Palynological and palynofacies assemblage from the Subathu Formation (Eocene) of Northwestern Himalaya, Nilkanth, Uttarakhand, India

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The study reports a record of palynological and palynofacies assemblage comprising 29 genera and 34 species of acritarchs, pteridophytes, gymnosperms, fungal and dinoflagellates from the Kothar Section of Nilkanth, Uttarakhand. The lower part of the succession indicates terrestrial warm and humid conditions with intermittent marine influences. Presence of dinoflagellate cysts in the middle part shows slight deepening of the shallow basin, while nummulites in the upper part indicate marine conditions. The overall assemblage of the Subathu Kothar area succession dates this formation to Early–Middle Eocene.

Keywords: Dinoflagellate cysts, marine influences, nummulites, palynology, palynofacies analysis.

THE Himalayan foreland basin comprises Palaeogene sedimentary succession referred to as Subathu, Dagshai, Muree and Kasauli formations, which are succeeded by the Middle Miocene to Early Pleistocene Siwalik Group in different parts of Northwestern Himalaya. Of these, the Palaeogene Subathu succession is of importance as it is the period related to the suturing of, India–Asia plates, initiation of mountain-building events and depositional environmental changes, i.e. swamp–lagoonal environment to foreshore or beach environment indicating marine transgression and regression[1–7]. Thus, it preserves biotic evidences and ecological changes in the sedimentary deposition induced by the closing of the Subathu Sea.

The present study focuses on the palynology and the palynofacies analysis of the Palaeogene Subathu lithounit exposed in the Kothar area of Nilkanth (29°50′ to 30°05′N and 78°20′30″ to 78°39′E), located in the western part of the Garhwal syncline in Uttarakhand, India (Figure 1). The exposed Subathu rock sequence in the Nilkanth area is about 37 m thick (measured in the present study) and rests along a regional unconformity over the Upper Cretaceous Nilkanth/Singtali Formation (=shell limestone)[8–10], while this succession is tectonically overlain by the rocks of the Garhwal Group of Precambrian age along the Garhwal thrust. The lithology of the Subathu succession in the present area is made up of grey splintery shale and siltstone at the base overlain by grey shales with minor bands of green and red shales and packstone which are succeeded with red facies, i.e. red shales at the base and siltstone, sandstone at the top[11]. Table 1 shows the stratigraphic succession of the present area.

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Review of the literature

Pioneering geological studies in the Garhwal syncline have been published by several workers[4,12–17]. Mathur[15] studied in detail the Subathu Formation exposed in the Singtali, Nilkanth, Dhamand, Bidasini and Dogadda areas and recognized five major zones (A–E) in stratigraphic order, and assigned Upper Palaeocene to Early Eocene age to them. Mathur and Jain[18] identified two longitudinal basins running almost northern and southern peripheries of the main Himalayan ranges. The northern basin passes through Upshi, Khalsi and Burzil pass whereas the southern basin extended from salt range through Kohat, Kalakot, Sataun–Subathu–Bilaspur, Dogadda Nilkanth to Mahabharat range (Nepal). Singh[19] recorded the geological sequence exposed in Nilkanth, Garhwal Himalaya. Kumar and Dhaundiyal[20] observed that the Subathu Formation exposed has lithological resemblance with the Beragua and Kalakot formations of Jammu region. Pant[21] worked on the Subathu Formation of Garhwal at Nilkanth and recorded Ranikothalia, Miscellanea and Lockhartia, etc. and assigned a probable Ranikot horizon to this formation. Tewari and Kumar[22] recorded *Nummulites atacicus*, *Nummulites subatacicus*, *Assilina subspinosa* and *Dictyoconoides vredenburgi* from the Subathu Formation of Nilkanth in Garhwal synform and assigned Laki (Early Eocene age) to these sediments. Tewari and Singh[23] recorded *Nummulites* cf. *mamilla*, *Operculina patalensis*, *N. atacicus*, *Assilna granulosa chhumbiensis* and *Globorotalia* sp. from the Subathu Formation of Dogadda, Garhwal Himalaya and assigned an Upper Palaeocene to Early

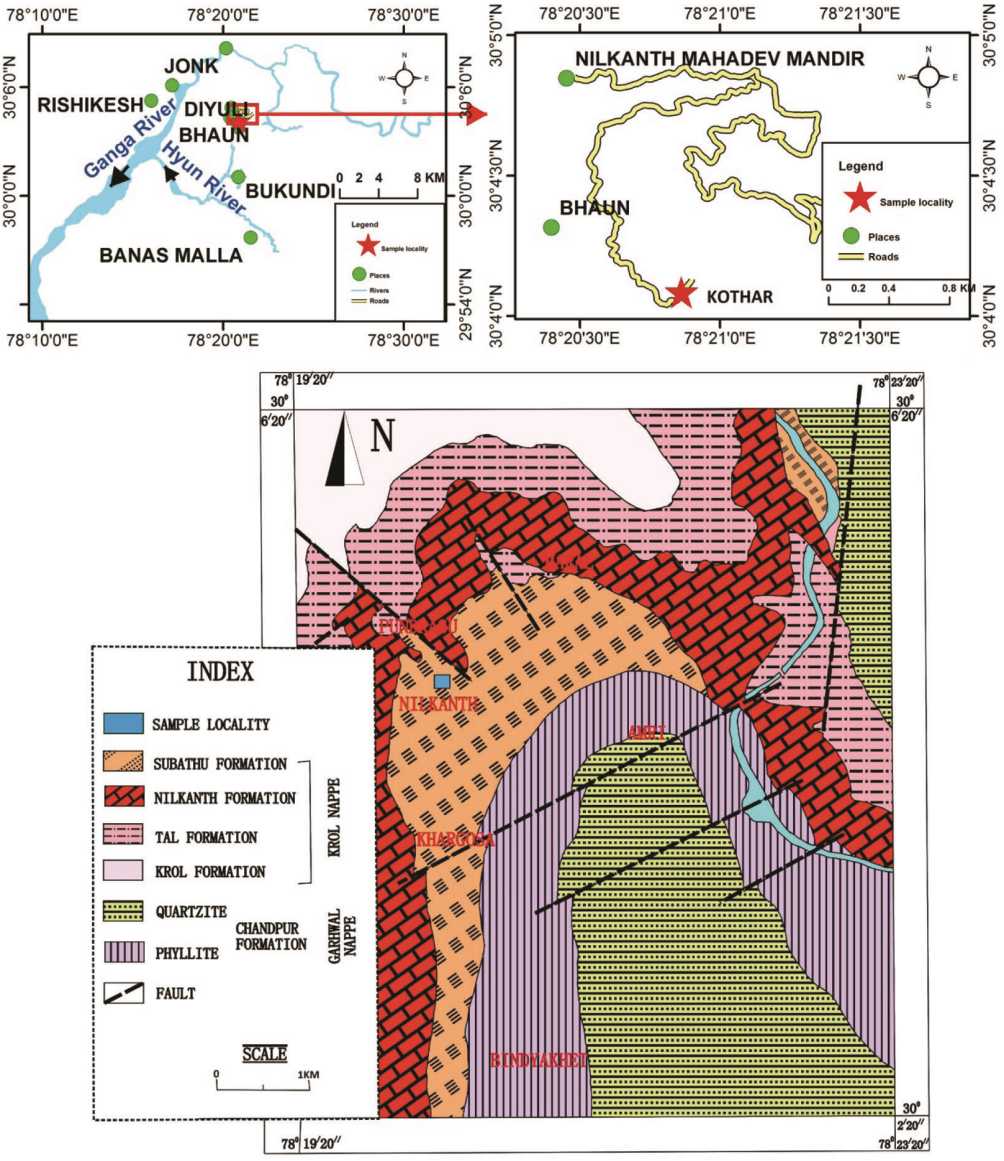

Figure 1. Geological map of Kothar area, Nilkanth, Pauri Garhwal district, Uttarakhand, India (after Yadava and Gairola[36]).

Table 1. Tectonic set-up in Tal Valley, Garhwal Himalaya, India (modified after Mathur and Juyal[10])

Lithounits character	Age	Lithology
Garhwal Group	Precambrian	Phyllite
	Thrust contact	
Subathu Formation	Ypresian	Calcareous shales, nummulitic limestone, grey–olive green, siltstone, mudstone
Kakara Formation	Late Thanetian	Cabonaceous shale, siltstone, mudstone
	Unconformity	
Shell Limestone Formation (Nilkanth Formation)	Late Cretaceous	Oolitic, shelly limestone

Eocene age. Srivastava *et al.*[24] recorded lamellibranch genera *Perna*, *Cardiocardita*, *Astarte* from the Dogadda Formation in Garhwal synform at Golikhet, Garhwal, Uttar Pradesh Shringarpure and Shah[25] assigned an Upper Palaeocene to Middle Miocene age based on the occurrence of *Palacophycus* and *Planolites* trace fossils documented

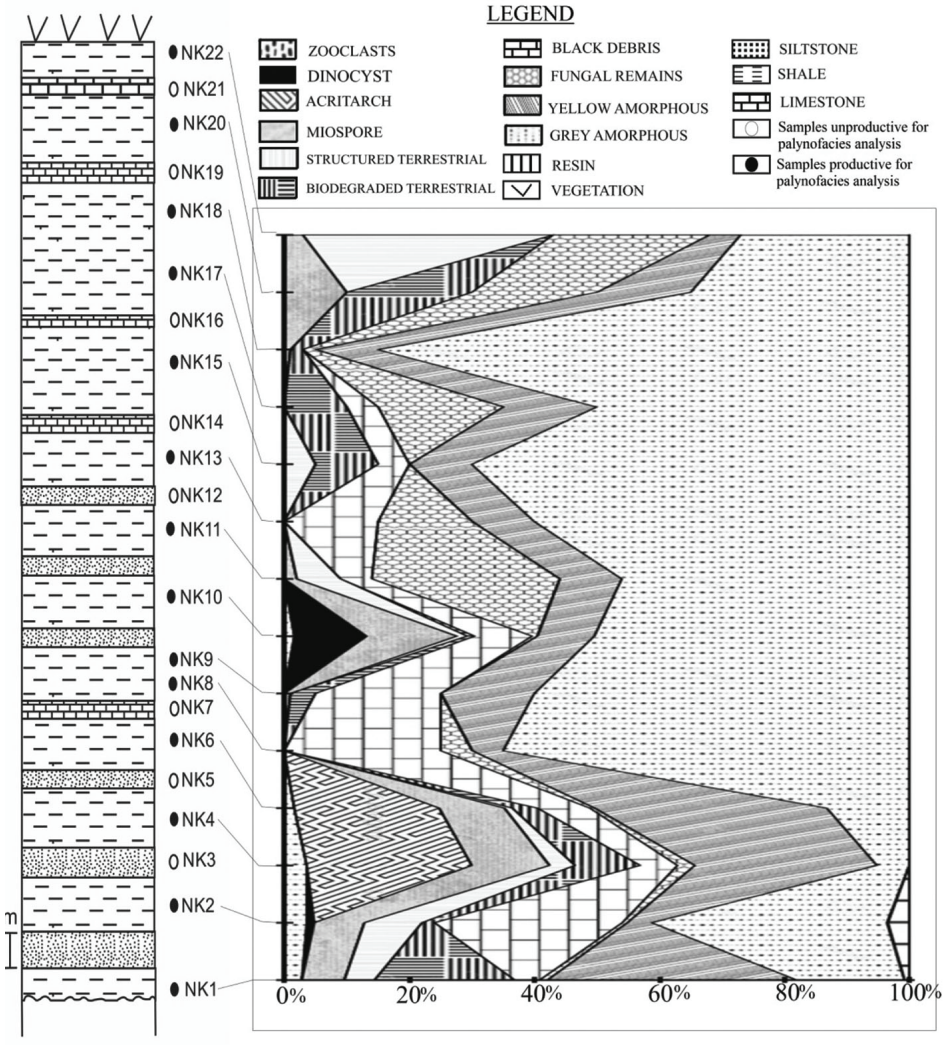

Figure 2. Quantitative representation of various types of sedimentary organic matter in the stratigraphic section of Subathu Formation in the study area.

from Subathu Formation of Nilkanth. Microvertebrate remains were found from Subathu Formation exposed near Nilkanth[26,27]. *Scytonema* referable to the genus *Palaeoscytonema* was documented from the Subathu succession, exposed near village Bidasini, Garhwal Himalaya[28].

The literature, however, reveals that no palynological investigations have ever been carried out in the Kothar area, Uttarakhand. The aim of the present study was to document palynofossil biota and obtain palynofacies data within the Subathu Formation of Kothar area and utilize these data to draw inferences on the age and depositional environment of this formation in the study area.

Methodology

The present study was carried out on 22 representative samples collected from 37 m thick lithosection of Subathu Formation using the standard maceration technique. For this, each sample was processed using HCl (40%) followed by HF (40%) for removal of carbonates and silicates respectively. The residue left was sieved using a 40 micron size sieve to eliminate the remaining clay particles. Next, the residue was divided into two parts. One part was used for preparing permanent slides using mountant polyvinyl alcohol and Canada balsam for palynofacies analysis. The organic matter particles were counted under transmitted light microscope to draw the frequency variation diagram given in Figure 2, based on the classification of sedimentary organic matter[29]. The other part of the residue was treated with concentrated HNO_3 to remove humic material followed by treatment with 10–20% KOH solution. After the digestion process, permanent slides were made using polyvinyl alcohol and Canada balsam for palynomorph counting and identification. The prepared slides were examined under transmitted light using a light microscope (Olympus). Table 2 shows the temporal distribution of the counted palynotaxa.

Table 2. Vertical distribution of microfossil in Kothar village, Nilkanth area

Sample/Taxa		1	2	4	6	10	13	15	18	20	22
Dinoflagellates	*Areoligera coronata*	+				+					
	Cordosphaeridium inodes					+					
	Cleistosphaeridium diversispinosum					+					
	Glaphyrocysts exuberans					+					
	Homotryblium plectilum	+				+					
	Hystrichokolpoma rigaudiae					+					
	Hystrichosphaeridium tubiferum		+								
	Lingulodinium macherophorum	+				+					
	Muratodinum fimbriatum	+				*					
	Oligosphaeridium complex					+					
	Operculodinium centrocarpum		+			+					
	Operculodinium sp.					+					
	Polysphaeridium zoharyii					*					
	Spiniferites membranaceus					+					
	Thalassiphora pelagica					*					
	Thalassiphora velata					+					
Algal remains	*Thecombian cyst*	–	–								
Spores-pollen	*Lycopodiumsporites globatus*			+	*						
	Lycopodiumsporites sp.										
	Lygodiumsporites sp.	+									
	Megaspore trilete						*	*		*	
	Papulosporonites sphaeromorphus		+				+			+	
	Podocarpidites couperi				*	+					
	Todisporites minor				+						
	Veryhachium morniensis			–	–						
	Veryhachium sp.				•						
Fungal remains	*Densoipollenites*	•						+	+		
	Helminthosporium type						+			+	
	Multicellites ovatus								+		
	Polycellaesporonites bellus						–	–	–	–	–
	Peltate trichome			+			+	*	+		*
	Scolecosporites maslinensis			+			•				
	Spinisporonites angularis						+				
	Trichothyrites							+			
	Microforaminiferal lining						+				

(+) 1–5%; (*) 6–10%; (•) 11–20%; (–) >20%.

Results and discussion

Palynofacies

Palynofacies study is an analysis of various types of sedimentary organic matter embodied in the sedimentary formations. In the present study, three palynofacies assemblage zones, i.e. palynofacies assemblage-A (PF-A), palynofacies assemblage-B (PF-B) and palynofacies assemblage-C (PF-C) were identified, which have been classified based on the relative frequencies of each category of palynofacies matter according to Masron and Pocock[29], viz. structured terrestrial, biodegraded terrestrial, yellow amorphous, grey amorphous, black debris, fungal remains, resin, zooclast, dinocyst, acritarchs and spore-pollen. Figure 2 is a quantitative representation of various types of sedimentary organic matter in the stratigraphic section of Subathu Formation in the study area.

Palynofacies assemblage-A

This assemblage was identified in samples NK1, NK2, NK4, NK6 and NK8. It is characterized by dominance of grey amorphous organic matter (37.6%) with sub-dominance of black debris (25%). Structured terrestrial organic matter and spores-pollen are 9.2% and 8% respectively, whereas fungal remains are scarce. A small quantity of dinoflagellates (2%) is also present in the lower part whereas some terrestrial palynomorphs are present in the upper part of PF-A. Significant amounts of amorphous organic matter with black organic matter and terrestrial organic matter show shoreline and marginal marine environment under dysoxic condition.

Palynofacies assemblage-B

This zone is represented by samples NK9 and NK10 and is characterized by high abundance of grey amorphous

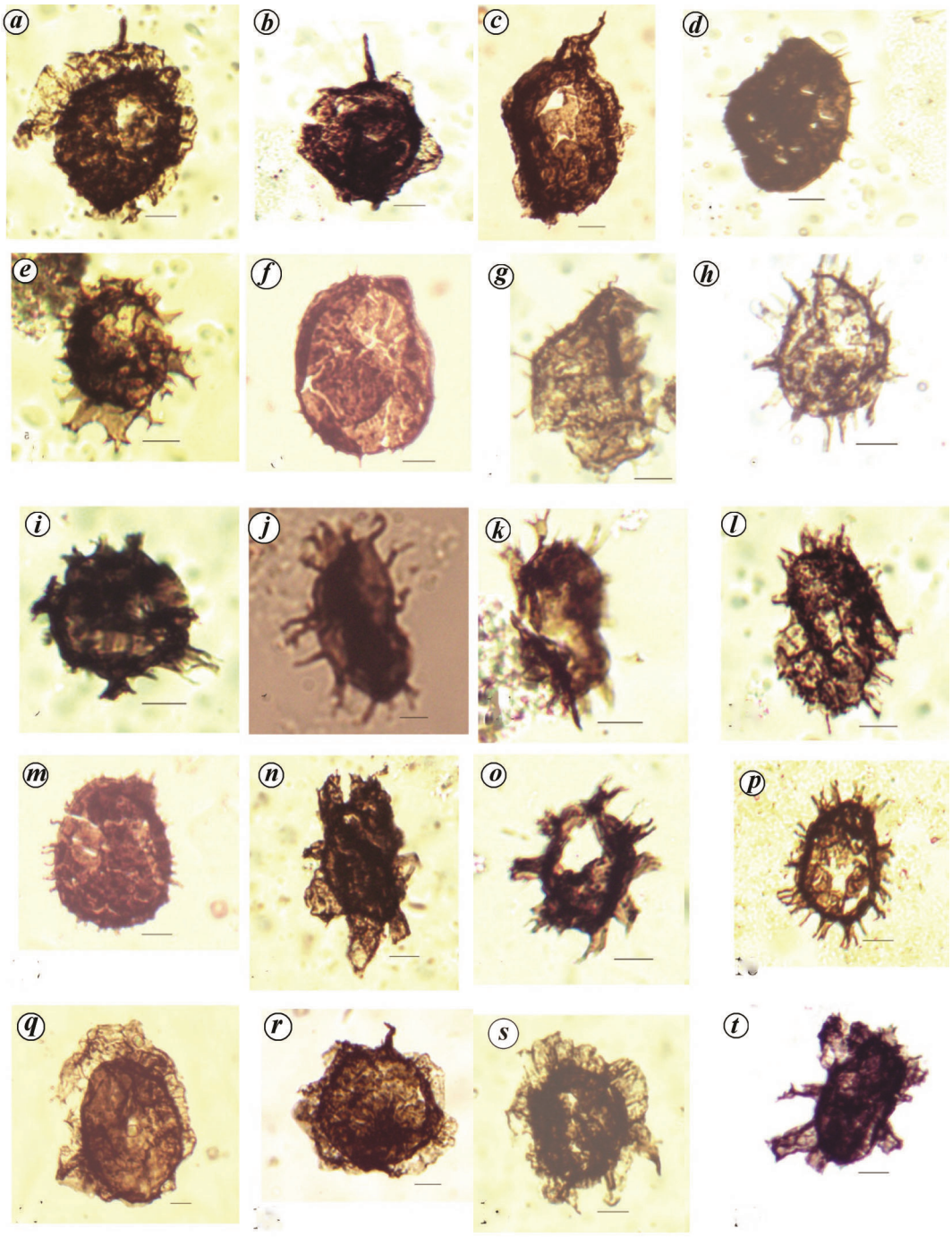

Figure 3. ***a–c***, ***r***, *Muratodinium fimbriatum*; ***d***, *Oligosphaeridium* sp.; ***e***, *Spiniferites membranaceous*; ***f***, ***m***, *Operculodinium centrocarpum*; ***g***, *Areoligera coroneta*; ***h***, *Polysphaeridium zoharyii*; ***i***, *Cordosphaeridium inodes*; ***j***, *Homotryblium plectilum*; ***k***, *Oligosphaeridium* complex; ***l***, *Operculodinium* sp.; ***n***, ***t***, *Hystrichokolpoma rigaudiae*; ***o***, *Cleistosphaeridium diversispinosum*; ***p***, *Lingulodinium macherophorum*; ***q***, *Thalassiphora pelagic*; ***s***, *Glaphyrocysta exuberans* (scale: 10 µm).

organic matter (50–65%) with black debris (9.2–20%) and yellow amorphous (9.2–15%) which decreases from bottom to top with scarce fungal activity. A significant amount of marine palynomorphs (11.6%) is also present in this zone. High amount of amorphous organic matter shows preservation in oxygen-deficient environment, which depicts anoxic conditions in PF-B.

Palynofacies assemblage-C

Samples NK11, NK13, NK15, NK17, NK18, NK20 and NK22 demarcate PF-C. There is high dominance of grey amorphous organic matter (85%) with sub-dominance of fungal remains (15–25%). Some amounts of biodegraded terrestrial and spore-pollen followed by yellow amorphous

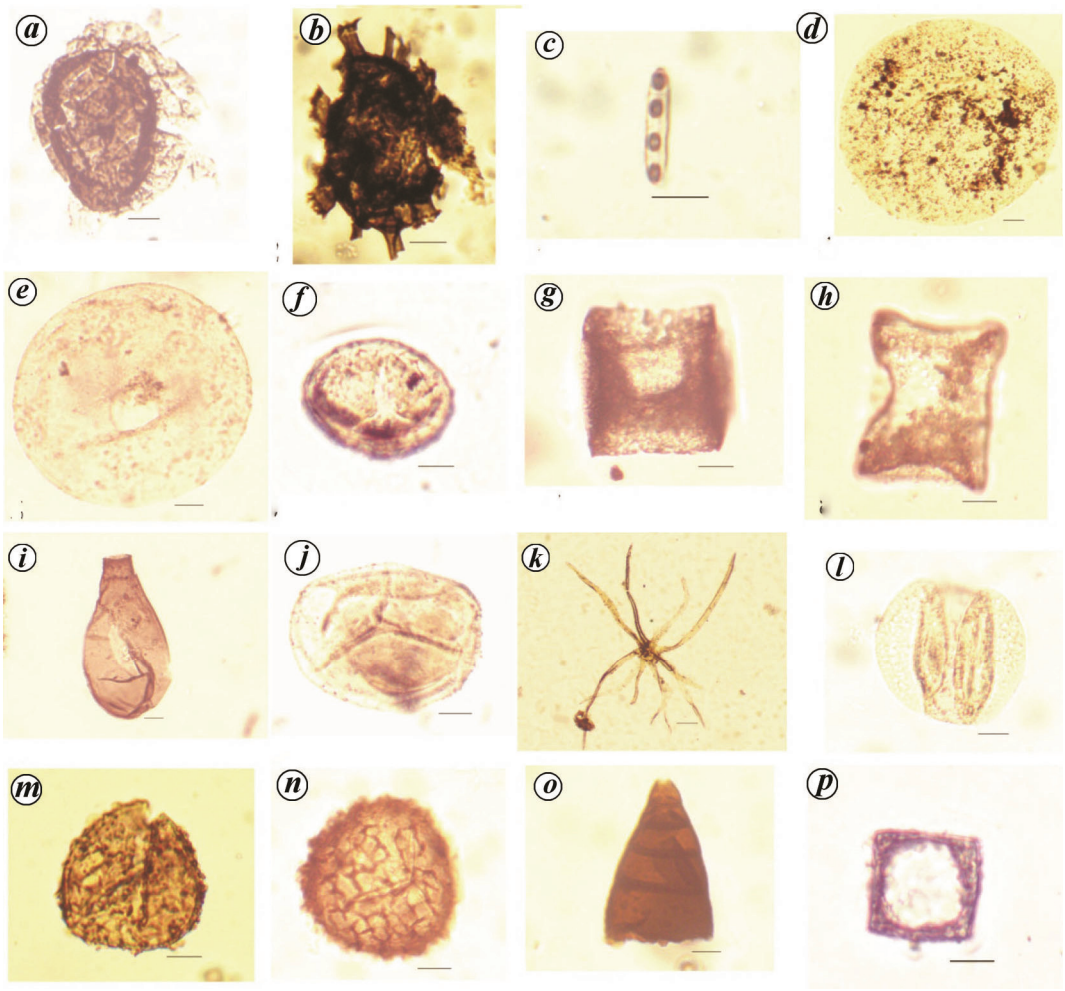

Figure 4. ***a***, *Thalassiphora velata*; ***b***, *Hystrichosphaeridium tubiferum*; ***c***, *Helminthosporium* sp.; ***d***, *Densoipollenites*; ***e***, *Thecombian cyst*; ***f***, *Todisporites minor*; ***g***, ***h***, *Verhacyium morniensis*; ***i***, *Calilida*; ***j***, *Lygodiumsporites* sp.; ***k***, *Peltate trichome*; ***l***, *Podocarpidites couperi*; ***m***, *Lycopodiumsporites* sp.; ***n***, *Lycopodiumsporites globatus*; ***o***, *Scolecosporites maslinensis*; ***p***, *Verhacyium* sp. (scale: 10 µm).

are also present. Some microforaminiferal test linings are also present in this zone. Occurrence of microforaminiferal linings with amorphous organic matter represents marine conditions. High percentage of grey amorphous organic matter indicates deposition in a low energy setting. Thus, this zone is a good source for hydrocarbon generation.

Palynology

The palynofloral assemblage recovered from the Kothar section of Nilkanth, comprises 34 species belonging to 29 form genera (Figures 3 and 4). Dinoflagellates constitute 16 species referable to 14 form genera having affinity to Dinophyceae. The pteridophytes are represented by four species belonging to three form genera having affinities to families Osmundaceae, Lygodiaceae and Lycopodiaceae. The gymnosperms include one species in one form genus having affinity with Podocarpaceae. The fungal spores constitute eight taxa in the assemblage. Acritarchs are represented by only two species. Table 3 shows the checklist of selected taxa along with their affinities, present-day distribution and ecological groups.

Age of the succession

Altogether 17 dinoflagellate cyst taxa have been recognized with low to moderate diversity in the recovered palynoflora. The Dinoflagellate assemblage is characterized by age-marker taxa, namely *Muratodinium fimbriatum*, *Cleistosphaeridium diversispinosum*, *Glaphyrocysta exuberans* and *Thalassiphora velata*, which are significant for reasonably precise age inferences. Evaluation of Last Appearance Datum/First Appearance Datum (LAD/FAD) and restricted occurrences of taxa in the late Palaeocene to early Eocene have been used for age determination. Age range of selected palynotaxa given in Table 4 reveals that *M. fimbriatum* is a cosmopolitan age marker with its

Table 3. Checklist of palynomorphs recovered and their ecological group from the Kothar section, Nilkanth area, Uttarakhand, India

Affinity	Palynotaxa	Climate	Ecological group
Dinophyceae	*Areoligera coronata*		Marine elements
	Cordosphaeridium inodes		
	Cleistosphaeridium diversispinosum		
	Glaphyrocysta exuberans		
	Homotryblium plectilum		
	Hystrichokolpoma rigaudiae		
	Hystrichosphaeridium tubiferum		
	Lingulodinium machaerophorum		
	Oligosphaeridium complex		
	Operculodinium centrocarpum		
	Operculodinium sp.		
	Polysphaeridium zoharyii		
	Spiniferites membranaceus		
	Thalassiphora pelagica		Brackish water elements
	Thalassiphora velata		
	Muratodinium fimbriatum		
Freshwater algae	Thecombian cyst	Cosmopolitian	Aquatic (freshwater)
Acritarch	*Veryhachium morniensis*		Marine
	Veryhachium sp.		
Schizaeaceae	*Lygodiumsporites* sp.	Tropical–subtropical	Freshwater element
Osmundaceae	*Todisporites minor*	Tropical	Evergreen
Lycopodiaceae	*Lycopodiumsporites globatus*	Cosmopolitian	Terrestrial
	Lycopodiumsporites sp.		
Podocarpaceae	*Podocarpidites couperi*	Tropical–moist temperate	Evergreen
Fungal remains	*Densoipollenites*		Warm and humid
	Helminthosporium sp.		Warm and humid
	Multicellites ovatus	Terrestrial	Warm and humid
	Peltate trichome	Cosmopolitian	
	Polycellaesporonites bellus		
	Scolecosporites maslinensis	Tropical	
	Spinisporonites angularis		
	Trichothyrites	Tropical–subtropical	Terrestrial

Table 4. Age range of selected taxa recovered from the Subathu Formation, NW Himalaya, India

Species	First appearance datum	Last appearance datum	Author
Cleistosphaeridium diversispinosum	Ypresian (56 m yr)	Rupelian (27 m yr)	Eaton, 2001
Homotryblium plectilum	Bartonian (41 m yr)	Serravallian (16 m yr)	Haq *et al*., 1987
Hystrichokolpoma rigaudiae	Mid Ypresian (52 m yr)	Recent (1 m yr)	Stover, 1996
Hystrichosphaeridium tubiferum	Aptian (111 m yr)	Ypresian (49 m yr)	Stover, 1996
Lingulodinium machaerophorum	Ypresian (54 m yr)	Recent (0.0 m yr)	Haq *et al*., 1987
Oligosphaeridium complex	Valanginian (124 m yr)	Ypresian (48 m yr)	Stover *et al*., 1996
Polysphaeridium zoharyii	Ypresian (52 m yr)	Recent (0.0 m yr)	Stover, 1996
Thalassiphora pelagica	Maastrichtian (70 m yr)	Rupelian (27 m yr)	Stover *et al*., 1996
Muratodinium fimbriatum	Late Thanetian (56 m yr)	Mid Ypresian (52 m yr)	Powell, 1992

FAD (~56 myr)[30]. In addition, the LAD and FAD limits[31] of dinocyst taxa recovered from the middle and upper parts of the section are represented by *C. diversispinosum* (FAD ~56 m yr), *Lingulodinium machaerophorum* (FAD ~54 m yr), *Polysphaeridium zoharyi* (FAD ~52.0 m yr) and *Hystrichokolpoma riguadae* (FAD ~52.0 m yr)[31]. The presence of these taxa in the assemblage rules out any age older than ~41 m yr to this horizon. In the LAD limits of dinoflagellate cysts, viz. *C. diversispinosum* (LAD ~27.0 m yr), *Hystrichosphaeridium tubiferum* (LAD ~49.0 m yr), *Muratodinium fimbriatum* (LAD ~52.0 m yr), *Oligosphaeridium complex* (LAD ~48.0 m yr), the youngest LAD is represented by *M. fimbriatum* (LAD 52 Ma). Hence the upper age limit to this horizon will be ~52.0 Ma. Among 35 species reported in the present assemblage, majority of the dominant ones are also known from Kalka–Shimla, Banethi–Bangthan and Bilaspur Eocene assemblage of the Simla hills[32,33] and Subathu Formation from Solan district, Himachal Pradesh, India[34,35]. Therefore, it is concluded that the present dinoflagellate cyst

assemblage and nummulitics indicate Early to Middle Eocene (Lutetian) age for the Subathu Formation of the study area.

Depositional environment

The palynofloral assemblage recovered from the Subathu Formation consists of algal and fungal remains, pteridophytic spores and gymnospermous pollen. Among these, *Homotryblium plectilum*, *Areoligera coronata*, *Hystrichosphaeridium tubiferum*, *Lingulodinium machaerophorum*, *Muratodinium fimbriatum* and *Operculodinium centrocarpum* are the major constituents of the Subathu palynofloral assemblage. The lower part of the sequence is represented by dinocysts, namely *Homotryblium plectilum*, *Areoligera coronata*, *Hystrichosphaeridium tubiferum*, *Lingulodinium machaerophorum*, *Muratodinium fimbriatum* and *Operculodinium centrocarpum*, which are indicators of near-shore marine environment. Presence of pteridophytic spores assignable to families Lygodiaceae (*Lygodiumsporites* sp.), Osmundaceae (*Todisporites minor*) and Lycopodiaceae (*Lycopodiumsporites globatus*, *Lycopodiumsporites* sp.) depicts tropical to subtropical climate and deposition in sub-aquatic to swampy habitats. Occurrence of fungal remains (*Densoipollenites*, *Peltate trichome*, *Scolecosporites maslinensis*) along with gymnosperm pollen assignable to the family Podocarpaceae (*Podocarpidites couperi*) suggests prevalence of tropical, warm, humid climate with abundant rainfall during the deposition. Thus, the lower part of the present section is probably deposited in low energy and poorly oxygenated restricted lagoonal condition with intermittent marine influences. Moreover, enhanced frequency of dinoflagellate cysts: *Homotryblium plectilum*, *Hystrichosphaeridium tubiferum*, *Cordosphaeridium inodes*, *Cleistosphaeridium diversispinosum*, *Hystrichokolpoma riguadae*, *Operculodinium centrocarpum*, *Lingulodinium machaerophorum*, *Thalassiphora pelagica* and *Muratodinium fimbriatum* in the middle part of section shows slight deepening of the basin with shallow marine conditions. The presence of microforaminiferal linings and benthic foraminifera, i.e. *Nummulites* in the upper portion denotes proximal shelf environment. Hence, the palynological assemblage of Kothar section indicates depositional episodes in the area with intermittent marine influences in the lower part and onset of shallow marine depositional condition in the middle phase of deposition of the present section, whereas the upper portion represents the deeper part of the shallow marine shelf (i.e. lower shoreface).

Conclusion

- The present study documents a varied and diversified assemblage of dinoflagellates, pteridophytes, gymnosperms, acritarchs and fungal remains covering 34 species in 29 form genera recovered from the Nilkanth area.
- Occurrence of dinoflagellates along with pteridophytes and gymnosperms in the lower part of the Kothar section indicates that the lower part of this section was deposited in restricted lagoonal or marginal marine environment with intermittent marine influence, whereas the middle part was deposited under shallow marine environment as inferred from the enhanced frequency of dinoflagellates; and prevalence of marine proximal shelf condition in the upper part of the section on the basis of presence of nummulites in the upper part of the section.
- The age assigned to the present horizon was inferred from the LAD/FAD limits of dinoflagellate cysts and *Nummulites* present. The LAD/FAD limits of *Muratodinium fimbriatum*, *Cleistosphaeridium diversispinosum*, *Lingulodinium machaerophorum*, *Polysphaeridium zoharyi*, *Hystrichokolpoma riguadae*, *Hystrichosphaeridium tubiferum*, *Muratodinium fimbriatum* and *Oligosphaeridium complex* in the present sediments dated Subathu succession as Early to Mid-Eocene (Lutetian) age.
- The palynofacies data obtained show fluctuations in the palynofacies categories which are classified into three palynofacies zones. From bottom to top: PF-A represents dysoxic conditions, PF-B shows anoxic-conditions and PF-C shows deep marine proximal shelf conditions.
- The prevalence of tropical–subtropical warm humid climate is deciphered on the basis of pteridophytic spores, gymnospermous pollen and fungal remains. Palyno-complexes indicate proximity of depositional site to evergreen forest dominated by humid tropical climate type vegetation in the study area.

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