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K/T boundary species with Early Eocene nannofossils discovered from Subathu Formation, Shimla Himalaya, India

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Nannofossils discovered from classic Koshalia-Nala section are assigned to combined NP12-NP13: *Tribrachiatus orthostylus*-*Discoaster lodoensis* zones of Late Ypresian age. Significant reworked species of the Late Maastrichtian-Danian: *Micula murus* plus NP1-NP4 zones, closely matching those known from reputed K/T boundary sections of the world, suggest possible existence of complete K/T boundary section with ash-beds in Lesser Himalaya. Evaluation of nannofossil data supports an earlier postulation, permitting the entry of Subathu sea via Arunachal during the Late Maastrichtian, probably in response to coeval Deccan-vulcanism in peninsular India. Leaked Early Miocene nannofossils derived from nearby younger strata could signify a concurrent transgressive event in Himalayan foothills.

In the present paper, we report a documented account of an autochthonous Early Eocene (Late Ypresian) calcareous nannofossils from Subathu Formation (Figure 1, Table 1) containing some typical reworked species of Late Maastrichtian-Danian, including those straddling K/T boundary the worldover (Figures 2-74). From these samples, we document a few Early Miocene nannofossils (interpreted as Leaked Fossils) derived from unmapped younger marine rocks lying somewhere in close vicinity of the studied section, demanding a fresh look at the geotectonic evolution of the Himalaya.

Geologic setting, sampling and methods

One of us (SAJ) collected samples during an excursion on 11 February 1991. Details of the lithologic section can be found in ref. 1.

The Subathu Formation exposed in Koshalia Nala section (Figure 1) comprises gray-green laminated shales with intermittent bands rich in paraautochthonous and diminutive-sized larger foraminifera species, representing

offshore-mud facies with periodic poor connections with open ocean currents. Besides nannofossils, the section contains ostracodes, small benthic and larger foraminifera, crabs, molluscs, bryozoa, echinoids, charophytes and shark-teeth etc.¹ Detailed biozonation work requires close sampling at 10 cm interval. However, only four samples at large interval could be collected from a section exposed just below the bridge (Figure 1, b-d).

Conventional smear-slides were prepared and calcareous nannofossils studied using a polarizing research microscope (Leitz) and an oil-immersion objective. Nannofossils oriented (Figures 2-74) in the same position were photographed under the microscope.

Discussion

Age of Subathu Formation

Throughout the Lesser Himalayan belt stretching from Jammu to Arunachal Pradesh, Early Eocene (Ypresian) age was favoured for Subathu Formation, mainly backed by larger foraminiferal and palynofossil data²⁻⁴. Except Arunachal Pradesh, the Late Palaeocene age was also firmly established in several areas². Exposure containing autochthonous Danian and reworked Late Maastrichtian nannofossils at Dharampur of Shimla Himalaya supported the hypothesis of Late Maastrichtian transgressive event, probably triggered due to coeval Deccan trap activity and entry of the Subathu sea via Arunachal area^{5,6}.

Early Eocene nannofossils

Tectonics and adverse facies do not normally permit recovery of nannofossils from Subathu Formation⁶.

Table 1. Calcareous nannofossils recorded from Subathu Formation of the Koshalia-Nala section. Significant K/T boundary species having global distribution at low-latitude sites are grouped as: † vanishing Cretaceous; * survivors; * incoming Tertiary (after Perch-Nielsen¹⁰ and Kaenel *et al.*¹¹)

Reworked Autochth. Leaked			Nannofossil species
Late Maast.-Danian	Early Eocene (Late Ypresian)	Early Miocene	
+			* <i>Biantholithus sparsus</i> Bramlette and Martini 1964
+			<i>Braarudosphaera bigelowii</i> (Graan and Braarud 1935) Deflandre 1947
+			* <i>Chiasmolithus danicus</i> (Brotzen 1959) Hay and Mohler 1967
+			<i>Cribrosphaerella ehrenbergii</i> (Arkhangelsky 1912) Deflandre 1952
+			<i>Cruciplacolithus</i> cf. <i>C. frequens</i> (Perch-Nielsen 1977) Romein 1979
+			* <i>C. intermedius</i> Heck and Prins 1987
+			* <i>C. tenuis</i> (Stradner 1961) Hay and Mohler 1967
+			<i>Cruciplacolithus</i> spp.
+			* <i>Cyclagelosphaera reinhardtii</i> (Perch-Nielsen 1968) Romein 1977
+			! <i>Eiffelolithus gorkae</i> Reinhardt 1965
+			<i>Micrantholithus</i> sp.
+			! <i>Micula murus</i> (Martini 1961) Bukry 1973
+			<i>M. swastika</i> Stradner and Steinmetz 1984
+			<i>Micula</i> sp.
+			! <i>Prediscosphaera grandis</i> Perch-Nielsen 1979
+			<i>Prinsius bisulcus</i> (Stradner 1963) Hay and Mohler 1967
+			<i>Quadrum trifidum</i> (Stradner 1961) Prins and Perch-Nielsen 1977
+			! <i>Stradneria crenulata</i> (Bramlette and Martini 1964) Noël 1970
+			<i>Thoracosphaera deflandrei</i> Kamptner 1956
+			* <i>Th. operculata</i> Bramlette and Martini 1964
+			* <i>Th. saxea</i> Stradner 1961
+			<i>Thoracosphaera</i> sp.
+			! <i>Watznaueria barnesae</i> (Black 1959) Perch-Nielsen 1968
	+		<i>Dictyococcites</i> sp.
	+		<i>Discoaster barbadiensis</i> Tan 1927
	+		<i>D. deflandrei</i> Bramlette and Riedel 1954
	+		<i>Ericsonia eopelagica</i> (Bramlette and Riedel 1954) Bramlette and Sullivan 1961
	+		<i>Pontosphaera</i> spp.
	+		<i>Reticulofenestra dictyoda</i> (Deflandre 1954) Stradner 1968
	+		<i>Reticulofenestra</i> spp.
	+		<i>Sphenolithus radians</i> Deflandre 1952
	+		<i>Sphenolithus</i> spp.
		+	<i>Dictyococcites</i> cf. <i>D. productus</i> (Kamptner 1963) Backman 1980
		+	<i>Discoaster</i> sp.
		+	<i>Helicosphaera carterii</i> (Wallich 1877) Kamptner 1954 ex Jafar and Martini 1975
		+	<i>Helicosphaera</i> sp.
		+	<i>Sphenolithus conicus</i> Bukry 1971

Exceptional foraminiferal-rich facies of Koshalia-Nala section (Figure 1) however, yielded Early Eocene nannofossils for the first time from Lesser Himalayan belt. Associated larger foraminiferal species, viz. *Assilina mamillata*, *A. spira abradi*, *A. daviesi*, *A. granulosa*, *Nummulites atacicus*, *N. globulus*, *N. obtusus* support the Early Eocene age^{1,2}. Nannofossils preservation is moderate and the diversity low owing to both ecological and palaeoceanographic factors; the assemblage being dominated by sphenoliths and discoasters and favours assignment to combined NP12: *Tribra-chiatus orthostylus* and NP13: *Discoaster lodoensis* zones of the Late Ypresian age, despite the absence of both markers. The presence of *R. dictyoda* (Figure 16), *D. barbadiensis* (Figure 17, 18), *D. deflandrei* (Figure 19)

and *S. radians* (Figures 23–27), all having their first occurrence (FO) near the base of zone NP12, and the absence of younger markers, viz. *Discoaster sublodoensis*, *Rhabdosphaera inflata* and *Nannotetrina fulgens*, justifies Late Ypresian age assignment. Although no nannofossil data are available from younger levels, including Dagshai Formation, the larger foraminifer species cited in favour of the Lutetian age are rather controversial^{2,3}. Some typical Early Eocene index nannofossils, viz. *Discoaster kuepperii*, *Discoaster lodoensis*, *Tribra-chiatus orthostylus* seem to have been excluded from the Subathu Formation of Koshalia-Nala owing to facies constraints, but are well documented from nearby deep-sea flyschoid sediments exuded from Mud-volcanoes of Andaman basin^{7,8}.

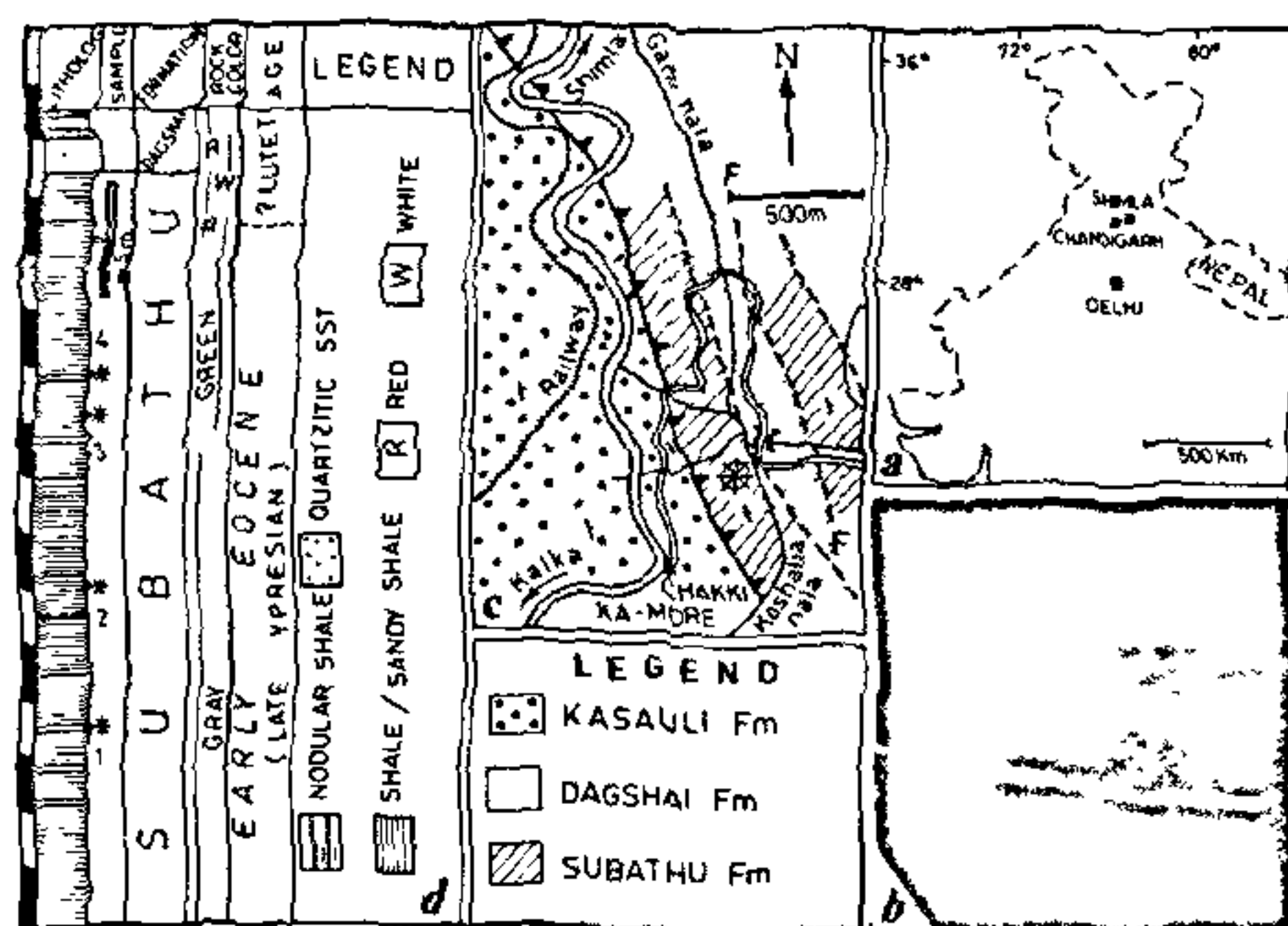


Figure 1. **a**, Position of Shimla town in Lesser Himalaya **b**, A view of Koshalia-Nala section, in Shimla Hills. Arrow points to an excellent exposure of larger foraminiferal-rich facies of Subathu Formation yielding calcareous nannofossils described herein. The beds dip towards concrete bridge seen in the foreground and distinctly visible from a place 'Chakki-ka-More' situated higher up on main Kalka-Shimla highway. **c**, Simplified geological map, showing a narrow jeepable road at 72 km milestone near 'Chakki-ka-More' on Kalka-Shimla highway, leading down to the bridge and adjoining sampling profile shown by an encircled asterisk (modified after Bhatia and Singh¹). **d**, Lithology of Subathu-Dagshai formations as seen in Koshalia-Nala, showing sample number/points (asterisk), lithology and age assigned on the basis of larger foraminifera and discovered calcareous nannofossils. (Modified after Bhatia and Singh¹.)

Reworked K/T boundary species

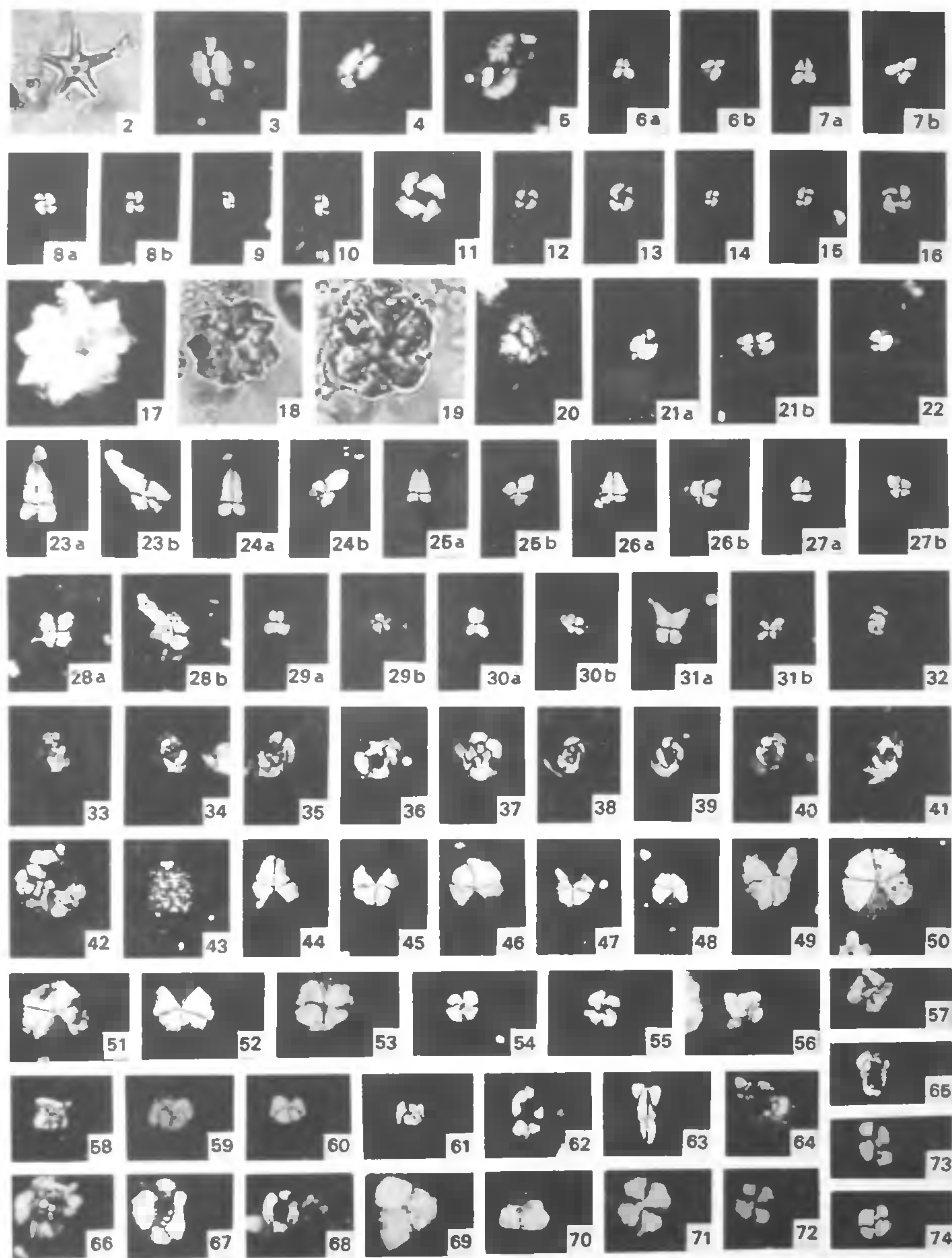
Dramatic mass extinctions induced by radical changes in both marine and terrestrial ecosystems and its possible relation to Deccan-vulcanism of India at K/T boundary have evoked global interest and debate^{6,9}. A 'complete' K/T boundary section in low-latitude sites must contain youngest Cretaceous nannofossil zone, *Micula prinsii*, followed upwards by 'boundary clay' lying within the Tertiary planktonic foraminifer zone, *Globigerina fringa*, and succeeded by *Globigerina eugbina* zone¹⁰. Although a Danian outcrop near Dharampur containing nannofossils was earlier reported⁶, no section is so far available in Lesser Himalaya for demarcation of the K/T boundary based on the above criteria. Nevertheless, the presence of characteristic Late Maastrichtian-Danian nannofossils strongly suggests the existence of K/T boundary section in Lesser Himalayan terrain. It must be emphasized that all global 'survivor' nannofossils except *Neocrepidolithus* spp (Table 1) are now known from Shimla Himalaya^{6,11}. *Markalius inversus*, *Hornibrookina*? spp and *Placozygus sigmoides* were documented earlier from Dharampur⁶, but could not be found in Koshalia-Nala section, which has now yielded *Cyclagelosphaera reinhardtii* (Figures 54, 55), typically known to straddle K/T boundary in El Kef (Tunisia), Lattengebirge (Germany), Biarritz (France),

Stevns (Denmark), Russian Platform sections^{10,12} and elsewhere. Three additional 'survivor' species, viz. *Thoracosphaera operculata*, *Th. saxea* and *Th. deflandrei*, belong to calcareous dinoflagellates; besides, typical incoming Tertiary nannofossil species denoting basal Tertiary zones, viz. NP1: *Biantholithus sparsus* NP2: *Cruciplacolithus tenuis* and NP3: *Cruciplacolithus danicus*, are present in Koshalia-Nala section.

Late Maastrichtian planktonic foraminifer *Abathomphalus mayaraensis*, though stated to occur in eastern Indian sections¹³, may in fact be missing altogether, e.g. in Russian platform¹² and elsewhere. Likewise, the latest Maastrichtian marker nannofossil *Micula prinsii* has not been observed in Andaman Islands, Meghalaya, Ukhrul Limestone of Manipur and Subathu Formation, and also appears to be absent, for example, in Gubbio (Italy), Stevns (Denmark) and Russian platform¹². However, eastern Indian sections contain low-latitude Late Maastrichtian marker *Micula murus*^{14,15} with well-diversified assemblage from Andaman Island, Meghalaya, Ukhrul Limestone of Manipur and Subathu Formation (Figures 56, 57). High-latitude Late Maastrichtian marker *Nephrolithus frequens* has not been observed in India and a report from Nagaland ophiolite belt¹⁶ is erroneous. Similarly, a documented report of basal Danian planktonic foraminifer marker *Globigerina eugbina* from Andaman Islands¹⁷ and Meghalaya¹⁸ is also dubious.

Potential K/T boundary marine sections in India

Thus a solitary exposed shallow marine section in India, viz. Um Sohryngkew River section of Meghalaya, despite displaying iridium spike within 1.5 cm Limonitic clay layer¹³, fails to fully satisfy the requirements of a complete K/T boundary section, mainly owing to: (a) mass extinctions including the disappearance of Cretaceous planktonic foraminifera must coincide with iridium anomaly defining K/T boundary^{19,20}, whereas in Meghalaya section, strongly bored Cretaceous planktonic foraminifera abnormally continue higher up to about 40 cm above the iridium-rich K/T boundary^{13,18}; (b) the section is not demonstrated to be biostratigraphically complete due to the absence or poor documentation of basal Danian planktonic foraminifers, *G. fringa* and *G. eugbina*¹⁸. Another potential area for demarcating K/T boundary lies in the subsurface of Andaman basin, as exposed sections are devoid of nannofossils, but the deep-sea flyschoid sediments exuded from Mud-Volcanoes contained Late Maastrichtian *Micula murus* and Early Danian *Biantholithus sparsus*⁷. Probably the only exposed and comparable section containing complete K/T boundary of deep-sea flyschoid facies lies in Martinsgraben of Switzerland¹¹. Another unique area valuable for demarcating K/T boundary lies near Imphal close to ophiolite belt: cream-coloured hard



pelagic limestone of geosynclinal facies containing *Globotruncana* and Late Maastrichtian *Micula murus* zone assemblage comparable to European K/T boundary section²¹, occurs as tectonic slices within Disang Formation (samples provided to SAJ by Mr Ch. Prithiraj and Prof. A. Sahni of Panjab University, Chandigarh).

Leaked Early Miocene nannofossils

Although a few sporadic marine Miocene elements were reported from Lesser Himalaya, especially the Jammu area^{22,23}, a more convincing find of foraminiferal-rich (poorly documented) pelagic limestone was reported from Darjeeling Sub-Himalaya²⁴. A few rare but authentic nannofossils of Early Miocene age were detected in all samples of Koshalia-Nala section (Figures 2-10, Table 1), despite strict precautions taken against contamination, suggesting the occurrence of such nannofossil-bearing rocks in the close vicinity of the section. Such leaked nannofossils signify that marine conditions prevailed along the present site of Himalayan foothills during the Early Miocene and warrants a vigorous search and mapping to study the coeval transgressive event and the geotectonic evolution of Himalaya.

Conclusions

Early Eocene nannofossils discovered from Subathu Formation of Koshalia-Nala section can be assigned to combined NP12-NP13 zones of the Late Ypresian age. Significant occurrence of reworked Late Maastrichtian-Danian nannofossil species, including those straddling reputed and complete K/T boundary sections, in Subathu Formation, signifies possible discovery of outcrops sandwiched between Precambrian rocks and containing K/T boundary with ash-beds in the Lesser Himalayan terrain. Unexpected find of a few Early Miocene nannofossils, interpreted as leaked from younger rocks lying in close vicinity of the Subathu section, could imply a coeval transgressive event in Lesser Himalaya.

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Figures 2-74. 2, *Discoaster* sp.; 3, 4, *H. carterii*; 5, *Helicosphaera* sp.; 6, 7, *S. contus*; 8, *Dictyococcites* cf. *D. productus*; 9, 10, *Dictyococcites* sp.; 11, *Reticulofenestra* sp. 1; 12, 13, *Reticulofenestra* sp. 2; 14, 15, *Reticulofenestra* sp. 3; 16, *R. dictyoda*; 17, 18, *D. barbadiensis*; 19, *D. deflandrei*; 20, *E. eopelagica*; 21, *Pontosphaera* sp. 1; 22, *Pontosphaera* sp. 2; 23-27, *S. radians*; 28, *Sphenolithus* sp. 1; 29, 30, *Sphenolithus* sp. 2; 31, *Sphenolithus* sp. 3; 32, *P. bisulcus*; 33, 34, *C. tenuis*; 35, *C. intermedius*; 36, *C. frequens*; 37, *Cruciplacolithus* sp. 1; 38, *Cruciplacolithus* sp. 2; 39-41, *C. danicus*; 42, *Th. savea*; 43, *Thoracosphaera deflandrei*; 44-51, *B. bigelowii*; 52, *Micrantholithus* sp.; 53, *B. sparsus*; 54, 55, *C. reinhardii*; 56, 57, *M. murus*; 58, *M. swastika*; 59-61, *Micula* sp.; 62, *E. gorkae*; 63, 64, *P. grandis*; 65, *C. ehrenbergii*; 66-68, *S. crenulata*; 69, 70, *Q. trifidum*; 71-74, *B. barnesae*. (All lightmicrographs taken under partial or crossed polarized illumination except Figures 2, 18, 19 which were taken under single polarizer. All figures $\times 1500$ except Figures 44-52 which were $\times 1000$). Figures 2-10 represent Leaked species from Early Miocene; Figures 11-31 represent Autochthonous Early Eocene = Late Ypresian species; Figures 32-74 represent Late Maastrichtian Danian Reworked species, including those straddling K/T boundary.