Paleocene and Eocene Dinocysts from the Salt Range, Punjab, Northern Pakistan

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Chapter C of

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Abstract

Dinoflagellate cysts were examined from 12 samples from the Nammal Pass–Nammal Dam composite section and from 3 samples from 2 coreholes in the Salt Range, northern Pakistan. The dinocysts indicate that the age of the Patala Formation in the studied samples is late Paleocene. Samples containing *Apectodinium augustum* (Harland) Lentin & Williams are most probably very late Paleocene in age. The dinocysts indicate that the age of the Nammal Formation at the Nammal Dam section is early Eocene, or possibly younger. The Paleocene-Eocene boundary may possibly be near the sample at 141.5–141.8 feet in the Basharat 34 core, but sample spacing, poor preservation, and the questionable identification of *Wetzeliella astra* Costa et al. make this boundary placement uncertain.

Introduction

Dinoflagellates are single-celled organisms that have both plantlike and animallike characteristics. Paleontologists generally classify them as plants in the division Dinoflagellata. Most dinoflagellates have a complex life cycle, and many produce cysts during some part of this life cycle. Some of these cysts have an organic wall composed of a sporopollenin-like material. These cysts can be recovered as fossils by the same techniques used to recover fossil pollen and spores from sediments. Dinoflagellate cysts, or dinocysts, were included in the U.S. Geological Survey (USGS) paleontological study of material from northern Pakistan (figs. C1, C2).

Paleocene and Eocene dinoflagellate cysts from the northwest European basins and surrounding areas have been studied extensively (see recent compilations by Costa and Manum (1988) and Powell (1988)). Paleocene and Eocene dinocysts and calcareous nannofossils from Pakistan were studied by Köthe (1988), who erected a dinoflagellate zonation and correlated this zonation where possible with the nannofossil zonation of Martini (1971). Other studies resulting in dinocyst occurrence or range charts that depict Paleocene and Eocene sediments are the work of Wilson (1988) for New Zealand and Edwards (1980, 1990) for the southeastern U.S. Atlantic Coastal Plain.

Paleocene sediments containing dinocysts have been reported from southern India (Jain and Garg, 1986). In eastern India, Tripathi (1989) dated samples from the Therria Formation as late Paleocene. However, material from the upper part of the Therria contains *Homotryblium tenuispinosum* Davey & Williams and may actually be of early Eocene age (see discussion below). Jan du Chêne and Adediran (1984) recorded dinocyst occurrences from a section in southwestern Nigeria that they could date as no older than late Paleocene (Zone NP 9 of Martini (1971)), or possibly younger (Zones NP 10 and NP 11 of Martini (1971)).

Williams and Bujak (1985) synthesized published data on worldwide dinocyst ranges and presented these data in the framework of Cenozoic standard calcareous nannofossil and planktic foraminiferal zonations.

Acknowledgments

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Materials and Methods

Outcrop samples.—Twelve outcrop samples were examined from a composite section at Nammal Pass and Nammal Dam (fig. C3). The Nammal Pass section, lat 32º40.75′ N., long 71º47.19′ E., was measured by B.R. Wardlaw, W.E. Martin, and I.H. Haydri. Here, the section consists of the coal-bearing Hangu Formation (thickness 138 feet (ft), or 42.1 meters (m)) and the overlying cliff-forming Lockhart Limestone (thickness 159 ft, or 48.5 m). One sample from

Figure C1. Location map showing the Salt Range study area (box) and selected regional features.

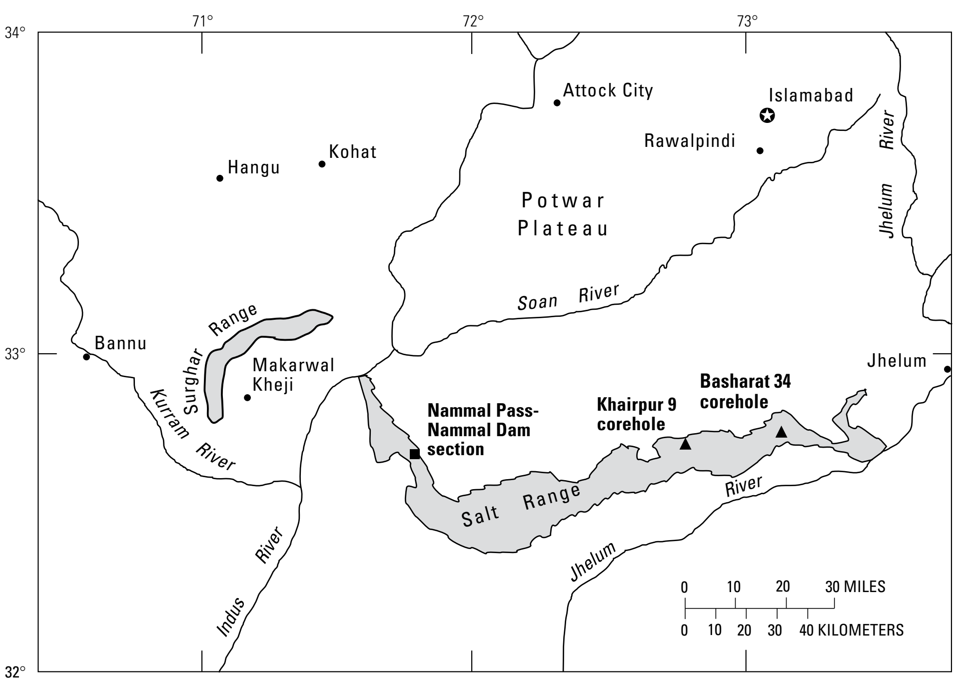


Figure C2. Locations of outcrops (solid square) and coreholes (solid triangles) studied in the Salt Range study area, northern Pakistan.

the Hangu Formation at 129 ft (39.3 m) in the measured section and two samples, R4383A and R4383C, from the Hangu Formation taken by N.O. Frederiksen in mudstone from a coal mine dump at Nammal Pass were examined for dinocysts. The Nammal Dam section was measured by B.R. Wardlaw, W.E. Martin, I.H. Haydri, J.M. Self-Trail, N.O. Frederiksen, and Tariq Masood at lat 32º39.81′ N., long 71º48.05′ E. Five samples from the Patala Formation (thickness 138 ft, or 42.1 m) and four samples from the Nammal Formation (thickness 295 ft, or 89.9 m) were examined for dinocysts. All samples were collected during October–November 1989.

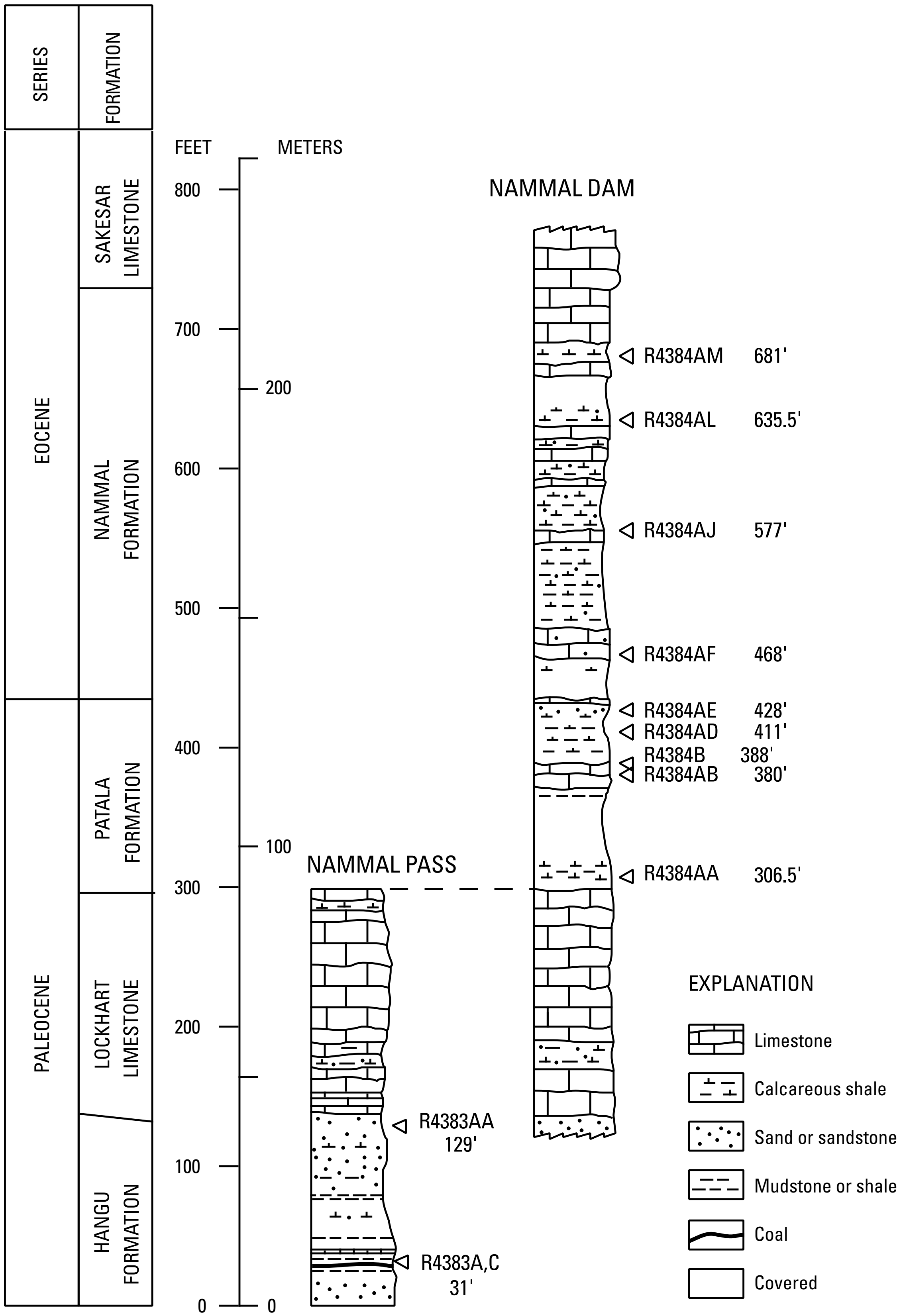


Figure C3. Columnar sections at Nammal Pass and Nammal Dam (simplified from Wardlaw and others, this volume, chap. F) showing positions of samples studied. Height of sample (in feet) above base of section shown after each sample number. See figure C2 for location of sections.

Core samples.—While in Pakistan, Frederiksen and Self-Trail collected samples from seven coreholes drilled by the Geological Survey of Pakistan (GSP) during 1987–1989 and stored at the GSP offices in Lahore. These samples were taken for pollen and spores or for calcareous microfossils and nannofossils, not specifically for dinocysts. However, a few of these samples were also processed for dinocysts.

Processing techniques.—Samples were treated in hydrochloric acid and hydrofluoric acid to remove carbonate and silicate material, respectively. Samples were then oxidized in nitric acid and centrifuged in laboratory detergent to remove fine debris. Sample residues were then stained in Bismark brown, sieved at 10 and 20 micrometers (µm), swirled in a watch glass, and mounted in glycerin jelly for light-microscope observation. One sample, R4372N from the Khairpur 9 corehole (fig. C2), was subjected to $ZnCl_2$ separation and was not stained.

The slide numbers and microscope coordinates of photographed dinoflagellates (pls. C1, C2) locate the specimens on Olympus Vanox microscope 201526 at the U.S. Geological Survey, Reston, Va. On this microscope, the coordinates for the center point of a standard 25.4 × 76.2 mm slide are 27.5, 112.7 (vertical, horizontal axes). The vertical coordinates increase as the stage is moved up, and the horizontal coordinates increase as the slide is moved from left to right. All palynological slides are stored at the U.S. Geological Survey, Reston, Va.

Stratigraphic Palynology

Hangu Formation

Three samples from the Hangu Formation at the Nammal Pass section were examined for dinocysts (figs. C3, C4). Two of these samples yielded very sparse dinofloras. A single, poorly preserved specimen of ?*Apectodinium* sp. suggests, but by no means confirms, a late Paleocene age. A third sample was barren of dinoflagellate cysts.

Lockhart Limestone

No samples from the Lockhart Limestone were studied for dinoflagellate cysts.

Patala Formation

Five samples from the Patala Formation at the Nammal Dam section were studied (figs. C3, C4), as well as one sample from the Patala in the Khairpur 9 corehole (table C1). Preservation is fair to good. *Eocladopyxis peniculata* Morgenroth, *Hystrichokolpoma unispinum* Williams & Downie, *Apectodinium augustum* (Harland) Lentin & Williams, *Hafniasphaera septata* (Cookson & Eisenack) Hansen, and *Ifecysta pachyderma* Jan du Chêne & Adediran are apparently restricted to this formation.

On the basis of the dinocysts, the age of the Patala in the studied samples is late Paleocene. *Apectodinium homomorphum* (Deflandre & Cookson) Lentin & Williams has not been reported from material older than that correlated with calcareous nannofossil Zones NP 7 or NP 8 (Edwards, 1980; Costa and Manum, 1988). Samples containing *A. augustum* are most probably correlative with Zone NP 9.

Nammal Formation

Four samples from the Nammal Formation at the Nammal Dam section (figs. C3, C4) and two samples from the Nammal in the Basharat 34 corehole (table C2) were studied. Preservation is fair to poor. *Homotryblium tenuispinosum sensu lato* and ?*Wetzeliella astra* Costa et al. are apparently restricted to this formation.

The dinocysts indicate that the age of the Nammal Formation at the Nammal Dam section is early Eocene, or possibly younger. The Paleocene-Eocene boundary may possibly be near the sample at 141.5–141.8 ft in the Basharat 34 core, but sample spacing, poor preservation, and the questionable identification of *W. astra* make this boundary placement uncertain.

Discussion

Biostratigraphy

At the Nammal Dam section, the dinoflora shows a distinctive break between the uppermost sample (R4384AE) from the Patala Formation and the lowermost sample (R4384AF) from the Nammal Formation. Samples from the upper part of the Patala have moderately well preserved, relatively diverse dinofloras and contain the distinctive species *Hystrichokolpoma unispinum, Achilleodinium*? sp. I, *Apectodinium augustum*, and *Hafniasphaera septata*. Samples from the Nammal Formation are poorly preserved and have sparse dinofloras lacking these species and containing *Homotryblium tenuispinosum sensu lato*. For the Basharat 34 corehole, only two samples, both from the Nammal Formation, were studied. Here preservation is poor, and so the lowest occurrence of *Homotryblium* sp. may not be stratigraphically significant. This lowest occurrence is seen in the same sample as ?*Wetzeliella astra*.

The lowest stratigraphic occurrence of *W. astra* is commonly used to recognize the Paleocene-Eocene boundary using dinoflagellate cysts (Costa and others, 1978; Morton and others, 1983; Jolley and Spinner, 1989). Other workers (for example, Knox and others, 1983; Powell, 1988) did not find this species to be a reliable marker. For material from central Pakistan, Köthe (1988) used *W. astra* as a marker and defined her Zone Pak D VII on its first occurrence, but noted (Köthe, 1988, p. 11) that she found only one specimen.

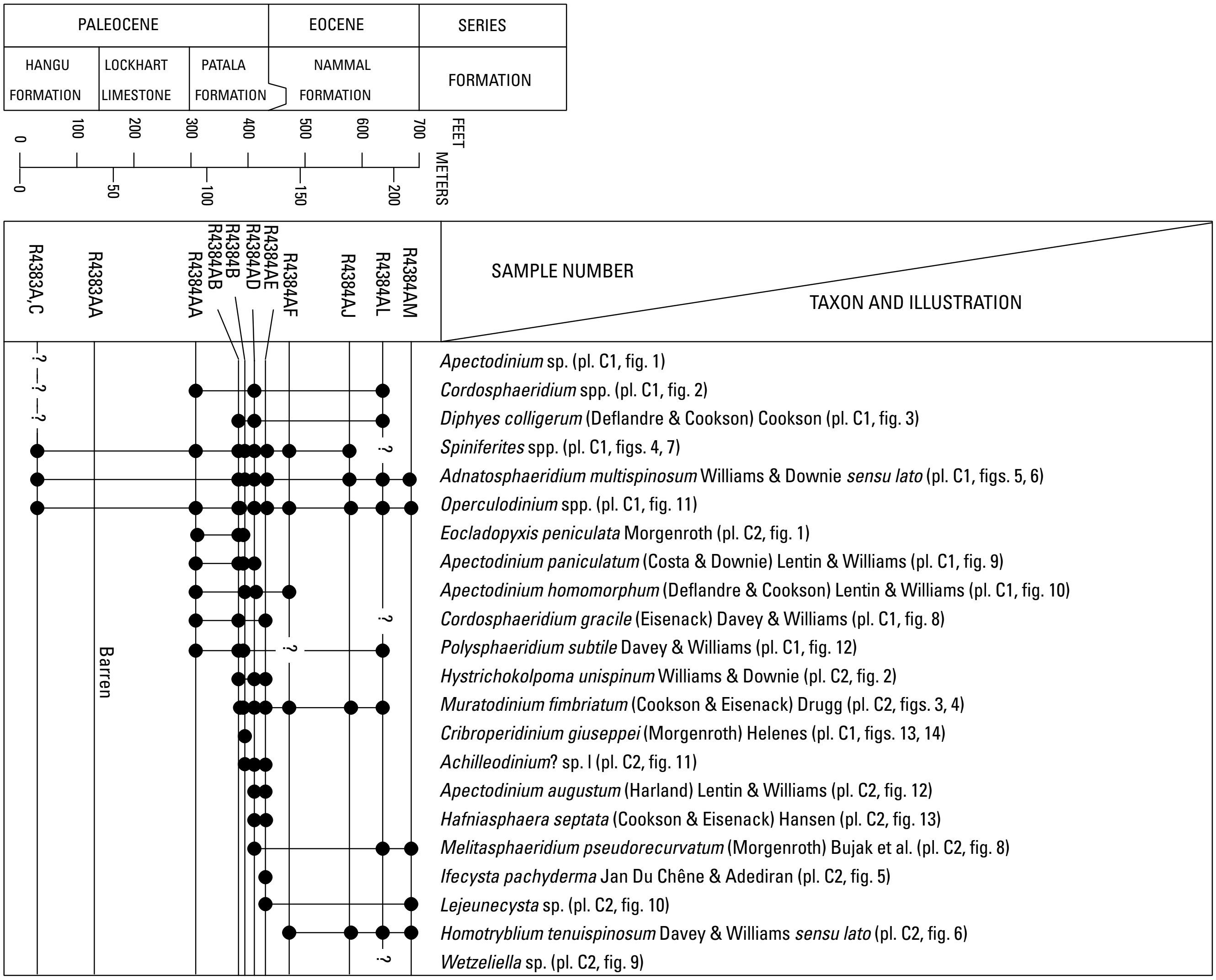


Figure C4. Occurrence and range chart of dinocysts recovered from the Nammal Pass–Nammal Dam composite section. Occurrence queried where uncertain.

Powell (1988) concluded that the highest stratigraphic occurrence of *Apectodinium augustum* should be used as the marker for the Paleocene-Eocene boundary in the central North Sea area. However, indirect correlations using calcareous nannofossils and ash beds (Knox, 1984) coupled with Powell's (1988) data suggest that the highest occurrence of *A. augustum* is actually slightly above the Paleocene-Eocene contact if this contact is placed at the base of Martini's (1971) calcareous nannofossil Zone NP 10.

Within the Eocene, Köthe (1988) used the lowest occurrence of *Homotryblium tenuispinosum* to mark the base of her Zone Pak D VIII and the lowest occurrence of *H. oceanicum* Eaton to mark the base of her Zone Pak D IX. However, on her individual occurrence charts, these species are never found in succession. Williams and Bujak (1985) considered the lowest stratigraphic occurrences of *H. tenuispinosum* and *H. pallidum* Davey & Williams to occur in lower Eocene sediments within calcareous nannofossil Zone NP 10. They showed the lowest occurrences of *H. abbreviatum* Eaton and *H. oceanicum* somewhat higher (within NP 13 and at the base of NP 14, respectively). Costa and Manum (1988) stated that the lowest stratigraphic occurrence of *H. tenuispinosum* is within their highest Paleocene zone, their D 5; however, none of the individual range charts showed this species below the base of their Zone D 6 (lowest Eocene). They reported the lowest occurrences of *H. abbreviatum* in their Zone D 8 (calibrated to NP 12 and part of NP 13) and *H. oceanicum* in their Zone D 9 (calibrated to parts of NP 13 and NP 14). Tripathi (1989) reported *H. tenuispinosum* from upper Paleocene sediments in the upper part of the Therria Formation in Meghalaya, eastern India. He considered these sediments to be Paleocene on the basis of the lowest occurrence of *Apectodinium parvum* (Alberti) Lentin & Williams. Because the reported range of *A. parvum* is late Paleocene to early Eocene (NP 9 to NP 10 according to Jain and Garg (1986); NP 9 to NP 10, but possibly to NP 12 according to Costa and Manum (1988)), and because strati-

Table C1. Dinocysts in sample R4372N from the Khairpur 9 corehole.

[Sample is from the Patala Formation, 30.6–30.9 ft above the base of the Patala. X, present in sample; ?, questionably present]

Taxon	Sample number and depth from surface R4372N 446.6–446.9 ft
Achilleodinium? sp. I	X
Apectodinium homomorphum (Deflandre & Cookson) Lentin & Williams	?
Fibrocysta sp.	?
Operculodinium spp.	X
Polysphaeridium subtile Davey & Williams	?
Spiniferites sp.	X
Thalassiphora pelagica (Eisenack) Eisenack & Gocht	X

Table C2. Dinocysts in two samples from the Basharat 34 corehole.

[Both samples are from the Nammal Formation; sample R4379K is from 81.2–81.5 ft above the base of the Nammal, and sample R4379S is from 19.0–19.3 ft above the base. X, present in sample; ?, questionably present; —, not detected]

Taxon	Sample number and depth from surface	
	R4379S 203.7–204 ft	R4379K 141.5–141.8 ft
Areoligera sp.	—	X
Cribroperidinium giuseppei (Morgenroth) Helenes	—	X
Diphyes colligerum (Deflandre & Cookson) Cookson	—	?
Homotryblium sp.	—	?
Lejeunecysta sp.	—	X
Muratodinium fimbriatum (Cookson & Eisenack) Drugg	—	X
Operculodinium spp.	—	X
Wetzeliella astra Costa et al.	—	?
Polysphaeridium subtile Davey & Williams	X	X
Spiniferites spp.	X	X
Adnatosphaeridium multispinosum Williams & Downie	X	—
Apectodinium hyperacanthum-paniculatum	X	—

graphically lower sediments contain a sparse dinoflora (only one species is shown on their fig. 1), this lowest occurrence should not be considered reliable for correlation, and the Therria sediments may be of Eocene age.

Studied samples from the Nammal Dam section containing *H. tenuispinosum sensu lato* are most probably of early Eocene age. It is unlikely that the lowest occurrence of this species coincides exactly with the base of nannofossil Zone NP 10.

The dinoflora from the Patala Formation is similar to that reported by Jan du Chêne and Adediran (1984) from Nigeria. These authors, too, had difficulty in determining whether their samples are of late Paleocene or early Eocene age.

Paleoenvironment

Given the generally poor dinocyst preservation, little can be said about the paleoenvironments represented by the studied material except that this material probably represents subtropical to tropical paleoenvironments.

Köthe (1988) noted that the first occurrence of *Polysphaeridium subtile* Davey & Williams in Pakistan is older (approximately Zone NP 8) than previously reported (NP 12, according to Williams and Bujak (1985)). However, Caro (1973) also reported this species from the Paleocene of the Spanish Pyrenees. This species may be a direct ancestor (or perhaps a junior synonym; see Lentin and Williams (1989)) of *Polysphaeridium zoharyi* (Rossignol) Bujak et al., a species whose modern distribution is subtropical to tropical and euryhaline (Wall and others, 1977; Harland, 1983). Thus, *P. subtile* may have evolved in lower paleolatitudes.

Muratodinium fimbriatum (Cookson & Eisenack) Drugg also seems to have a diachronous range base: in the Paleocene in more tropical environments such as Pakistan (this report) and the southeastern United States (Edwards, unpub. data), and in the Eocene in less tropical environments such as the eastern United States (Edwards, 1990).

Taxonomic Comments

Genus *Achilleodinium* Eaton
Achilleodinium? sp. I

Plate C2, figure 11

Remarks.—Cyst is subspherical to ellipsoidal, with hollow, tubiform, foleate processes. Processes are intratabular and may occur as a single process per paraplate, as several separate processes per paraplate, or as several proximally joined processes per paraplate. The paracingulum is indicated by aligned processes; the parasulcus is indicated by more slender processes. The antapical process is distinctively shaped and larger than the other processes. Paratabulation is gonyaulacacean, exact formula uncertain due to process fusion. Archeopyle is precingular, type P (3″ only), and the operculum is free.

Occurrence in studied samples.—Patala Formation, Nammal Dam section; Patala Formation, Khairpur 9 corehole.

Genus *Adnatosphaeridium* Williams & Downie

Adnatosphaeridium multispinosum Williams & Downie *sensu lato*

Plate C1, figures 5, 6

Remarks.—This species shows considerable variation in size and process development. Older specimens (like that shown in pl. C1, fig. 6) more commonly are larger and have more robust processes. Younger specimens (like that shown in pl. C1, fig. 5) are more commonly smaller and have more delicate processes. Although two endmembers are illustrated, a wide range of forms is present in many samples.

Occurrence in studied samples.—Hangu Formation, Nammal Pass section; Patala and Nammal Formations, Nammal Dam section; Nammal Formation, Basharat 34 corehole.

Genus *Apectodinium* Lentin & Williams

Apectodinium augustum (Harland) Lentin & Williams

Plate C2, figure 12

Remarks.—This species of *Apectodinium* is distinguished by its reduced apical horn, its long antapical horns, and, especially, its very long lateral horns.

Occurrence in studied samples.—Patala Formation, Nammal Dam section.

Apectodinium homomorphum (Deflandre & Cookson) Lentin & Williams

Plate C1, figure 10

Remarks.—Specimens of the genus *Apectodinium* that do not have prominent apical, lateral, or antapical horns are placed in this species.

Occurrence in studied samples.—Patala and Nammal Formations, Nammal Dam section; Patala Formation, Khairpur 9 corehole.

Apectodinium paniculatum (Costa & Downie) Lentin & Williams

Plate C1, figure 9

Remarks.—Costa and Downie (1976) differentiated this species from *A. quinquelatum* (Williams & Downie) Costa & Downie by its longer lateral horns, but noted that they encountered numerous transitional forms between the two taxa. They stated that *A. paniculatum* differs from *A. hyperacanthum* (Cookson & Eisenack) Lentin & Williams by the absence of a well-developed apical horn and by the shape of the antapical horns. Folded and poorly preserved specimens are difficult to identify to species level. Specimens from the Patala Formation show prominent lateral horns and weakly developed apical horns and are thus placed in *A. paniculatum*. They may, however, be conspecific with some of the forms called *A. quinquelatum* by Köthe (1988). Specimens from the Nammal Formation are designated as *A. hyperacanthum-paniculatum* because the poor preservation precludes unequivocal identification.

Occurrence in studied samples.—Patala Formation, Nammal Dam section; Nammal Formation, Basharat 34 corehole.

?*Apectodinium* sp.

Plate C1, figure 1

Remarks.—A single, poorly preserved specimen was found in sample R4383C from the Hangu coal mine dump at Nammal Pass. If this specimen is an *Apectodinium*, it indicates that the age of this sample is late Paleocene or younger.

Occurrence in studied samples.—Hangu Formation, Nammal Pass section.

Genus *Cordosphaeridium* Eisenack

Cordosphaeridium gracile (Eisenack) Davey & Williams

Plate C1, figure 8

Occurrence in studied samples.—Patala Formation and questionable in Nammal Formation, Nammal Dam section.

Cordosphaeridium spp.

Plate C1, figure 2

Remarks.—This category probably includes *Cordosphaeridium inodes* (Klumpp) Eisenack, *Cordosphaeridium exilimurum* Davey & Williams, *Cordosphaeridium fibrospinosum* Davey & Williams, other representatives of the genus that are too poorly preserved to identify with certainty, and possibly *Amphorosphaeridium*? *multispinosum* (Davey & Williams) Sarjeant.

Occurrence in studied samples.—Patala and Nammal Formations, Nammal Dam section.

Genus *Cribroperidinium* Neale & Sarjeant

Cribroperidinium giuseppei (Morgenroth) Helenes

Plate C1, figures 13, 14

Occurrence in studied samples.—Patala Formation, Nammal Dam section; Nammal Formation, Basharat 34 corehole.

Genus *Diphyes* Cookson

Diphyes colligerum (Deflandre & Cookson) Cookson

Plate C1, figure 3

Remarks.—In several of the observed specimens, it was difficult to determine the exact shape of the antapical process. Thus, it is quite possible that specimens of *Diphyes spinulum* (Drugg) Stover & Evitt have been included here.

Occurrence in studied samples.—Patala and Nammal Formations, Nammal Dam section; questionable in Hangu Formation, Nammal Pass section and Nammal Formation, Basharat 34 corehole.

Genus *Eocladopyxis* Morgenroth
Eocladopyxis peniculata Morgenroth

Plate C2, figure 1

Remarks.—As is typical for this species, most specimens are fragments.

Occurrence in studied samples.—Patala Formation, Nammal Dam section.

Genus *Hafniasphaera* Hansen
Hafniasphaera septata (Cookson & Eisenack) Hansen

Plate C2, figure 13

Remarks.—The unique vacuolar structure of the walls is considered worthy of generic distinction. Thus, the conclusion of Stover and Williams (1987) that the genus *Hafniasphaera* is a junior synonym of *Spiniferites* is rejected.

Occurrence in studied samples.—Patala Formation, Nammal Dam section.

Genus *Homotryblium* Davey & Williams
Homotryblium tenuispinosum Davey & Williams *sensu lato*

Plate C2, figure 6

Remarks.—The Pakistan specimens bear processes that are less flared than typical *Homotryblium tenuispinosum*, but not as cylindrical as *H. oceanicum* Eaton, and should perhaps be considered intermediate between the two endmembers.

Occurrence in studied samples.—Nammal Formation, Nammal Dam section; questionable representatives of the genus *Homotryblium* were found in the Nammal Formation, Basharat 34 corehole.

Genus *Hystrichokolpoma* Klumpp
Hystrichokolpoma unispinum Williams & Downie

Plate C2, figure 2

Remarks.—On specimens in which the paracingular processes could be observed, only one process per paraplate was noted.

Occurrence in studied samples.—Patala Formation, Nammal Dam section.

Genus *Ifecysta* Jan du Chêne & Adediran
Ifecysta pachyderma Jan du Chêne & Adediran

Plate C2, figure 5

Remarks.—The Pakistan forms show the typical apical and antapical hornlike protrusions that are formed by the closely appressed endophragm and periphragm. This species has been reported only from the Paleocene and Eocene (undifferentiated) of Nigeria.

Occurrence in studied samples.—Patala Formation, Nammal Dam section.

Genus *Lejeunecysta* Artzner & Dörhöfer
Lejeunecysta sp.

Plate C2, figure 10

Remarks.—These cysts are rare. They all have a distinctive dark-brown color.

Occurrence in studied samples.—Patala and Nammal Formations, Nammal Dam section; Nammal Formation, Basharat 34 corehole.

Genus *Melitasphaeridium* Harland & Hill
Melitasphaeridium pseudorecurvatum (Morgenroth) Bujak et al.

Plate C2, figure 8

Occurrence in studied samples.—Patala and Nammal Formations, Nammal Dam section.

Genus *Muratodinium* Drugg
Muratodinium fimbriatum (Cookson & Eisenack) Drugg

Plate C2, figures 3, 4

Remarks.—According to Drugg (1970), *Muratodinium fimbriatum* is more or less ovoidal in shape and has apical and antapical projections. *Thalassiphora patula* (Williams & Downie) Stover & Evitt closely resembles and probably intergrades with *M. fimbriatum*. *T. patula* is more spherical and lacks apical and antapical projections. Some of the Pakistan specimens (pl. C2, fig. 3) show only the faintest projections. In the material studied here, there seems to be no consistent stratigraphic relation to horn prominence.

Occurrence in studied samples.—Patala and Nammal Formations, Nammal Dam section; Nammal Formation, Basharat 34 corehole.

Genus *Operculodinium* Wall
Operculodinium spp.

Plate C1, figure 11

Remarks.—A wide variety of spherical forms with nontabular processes was encountered. Many show some evidence of a precingular archeopyle and thus belong to *Operculodinium*.

Occurrence in studied samples.—Hangu Formation, Nammal Pass section; Patala and Nammal Formations, Nammal Dam section; Patala Formation, Khairpur 9 corehole; Nammal Formation, Basharat 34 corehole.

Genus *Polysphaeridium* Davey & Williams
Polysphaeridium subtile Davey & Williams

Plate C1, figure 12

Occurrence in studied samples.—Patala and Nammal Formations, Nammal Dam section; Nammal Formation, Basharat 34 corehole; questionable in Patala Formation, Khairpur 9 corehole.

Genus *Spiniferites* Mantell
Spiniferites spp.

Plate C1, figures 4, 7

Remarks.—Assorted forms assignable to the genus *Spiniferites* were encountered in the samples studied. No attempt was made to assign these often poorly preserved forms to species. Two better preserved specimens are illustrated in plate C1, figures 4 and 7.

Occurrence in studied samples.—Hangu Formation, Nammal Pass section; Patala and Nammal Formations, Nammal Dam section; Patala Formation, Khairpur 9 corehole; Nammal Formation, Basharat 34 corehole.

Genus *Wetzeliella* Eisenack
?*Wetzeliella astra* Costa et al.

Plate C2, figure 7

Remarks.—Several specimens were encountered in a single sample from the Basharat 34 corehole at a depth of 141.5–141.8 ft. The best preserved is illustrated in plate C2, figure 7.

Occurrence in studied samples.—Nammal Formation, Basharat 34 corehole.

?*Wetzeliella* sp.

Plate C2, figure 9

Remarks.—The single poorly preserved specimen illustrated in plate C2, figure 9 has a more prominent pericoel than is generally accepted in the genus *Apectodinium*, and, therefore, it is questionably placed in the genus *Wetzeliella*.

Occurrence in studied samples.—Nammal Formation, Nammal Dam section.

References Cited

Caro, Yves, 1973, Contribution à la connaissance de dinoflagellés du Paléocène-Eocène inférieur des Pyrenées espagnoles: Revista Española de Micropaleontología, v. 5, p. 329–373, pls. 1–5.

Costa, L.I., Denison, C.N., and Downie, Charles, 1978, The Paleocene/Eocene boundary in the Anglo-Paris basin: Journal of the Geological Society of London, v. 135, pt. 3, p. 261–264.

Costa, L.I., and Downie, Charles, 1976, The distribution of the dinoflagellate *Wetzeliella* in the Palaeogene of northwestern Europe: Palaeontology, v. 19, p. 591–614, pl. 92.

Costa, L.I., and Manum, S.B., 1988, The description of the interregional zonation of Paleogene (D 1–D 15) and the Miocene (D 16–D 20), *in* Vinken, Renier, comp., The northwest European Tertiary basin—Results of the International Geological Correlation Programme Project no. 124: Geologisches Jahrbuch, pt. A, v. 100, p. 321–344, figs. 165–179.

Drugg, W.S., 1970, Some new genera, species and combinations of phytoplankton from the lower Tertiary of the Gulf Coast, USA: Proceedings of the North American Paleontological Convention, Chicago, 1969, pt. G, p. 809–843, figs. 1–19.

Edwards, L.E., 1980, Dinoflagellate stratigraphy—A first look, *in* Reinhardt, Juergen, and Gibson, T.G., Upper Cretaceous and lower Tertiary geology of the Chattahoochee River Valley, western Georgia and eastern Alabama, *in* Frey, R.W., ed., Excursions in southeastern geology, v. 2: Geological Society of America annual meeting, 93d, Atlanta, Ga., 1980, Field trip guidebooks, p. 424–427.

Edwards, L.E., 1990, Dinoflagellate cysts from the lower Tertiary formations, Haynesville cores, Richmond County, Virginia, chap. C *of* Mixon, R.B., ed., Geology and paleontology of the Haynesville cores—Northeastern Virginia Coastal Plain: U.S. Geological Survey Professional Paper 1489, p. C1–C12, pls. 1–5.

Harland, Rex, 1983, Distribution maps of recent dinoflagellate cysts in bottom sediments from the North Atlantic Ocean and adjacent seas: Palaeontology, v. 26, p. 321–387, pls. 43–48.

Jain, K.P., and Garg, Rahul, 1986, Upper Paleocene dinoflagellate cysts and acritarchs from Vriddhachalam, Cauvery basin, southern India: Palaeontographica, ser. B, v. 198, p. 101–132, pls. 1–6.

Jan du Chêne, R.E., and Adediran, S.A., 1984, Late Paleocene to early Eocene dinoflagellates from Nigeria: Cahiers de Micropaléontologie, v. 3–1984, p. 1–38, pls. 1–25.

Jolley, D.W., and Spinner, E., 1989, Some dinoflagellate cysts from the London Clay (Palaeocene-Eocene) near Ipswich, Suffolk, England: Review of Palaeobotany and Palynology, v. 60, p. 361–373.

Knox, R.W.O., 1984, Nannoplankton zonation and the Palaeocene/Eocene boundary beds of NW Europe—An indirect correlation by means of volcanic ash layers: Journal of the Geological Society of London, v. 141, p. 993–999.

Knox, R.W.O., Harland, Rex, and King, Christopher, 1983, Dinoflagellate cyst analysis of the basal London Clay of southern England: Newsletters on Stratigraphy, v. 12, p. 71–74.

Köthe, Angelika, 1988, Biostratigraphy of the Surghar Range, Salt Range, Sulaiman Range and the Kohat area, according to Jurassic through Paleogene calcareous nannofossils and Paleogene dinoflagellates: Geologisches Jahrbuch, pt. B, v. 71, p. 3–87, figs. 1–32, tab. 1, pls. 1–17.

Lentin, J.K., and Williams, G.L., 1989, Fossil dinoflagellates—Index to genera and species 1989 edition: American Association of Stratigraphic Palynologists Contribution Series, no. 20, p. 1–473.

Martini, Erlend, 1971, Standard Tertiary and Quaternary calcareous nannoplankton zonation: Proceedings of the Second Planktonic Conference, Rome, 1970, v. 2, p. 739–785.

Morton, A.C., Backman, Jan, and Harland, Rex, 1983, A reassessment of the stratigraphy of DSDP hole 117A, Rockall Plateau—Implications for the Paleocene-Eocene boundary in NW. Europe: Newsletters on Stratigraphy, v. 12, p. 104–111.

Powell, A.J., 1988, A modified dinoflagellate cyst biozonation for latest Palaeocene and earliest Eocene sediments from the central North Sea: Review of Palaeobotany and Palynology, v. 56, p. 327–344.

Stover, L.E., and Williams, G.L., 1987, Analyses of Mesozoic and Cenozoic organic-walled dinoflagellates 1977–1985: American Association of Stratigraphic Palynologists Contribution Series, no. 18, p. 1–243.

Tripathi, S.K.M., 1989, Algal and fungal remains from Jowai-Sonapur Road section (Palaeocene-Eocene), Meghalaya: Palaeobotanist, v. 37, no. 1, p. 63–76, pls. 1–3.

Wall, David, Dale, Barrie, Lohmann, G.P., and Smith, W.K., 1977, The environmental and climatic distribution of dinoflagellate cysts in modern marine sediments from regions in the North and South Atlantic Oceans and adjacent seas: Marine Micropaleontology, v. 2, p. 121–200.

Williams, G.L., and Bujak, J.P., 1985, Mesozoic and Cenozoic dinoflagellates, *in* Bolli, H.M., Saunders, J.B., and Perch-Nielsen, K., eds., Plankton stratigraphy: New York, Cambridge University Press, p. 847–964.

Wilson, G.J., 1988, Paleocene and Eocene dinoflagellate cysts from Waipawa, Hawkes Bay, New Zealand: New Zealand Geological Survey Paleontological Bulletin 57, 96 p., 26 pls.

Plates C1, C2

Plate C1

[All photographs × 500. Sample numbers are followed by the slide number in parentheses]

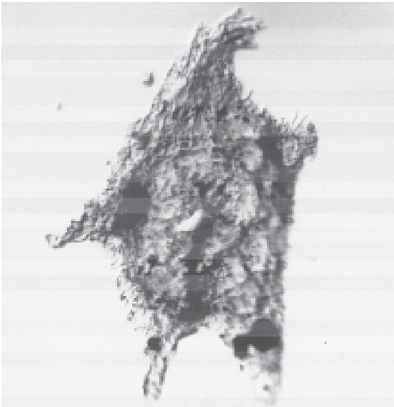
Figures 1–14. Dinocysts from the Hangu, Patala, and Nammal Formations.

1. ?*Apectodinium* sp. Orientation uncertain, sample R4383C (4), Hangu Formation. Slide coordinates 35.8, 75.0.
2. *Cordosphaeridium* sp. Left-lateral view (?), sample R4384AA (4), Patala Formation. Slide coordinates 21.1, 89.6.
3. *Diphyes colligerum* (Deflandre & Cookson) Cookson. Orientation uncertain, sample R4384AD (3), Patala Formation. Slide coordinates 32.9, 80.2.
4. *Spiniferites* sp. Right-lateral view at midfocus, R4384AF (4), Nammal Formation. Slide coordinates 27.3, 80.5.

5, 6. *Adnatosphaeridium multispinosum* Williams & Downie *sensu lato*.
   5. Orientation uncertain, sample R4384AJ (3), Nammal Formation. Slide coordinates 33.0, 106.6.
   6. Dorsal view (?) at midfocus, sample R4384B (2), Patala Formation. Slide coordinates 19.8, 82.3.

7. *Spiniferites* sp. Antapical view of apex, sample R4384AE (3), Patala Formation. Slide coordinates 36.4, 79.1.
8. *Cordosphaeridium gracile* (Eisenack) Davey & Williams. Orientation uncertain, sample R4384AB (4), Patala Formation. Slide coordinates 18.1, 92.9.
9. *Apectodinium paniculatum* (Costa & Downie) Lentin & Williams. Ventral view (?) at midfocus, sample R4384AA (4), Patala Formation. Slide coordinates 30.6, 77.7.
10. *Apectodinium homomorphum* (Deflandre & Cookson) Lentin & Williams. Ventral view (?) at midfocus, sample R4384AF (4), Nammal Formation. Slide coordinates 35.0, 78.0.
11. *Operculodinium* sp. Antapical view of apex, sample R4384AF (4), Nammal Formation. Slide coordinates 37.1, 102.8.
12. *Polysphaeridium subtile* Davey & Williams. Oblique antapical view of hypocyst, sample R4384B (2), Patala Formation. Slide coordinates 28.4, 81.8.

13, 14. *Cribroperidinium giuseppei* (Morgenroth) Helenes. Oblique right-lateral views, sample R4384AB (4), Patala Formation. Slide coordinates 22.5, 86.0.
   13. Focus on epicyst.
   14. Focus on hypocyst.



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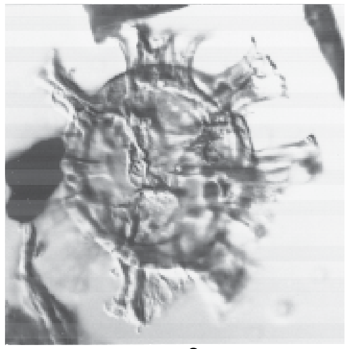

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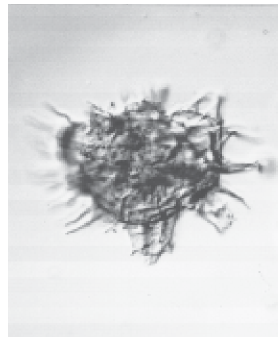

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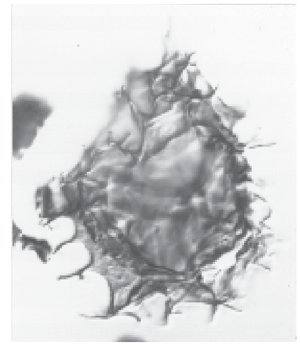

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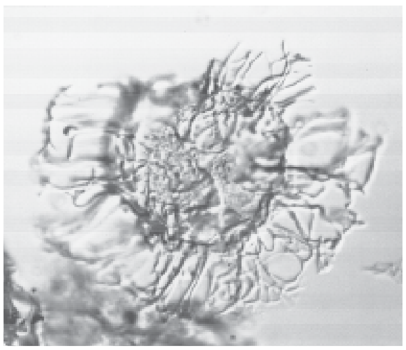

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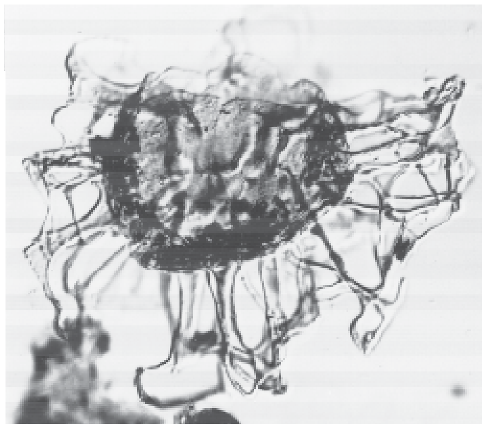

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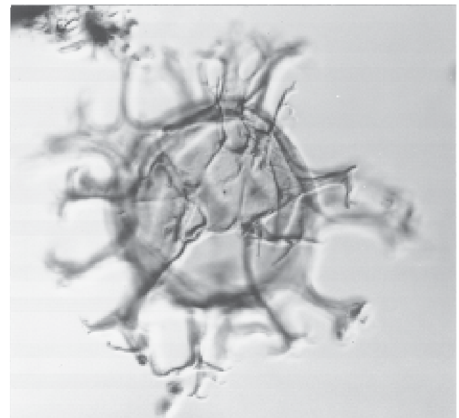

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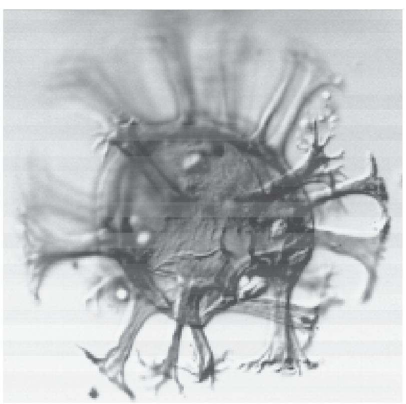

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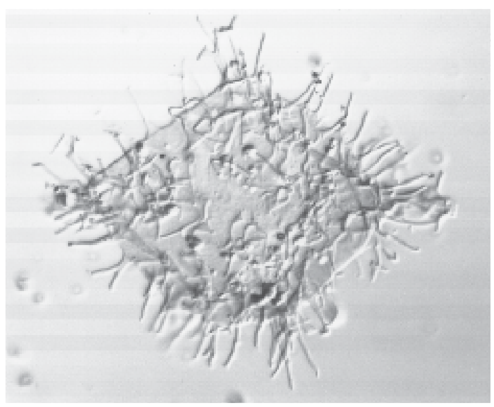

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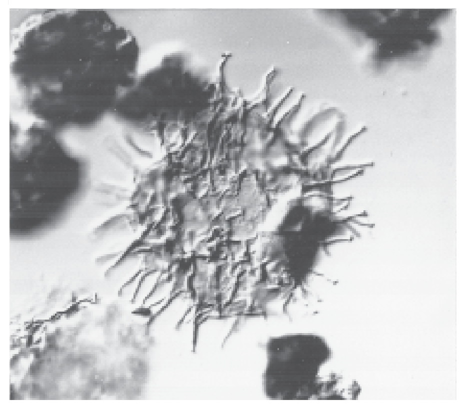

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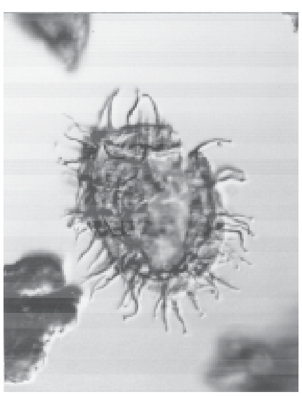

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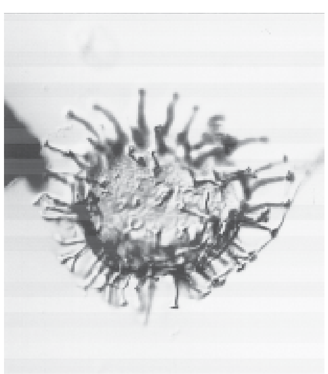

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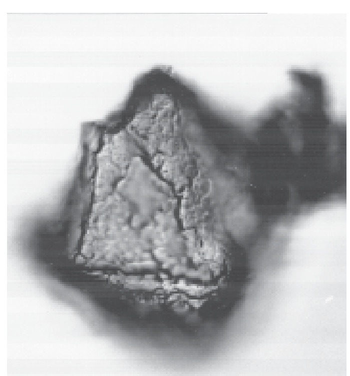

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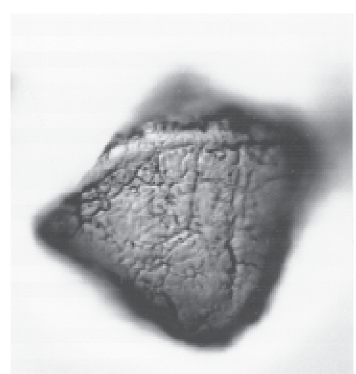


14

Dinocysts from the Hangu, Patala, and Nammal Formations

Plate C2

[All photographs × 500. Sample numbers are followed by the slide number in parentheses]

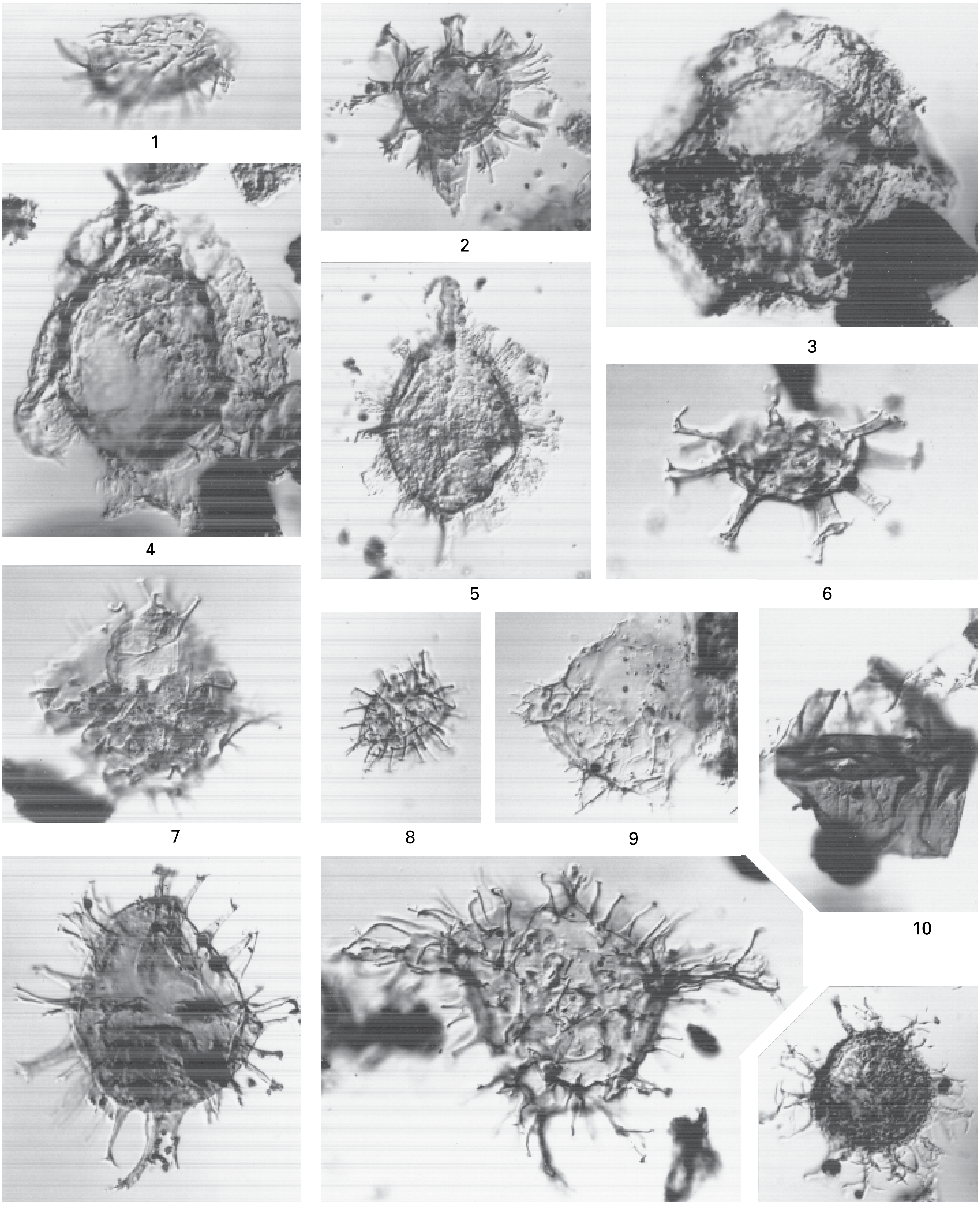
Figures 1–13. Dinocysts from the Patala and Nammal Formations.

1. *Eocladopyxis peniculata* Morgenroth. Interior view of fragment, sample R4384AB (4), Patala Formation. Slide coordinates 32.2, 73.6.
2. *Hystrichokolpoma unispinum* Williams & Downie. Orientation uncertain, sample R4384AD (3), Patala Formation. Slide coordinates 25.4, 81.1.

3, 4. *Muratodinium fimbriatum* (Cookson & Eisenack) Drugg.

   3. Dorsal view of dorsal surface, sample R4384AD (3), Patala Formation. Slide coordinates 18.2, 88.0.
   4. Ventral view (?) at midfocus, sample R4384AF (4), Nammal Formation. Slide coordinates 31.9, 89.1.

5. *Ifecysta pachyderma* Jan du Chêne & Adediran. Ventral view of ventral surface, sample R4384AE (3), Patala Formation. Slide coordinates 32.6, 103.4.
6. *Homotryblium tenuispinosum* Davey & Williams *sensu lato*. Left-lateral view (?), sample R4384AL (3), Nammal Formation. Slide coordinates 28.1, 85.9.
7. ?*Wetzeliella astra* Costa et al. Dorsal view of dorsal surface, sample R4379K (3), Nammal Formation. Slide coordinates 27.4, 106.3.
8. *Melitasphaeridium pseudorecurvatum* (Morgenroth) Bujak et al. Orientation uncertain, sample R4384AD (3), Patala Formation. Slide coordinates 36.8, 93.3.
9. ?*Wetzeliella* sp. Ventral view (?) at midfocus, sample R4384AL (3), Nammal Formation. Slide coordinates 19.7, 98.8.
10. *Lejeunecysta* sp. Ventral view at midfocus, sample R4384AE (3), Patala Formation. Slide coordinates 21.0, 85.2.
11. *Achilleodinium*? sp. I. Left-lateral view, sample R4384B (3), Patala Formation. Slide coordinates 19.1, 87.0.
12. *Apectodinium augustum* (Harland) Lentin & Williams. Dorsal view of dorsal surface, sample R4384AD (3), Patala Formation. Slide coordinates 26.4, 110.4.
13. *Hafniasphaera septata* (Cookson & Eisenack) Hansen. Right-lateral view, sample R4384AD (3), Patala Formation. Slide coordinates 34.1, 103.5.



Dinocysts from the Patala and Nammal Formations