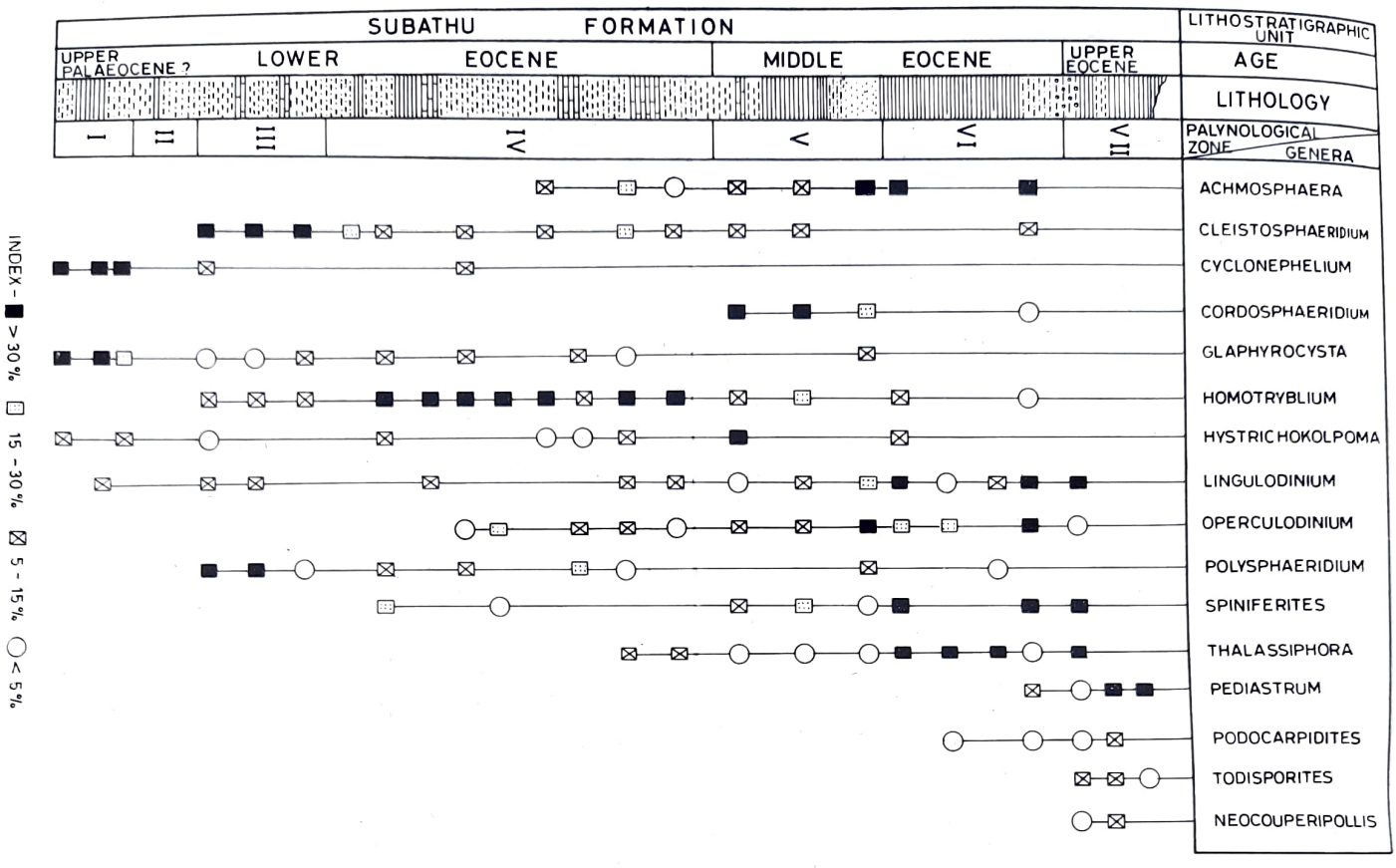


Plate 1



Text -figure 4. Distributional pattern of significant palynofossils in the Subathu succession of Garkhal area.

restrial elements and at the same time have poor representation of the dinocyst species. In the upper horizon the most abundant forms are: *Podocarpidites decorus*, *P. couperi* and *Todisporites major*.

The *Todisporites* spp. Assemblage Zone is apparently comparable with those published from Kalka-Shimla and Banethi-Bagthan area but it cannot be reliably correlated with them as it exhibits distinct abundance of *Operculodinium centrocarpum*, *Lingulodinium machaerophorum* and *Spiniferites ramosus*. Palynological dissimilarity in this part of the Subathu succesSsion is perhaps due to the prevalence of mildly saline environment. The upper part of the section has mostly terrestrial forms like *Todisporites major*, *Dictyophllidites* sp. and *Podocarpidites* spp. At this level the species diversity of dinoflagellate cyst is low.

The Garkhal-Kasauli Brewary palynological assemblage is characterised by having an overwhelming dominance of *Adnatosphaeridium multispinosum* and *Glaphyrocysta exuberans*. Some other common taxa are *Cyclonephelium compactum* and *Homotryblium tenuispinosum*. In general, the assemblage maintains a low species diversity. A few bisaccate pollen grains resembling the genus *Podocarpidites* have been found but due to bad preservation their identification up to specific level has not been possible.

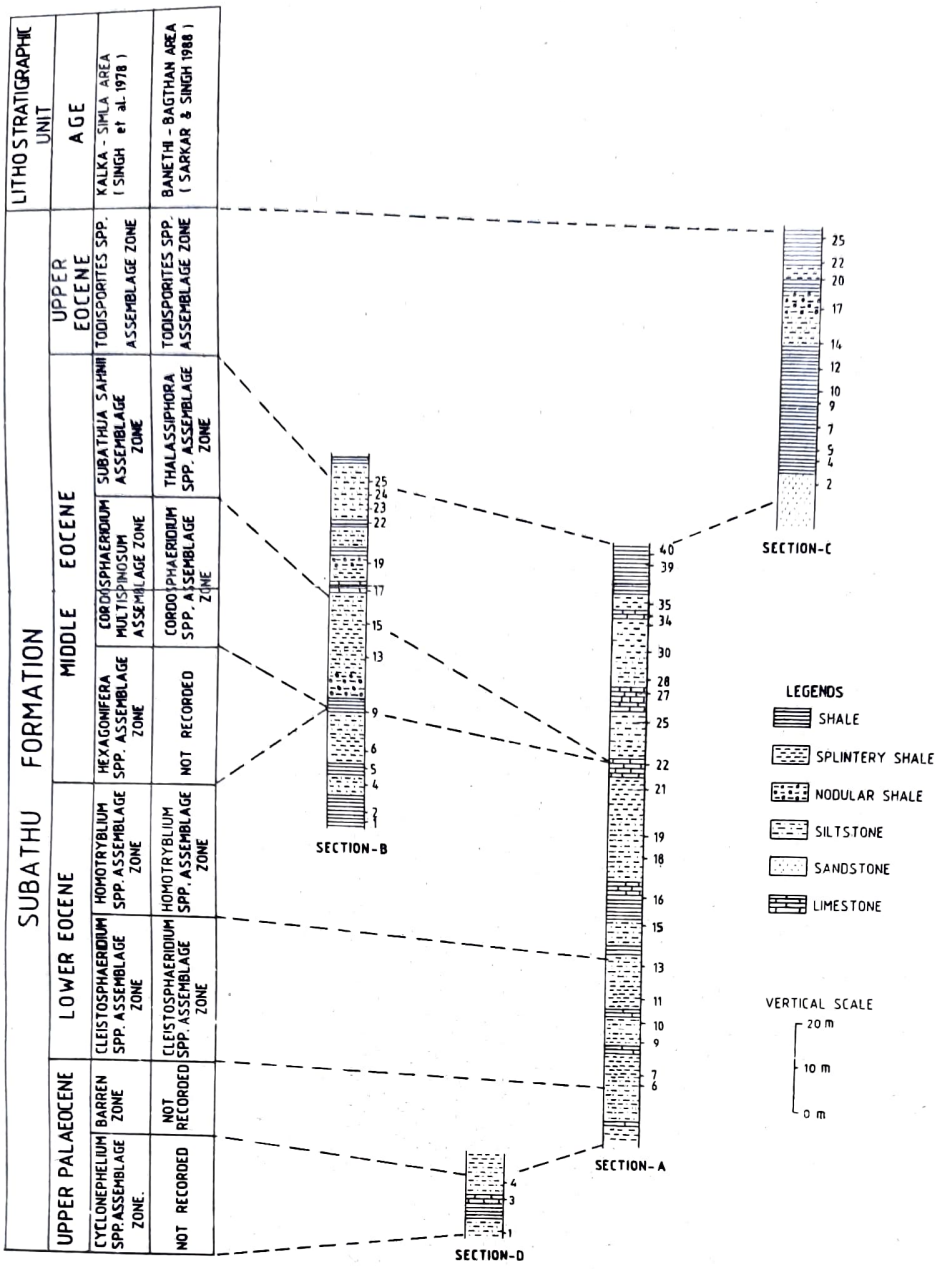
The abundance of *Glaphyrocysta exuberans*, *Cyclonephelium compactum* and *Adnatosphaeridium multispinosum* at the base suggests that the present dinocysts assemblage is broadly comparable to the basal *Cyclonephelium* spp. Assemblage Zone of Singh *et al.* (1979). However, because of the absence of Palaeocene forms in the Kasauli Brewary assemblage, it may be inferred that it is slightly younger in age as compared to the Kalka-Shimla area. The stratigraphic distribution of significant palynofossils in four different sections has been given Text-figure 4.

COMPARISON WITH OTHER SUBATHU ASSEMBLAGES

Salujha *et al.* (1969) have recorded a rich palynofloral assemblage (28 genera, 45 species) comprising spores, pollen, hystrichosphaerids and algal remains from Koshalia River Section, Kalka-Shimla highway and Kasauli area. The recorded palynofossils are ill-preserved and the stratigraphic position of the samples are not well defined. Therefore, a detailed comparison with this assemblage is not possible. Comprehensive records of Subathu palynofloras are available from two regions of Shimla hills, i.e., Kalka-Shimla area of Solan District (Khanna, 1978) and Banethi-Bagthan area of Sirmaur

Table 1. Distribution of significant species in different parts of Shimla hills

Taxa	Kalka-Shimla area (Khanna, 1979)	Banethi-Bagthan area (Sarkar & Singh, 1988)	Garkhal area (Present study)	North-Western area	South-Eastern area
Pteridophytic spores					
Amtaspora indica		+			
A. pseudostriata		+			+
Cyathidites cooksonii	+				
Intrapunctisporis intrapunctis	+				+
Lycopodiumsporites crossii	+				+
L. pattamorensis	+				
L. singhii	+				+
Lygodiumsporites barogensis	+				+
Striatriletes susannae		+			+
Todisporites dagshiaensis	+				+
T. kotiensis	+				
T. major		+	+		
T. minor		+			
T. rarus		+			
T. subathuensis	+				
Gymnospermous pollen					
Podocarpidites couperi		+	+	+	
P. decorus		+	+	+	
P. kumarhattiensis	+				+
Angiospermous pollen					
Graminidites media		+			
Monoporopollenites kasauliensis		+			
Neocouperipollis capitatus		+	+	+	
N. pyrispinosus			+	+	
Palmidites intrafoveolatus			+	+	
P. noviculatus			+		
Dinoflagellate cysts					
Achomosphaera ramulifera		+	+	+	
Amphorosphaeridium multispinosum	+		+	+	+
Adnatosphaeridium multispinosum			+	+	
Cleistosphaeridium brevispinosum	+	+	+		+
C. diversispinosum	+				
C. purvum	+		+	+	+
Cordosphaeridium exilimurum	+		+	+	+
C. fibrospinosum	+				+
C. inodes		+			
Cyclonephelium compactum	+		+	+	+
Diphyes colligerum			+		
Florentinia deanei					+
Glaphyrocysta divaricata		+			+
G. exuerans		+	+	+	+
G. retiintexta	+				+
G. spineta	+				+
Hexagonifera reticulata	+				+
H. sahii	+				
Homotryblium abbreviatum	+	+	+	+	+
H. pallidum		+	+	+	
H. tenuispinosum	+	+	+	+	+
Hystrichokolpoma indica	+				
H. palaeocaenica	+				
H. salacium			+	+	+
H. unispinum	+				+
Hystrichosphaeridium granulatum	+				
H. tubiferum		+			
Leberidocysta chlamydata	+				
Linguoldinium macherophorum		+	+	+	
Operculodinium centrocarpum		+	+		
Polysphaeridium subtile		+	+	+	
Sentusidinium rioultii		+			
Spiniferites ramosus			+	+	
Thalassiphora pelagica	+	+	+		
T. patula	+	+	+	+	
Tenua kutharensis	+				
T. simlaensis	+				
Trithyrodinium vermiculatum	+				



Text -figure 5. Palynological correlation of four sections in the Garkhal area.

District (Sarkar & Singh, 1988). A total of 40 species belonging to 30 genera are recorded in the present assemblage whereas their number is far more in Kalka-Shimla (42 genera, 111 species) and Banethi-Bagthan areas (58 genera, 106 species). Significant species recorded in these three areas of Shimla hills are listed in Table 1. From this table it is evident that many dominant species of Kalka-Shimla and Banethi-Bagthan assemblage are absent in Garkhal palynoassemblages thereby indicating a low species diversity. Nevertheless, the generic composition of south-eastern assemblages of the Punjab Basin is closely comparable to those of the north-western part. This distributional pattern seems to have resulted in response to the changes in environment of deposition, viz., varying degree of salinity and depth levels in different part of the basin. Based on geological studies Bhandari and Agarwal (1968) had earlier postulated that the floor of the Subathu epicontimental sea was partitioned with parallel and sub-parallel ridges. It is possible that compartmentalisation of the basin might have resulted in the development of locally restricted dinocyst associations.

DEPOSITIONAL ENVIRONMENT AND PALAEOECOLOGY

Dinocysts are sensitive to physical factors like depth, temperature and salinity, therefore variation in any one of these conditions well reflect a change in their composition (Köthe, 1990). The lowermost part of the Subathu succession exposed at Kasauli Brewary road, demonstrates open marine condition with normal salinity as it possesses rich representation of *Cyclonephelium compactum*, *Glaphyrocysta exuberans* and *Adnatosphaeridium multispinosum*. The same distributional pattern has been observed in the Subathu Section (Khanna & Singh, 1981). Similarity in lithofacies of these two localities also supports this distribution. The normal salinity loving taxa, viz., *Cleistosphaeridium*, *Homotryblium*, *Hystrichokolpoma* etc., are replaced

gradually by mesohaline forms like *Thalassiphora* spp., *Lingulodinium macherophorum* and *Operculodinium centrocarpum* (Köthe, 1990). Khanna and Singh (1981) have also noticed similar phenomenon in the Kalka-Shimla area. It is assumed that the top of the shallow basin had less saline concentration due to influx of fresh water from nearby rivers and other water channels. This inference is supported by the presence of *Pediastrum* spp., *Neocouperipollis brevispinosus* (Palm pollen) and many other terrestrial elements at upper stratigraphical levels of the Garkhal succession. The abundance of dinocysts, viz., *Spiniferites ramosus*, *Operculodinium centrocarpum* and *Lingulodinium machaerophorum* in the Lawrence School assemblage indicates the prevalence of flat tidal condition of deposition. The sedimentary features like cross bedding, ripple marks, load-cast at this horizon also corroborate this inference.

The paucity of land derived elements in the Garkhal assemblages imposes limitations to infer palaeoclimatic conditions. However, the occurrence of *Cyathidites australis* (Cyatheaceae), *Lygodiumsporites* spp. (Schizaeaceae), *Dictyophyllidites* (Matoniaceae), *Neocouperipollis brevispinosus* (Palmae) and *Podocarpidites* spp. (Podocarpaceae) reflects that a tropical climate prevailed during the time of Subathu sedimentation.

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