# 6. CALCAREOUS-NANNOFOSSIL BIOSTRATIGRAPHY, NAURU BASIN, DEEP SEA DRILLING PROJECT SITE 462, AND UPPER CRETACEOUS NANNOFACIES[1]

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**ABSTRACT**

The deep-sea sediments recovered at Deep Sea Drilling Project Site 462 are of middle Cretaceous through Pleistocene age. The biostratigraphic age assignments based on calcareous nannofossils as given in the Site Summary (this volume) are documented here in detail, and an attempt to recognize the depth-provenance of Upper Cretaceous nannofossil carbonate in the nannofacies is explained and illustrated.

## BIOSTRATIGRAPHY

Holes 462 and 462A were drilled in the Nauru Basin (western central Pacific), in 5189 and 5186 meters of water. They are at the foot of the northeastern slope of the Ontong-Java Plateau, at 07°14′N and 165°02′E, slightly off the up-slope axis of a northeast-trending deep-sea channel (Fig. 1). This topographic setting is reflected in the lithologies of the sediments and in the composition of most microfossil assemblages recovered. The sediments from large parts of the section are fine-grained, distal turbidites. Particularly in the Neogene sequence, the calcareous nannofossils, as observed in smear slides under the light microscope, are packed in radiolarian-test fragments, which are dominantly in the 20- to 50-$\mu$m size range. Comparatively few, isolated coccoliths were observable in these slides; in many cases the radiolarian tests had to be crushed and the coccoliths dispersed on the slide to provide a sufficient number of isolated and identifiable nannofossil specimens. Apparent lateral transport of sediment particles also resulted in mixed fossil assemblages, in which the reworked portion of the nannoflora often exceeded the younger, indigenous portion. Some of the apparent age discrepancies among the various microfossil groups (Figs. 2–4; Site Summary, this volume) may be related to these differential-transport mechanisms. Other biostratigraphic inconsistencies, as in the sediments in Cores 5 to 8, may be related to hole collapse, favored by the sandy nature of the sediments in the uppermost part of the hole.

The abundance, preservation, and stratigraphic distribution of identified calcareous nannofossils are listed in Figures 5 to 8 (Figs. 5 and 7 are in back pocket, this volume).

The full generic and specific names of all taxa considered in this report, and references to authors, are given in Table 1. The estimated relative abundances of each taxon as shown in Figures 5 to 8 are on a logarith-

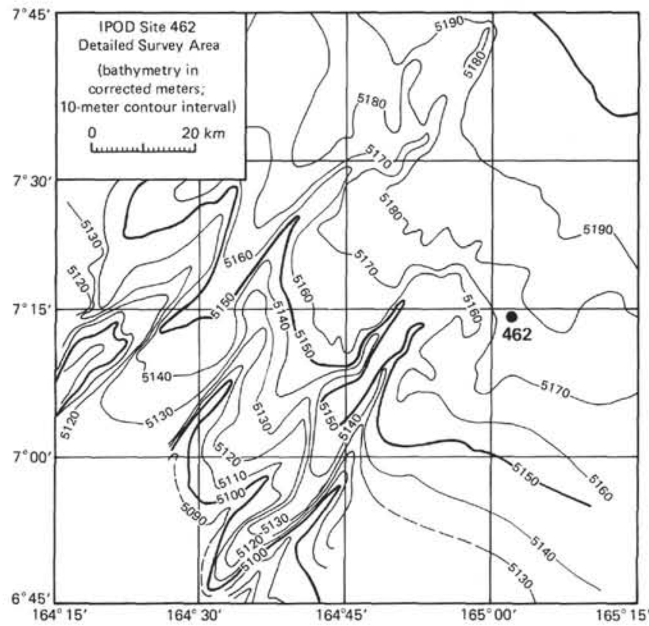


Figure 1. Geographic and bathymetric location of Site 462.

mic scale. Lower-case letters indicate that the taxon is considered reworked. Abundances and preservational data given in the left-hand column next to the sub-bottom depths, refer to the whole assemblage. Preservation is described as etching or overgrowth, both on a scale of 0 to 3, following the scheme developed by Roth and Thierstein (1972). The estimated proportion of reworked nannofossils in the examined assemblages is also listed in the left-hand column. The Cenozoic range charts for Holes 462 and 462A (Figs. 5 [back pocket] and 6) include the encountered taxa that were considered stratigraphically useful. The zonal scheme indicated is Martini's (1971) numbered standard zonation; stratigraphic criteria from Bukry (1973, 1975), however, have also been used with the correlation between the two zonal schemes as given in Bukry (1978). The Mesozoic range charts (Figs. 7 [back pocket] and 8) show all recognizable nannofossil taxa. The Campanian

[1] *Initial Reports of the Deep Sea Drilling Project*, Volume 61.

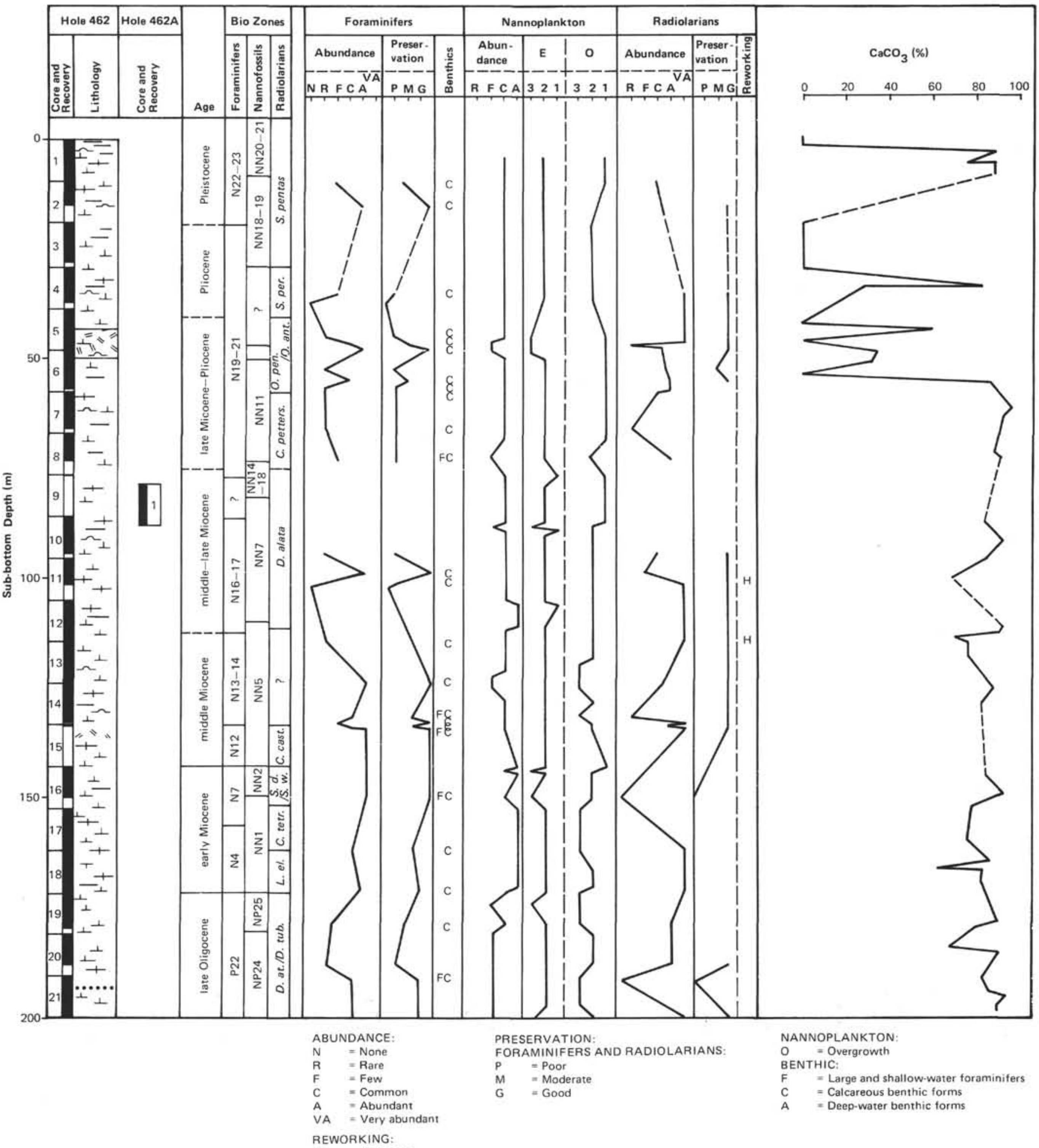


Figure 2. Neogene stratigraphy of Site 462 (see also Site Summary, this volume).

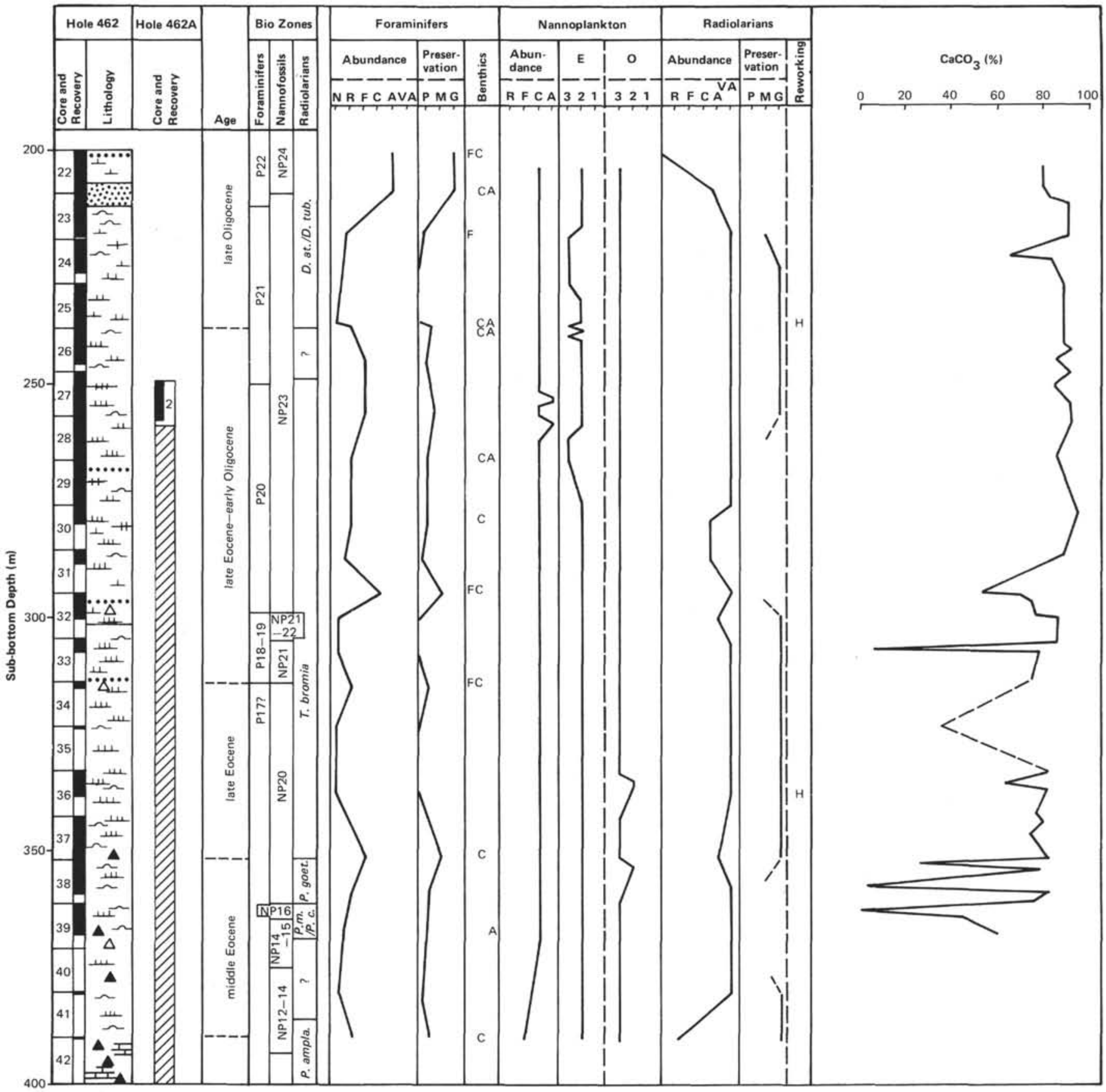

Figure 3. Paleogene stratigraphy of Site 462 (see also Site Summary, this volume). Symbols as in Figure 2.

and Maestrichtian zonation is that proposed by Verbeek (1977). Pre-Campanian assemblages cannot be assigned readily to a particular zone. Stratigraphic correlations are discussed individually below.

## Core 1 (0–9 m)

Pleistocene, based on the appearance of *G. oceanica* and the abundance and decrease of *P. lacunosa*, and on the planktonic foraminifers.

## Cores 2 through 5 (9–48 m)

Late Pliocene to Pleistocene, based on the presence of *G. caribbeanica*, *C. cristatus*, *P. lacunosa*, and *D. asymmetricus*, and the abundance of *D. brouweri*, *D. pentaradiatus*, and *D. surculus*. This age assignment is in agreement with the planktonic foraminifers. The presence of Pliocene *D. asymmetricus* in Core 4, and of *C. cristatus* in Core 5, indicates that the late Miocene radiolarians in these cores must be reworked.

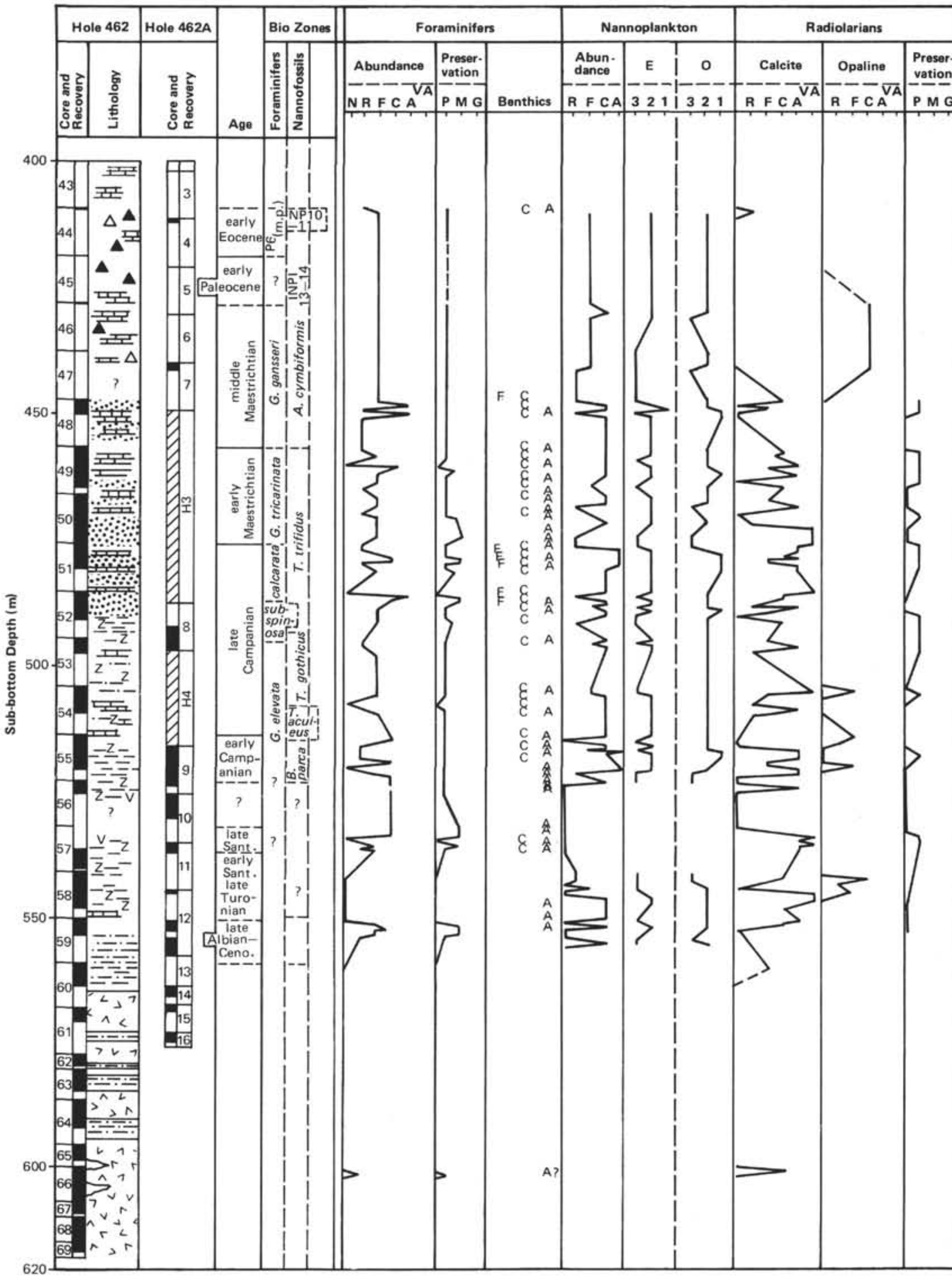


Figure 4. Mesozoic stratigraphy of Site 462 (see also Site Summary, this volume). Symbols as in Figure 2.

## Cores 6 through 8 (49–76 m)

Stratigraphic interpretation of this sequence is ambiguous. All samples examined in this interval (see Fig. 5), with the exception of 8,CC, contain late Miocene nannofossil assemblages. This age assignment is corroborated by radiolarians. The nannofossil assemblage from 8,CC contains latest Pliocene or younger species, such as *G. caribbeanica, C. cristatus*, and *P. lacunosa*, which however would be considerably younger than the early Pliocene foraminifers encountered in Cores 7 and 8 (Premoli Silva and Violanti, this volume). The possibility of down-hole contamination cannot be ruled out.

## Core 1A, Cores 10 through 15 (79–143 m)

Middle Miocene, based on the presence of *D. kugleri* in Cores 1A, 10, 11, and the top of 12, and of *S. heteromorphus* and *D. exilis* in Cores 12 through 15. This age

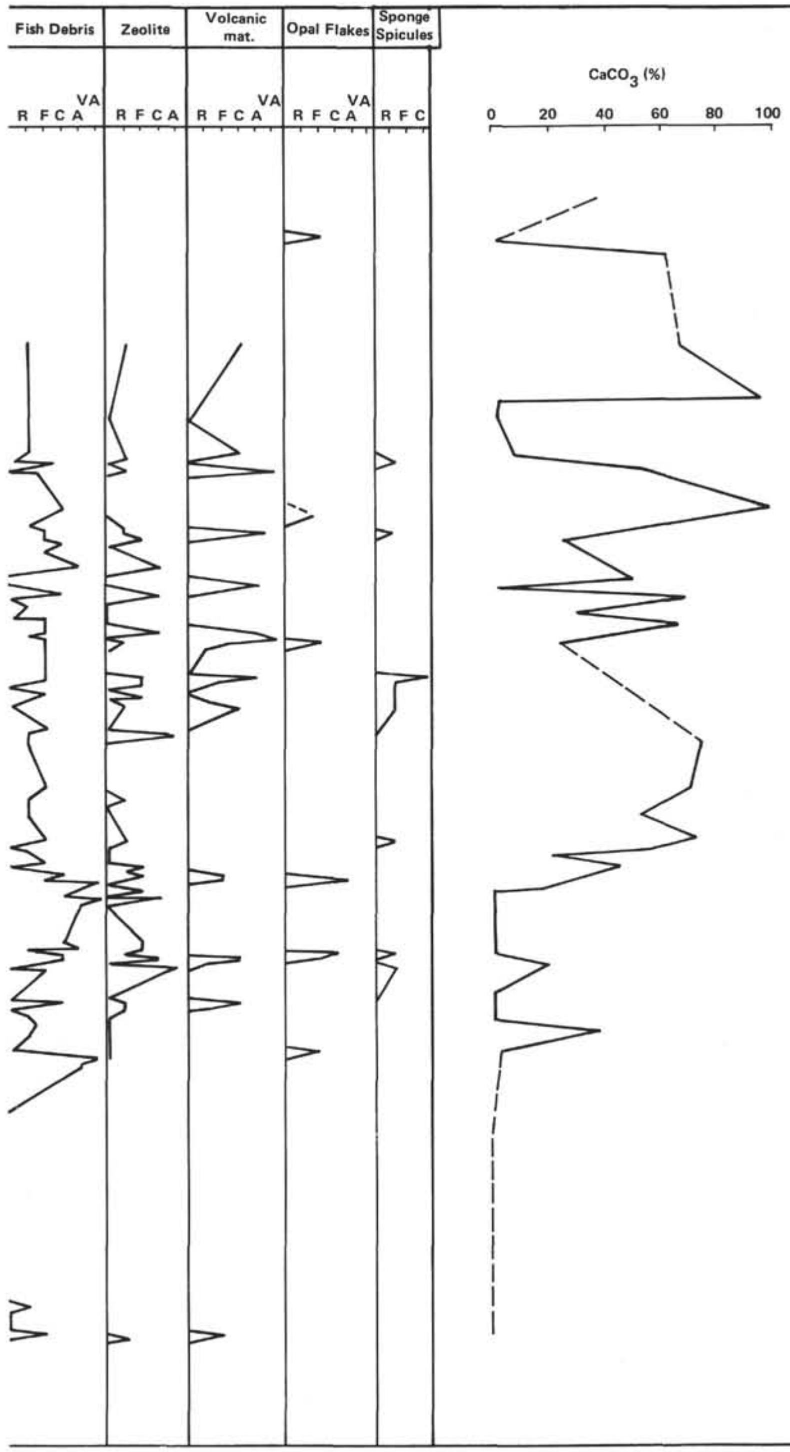


Figure 4. (Continued).

is confirmed by radiolarians. Planktonic foraminifers are interpreted as late Miocene in age. No late middle Miocene or late Miocene marker nannofossils could be identified in any of seven assemblages examined within this interval; their absence might, however, be due to moderate to poor preservation.

**Cores 16 through 18 (150–171 m)**

Early Miocene, based on the presence of *D. druggii* in Core 16, Section 1, and of *T. carinatus* in Core 16 through Core 19, Section 2. Radiolarians confirm this age. Planktonic-foraminifer assemblages are considered

| Age | Nannofossil Zone | Sample (interval in cm) | Sub-bottom Depth (m) | Abundance | Preservation | Etching | Overgrowth | Reworking | *Sphenolithus abies* | *Cycliargolithus abisectus* | *Ceratolithus acutus* | *Discoaster asymmetricus* | *Discoaster barbadiensis* | *Discoaster berggrenii* | *Zygrhablithus bijugatus* | *Dictyococcites bisectus* | *Discoaster bollii* | *Discoaster brouweri* | *Discoaster calcaris* | *Catinaster calyculus* | *Gephyrocapsa caribbeanica* | *Triquetrorhabdulus carinatus* | *Helicosphaera carteri* | *Discoaster challengeri* | *Sphenolithus ciperoensis* | *Catinaster coalitus* | *Helicosphaera compacta* | *Ceratolithus cristatus* | *Chiasmolithus danicus* | *Discoaster deflandrei* | *Discoaster diastypus* | *Sphenolithus distentus* | *Crenalithus doronicoides* | *Discoaster druggii* | *Discoaster exilis* | *Cyclicargolithus floridanus* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| late Miocene | NN7 | 1-1, 53–54 | 79.0 | C | M | 2 | 1 | r | F | | | | | | | | | | | | | | F | R | | | | | | | | | | | | |
| | NN7 | 1-6, 105–106 | 87.0 | C | M | 2 | 1 | r | R | | | | | | | | | | | | | | F | R | r | | | | | | | | | | | |
| ? | NN4–NN5 | 2-1, 90–91 | 250.4 | A | P | 2 | 3 | f | | | | | | | | | | | | | | f | | | f | | | | r | R | | F | | | | |
| early Oligocene | NP23 | 2,CC | 259.0 | A | P | 2 | 3 | r | | | | | | | | A | | | | | | | | | | | R | | | | | R | | | | |
| | NP23 | H1-7, 77–79 | | A | P | 2 | 3 | r | | | | | r | | | A | | | | | | | | | | | R | | | | | R | | | | |
| Eocene late | NP20 | H1,CC | | A | P | 2 | 3 | r | | | | | F | | | F | | | | | | | | | | | | | | | | | | | | |
| Eocene middle | NP15 | H2-1, 0–2 | | R | P | 3 | 3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Eocene early | NP10–NP12 | 5,CC | 430.0 | C | M | 2 | 2 | r | | | | | | | R | R | | | | | | | | | | | | | F | | F | | | | | |

Figure 6. Stratigraphic distribution of Cenozoic calcareous nannofossils in Hole 462A. Symbols as in Figure 5 (back pocket, this volume).

to be somewhat younger, although still early Miocene, by Premoli Silva and Violanti (this volume).

### Cores 19 through 32, Section 2, Core 2A (174–297 m)

Late Oligocene, based on the occurrence of *S. ciperoensis* in Cores 19 through 22, and *S. distentus* in Core 19 to Core 32, Section 2. The early/late Oligocene boundary is placed in Core 32, based on planktonic-foraminifer evidence. The radiolarians are of late Eocene age below Core 27, Section 2, and are considered reworked, an interpretation that is supported by abundant late Eocene nannofossils and very rare Oligocene marker species encountered in this interval.

### Cores 32 (bottom) and 33 (304–314 m)

Early Oligocene, based on the absence of *D. saipanensis* in Core 33. Planktonic foraminifers confirm this age assignment; whereas radiolarians indicate a late Eocene age and may be reworked.

### Cores 34 to 38 (314–361.5 m)

Late Eocene, based on the co-occurrence *S. moriformis, S. pseudoradians, H. reticulata*, and *D. saipanensis* in Cores 34 through 38. This age assignment correlates well with the planktonic foraminifers and radiolarian ages.

### Core 39 (361.5–371 m)

Middle Eocene, based on the co-occurrence of *S. furcatolithoides, C. grandis, D. kuepperi, C. solitus*, and *R. umbilica*.

### Cores 40 through 44, and Core 5A (390–410 m)

Early Eocene, based on the occurrence of *D. barbadiensis, D. diastypus, C. formosus*, and *D. multiradiatus* in some or all samples from Cores 40 through 44. This age is in agreement with that inferred from planktonic foraminifers. The lowermost Cenozoic radiolarian assemblage encountered at this site is from Core 41 and is considered of middle Eocene age.

### Core 45 (428 m)

Early Paleocene, based on the presence of *C. danicus, Z. sigmoides*, and *C. tenuis*.

### Core 46 through Core 48, Section 2, Core 7A (437–449 m)

Middle Maestrichtian, based on the absence of *T. gothicus, T. trifidus*, and *L. quadratus*. This age assignment is confirmed by the planktonic foraminifers.

### Cores 48 (bottom) through Core 52, Core 8A (top) 456–494 m)

Late Campanian to early Maestrichtian, based on the presence of *T. trifidus*. This age is confirmed by the planktonic foraminifers.

### Cores 53 through 54, Core 8A (below Section 1) (489–512 m)

Late Campanian, based on presence of *C. aculeus* and *T. gothicus*. This age assignment agrees with the evidence from planktonic foraminifers.

### Core 55 and Core 9A (514–522.5 m)

Early Campanian, based on the presence of *B. parca*. Planktonic foraminifers confirm this age assignment.

### Core 56 through Core 58, Core 11A, Core 12A (upper part) (522.5–549 m)

Turonian to Santonian, based on the presence of *M. decoratus, M. staurophora*, and *L. floralis* in this interval, as well as on the age of the nannofossil assemblages above and below. There is no contrary evidence from the few poorly preserved planktonic-foraminifer assemblages encountered in Core 57.

### Core 59, Section 1, Core 12A (lower part), and Core 13A (top) (549–553 m)

Late Albian to Cenomanian, based on the co-occurrence of *C. chiastia, C. signum, E. turriseiffelii*, and

| Coccolithus formosus | Sphenolithus furcatolithoides | Chiasmolithus grandis | Chiasmolithus gigas | Discoaster hamatus | Sphenolithus heteromorphus | Triquetrorhabdulus inversus | Fasciculithus involutus | Heliolithus kleinpellii | Discoasteroides kuepperi | Discoaster kugleri | Pseudoemiliania lacunosa | Calcidiscus leptoporus | Discoaster lodoensis | Sphenolithus moriformis | Discoaster multiradiatus | Sphenolithus neoabies | Discoaster neohamatus | Chiasmolithus oamaruensis | Gephyrocapsa oceanica | Coccolithus pelagicus | Discoaster pentaradiatus | Sphenolithus predistentus | Sphenolithus pseudoradians | Reticulofenestra pseudoumbilica | Discoaster quinqueramus | Sphenolithus radians | Helicosphaera recta | Isthmolithus recurvus | Helicosphaera reticulata | Ceratolithus rugosus | Triquetrorhabdulus rugosus | Discoaster saipanensis | Reticulofenestra samodurovi | Helicosphaera sellii | Bramletteius serraculoides | Orthorhabdus serratus | Zygodiscus sigmoides | Chiasmolithus solitus | Coccolithus subdistichus | Discoaster sublodoensis | Discoaster surculus | Discoaster tamalis | Discoaster tanii | Cruciplacolithus tenuis | Discoaster trinidadensis | Reticulofenestra umbilica | Discoaster variabilis | Thoracosphaera sp. | Toweius sp. |
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| | | | | | r | | | | | F | | C | | R | | F | | | | | | | | C | | | | | | | C | | | | | | | | | | | | | | | | F | | |
| | | | | | | | | | | F | | F | | R | | F | | | | | | | | C | | | | | | | F | | | | | | | | | | | | | | | | F | | |
| C | | | | | R | | | | | | | | | C | | | | | | F | | c | | | | | | | | | | | | | | | | r | | | | | | | | r | | | |
| C | | | | | | | | | | | | | | F | | | | | | F | | C | | | | | | | R | | | | | | C | | | | | | | | | | | C | | | |
| C | | | | | | | | | | | | | | F | | | | | | F | | C | R | | | | | | R | | | r | | | C | | | | | | | | | | | C | | | |
| C | | R | | | | R | | | | | | | | | | | | | | R | | | R | | | | | | R | | | F | C | | C | | | | | | | | | | | F | | | |
| R | | | R | | | | | | | | | | | | | | | | | | | | | | | R | | | | | | | R | | R | | | | | | | | | | | | | | |
| F | | | | | | | C | | | | | | | | | | | | | R | | | | | | R | | | | | | | F | | | | | | | | | | | | | | | | C |

Figure 6. (Continued).

*Cylindralithus spp.*, and questionable *L. alatus*. Only five samples of a total of 21 samples examined contained any calcareous nannofossils.

### Core 40A, Section 1 (702 m)

A single sample with a poorly preserved early Cretaceous nannofossil assemblage was recovered from the sediments within the basalts. The presence of *L. floralis* and *C. chiastia* limits its age range to late Aptian through Cenomanian; the absence of *P. cretacea* and other Albian marker species also indicates a likely age of late Aptian to earliest Albian for the nannofossils in Core 40A.

An additional 16 smear slides examined from sediments in Cores 40A through 44A, as indicated on the core-description sheets in chapter 2, the site summary, were barren of calcareous nannofossils.

## TAXONOMIC NOTES

A light-microscope examination of nannofossil assemblages from the lower Austin Chalk along Farm Road 1382, South Dallas County, Texas, the type locality of *Watznaueria oblonga* Bukry (1969), has revealed the presence of specimens of *Flabellites biforaminis* Thierstein (1973) without an asymmetric flange. Since symmetric specimens were included in the original definition of *F. biforaminis*, this species is considered a junior synonym of *Watznaueria oblonga* Bukry (1969), as proposed by Bukry (1975). Original description and illustrations of *W. oblonga* by Bukry (1969) were limited to the distal side of the coccolith. Thierstein's (1973) holotype and paratypes of *F. biforaminis* are herein designated as hypotypes of *W. oblonga*, and the definition of *W. oblonga* is amended to include the characteristics, size range, and stratigraphic distribution of *F. biforaminis* as given in Thierstein (1973).

## NANNOFACIES OF LATE CRETACEOUS SEDIMENTS

The purpose of this preliminary study was to elucidate the character and provenance of the Upper Cretaceous carbonate sequence at Site 462. A descent of the CCD in the central Pacific in the Campanian–Maestrichtian interval had originally been postulated by Winterer (1973), and has been documented recently by Thierstein (1979). Only a limited number of DSDP sites have been drilled previously in the Pacific on deep and old oceanic crust, and most of these sites were cored intermittently. The data coverage in an age–paleodepth framework was therefore rather spotty (Fig. 9), and the carbonate-deposition patterns could be delineated only in a tentative way (Fig. 10). Continuous coring at DSDP Site 462 in a basinal setting therefore had the potential of significantly improving the scant data base available.

With the recovery of volcaniclastic sediments with late Cretaceous shallow-water large benthic foraminifers in Cores 48, 51, and 52 of Hole 462, the question arose whether not all the carbonate deposited in Upper Cretaceous sediments had been transported from shallower elevations. There is no positive evidence to rule out such transport. The absence of positive evidence for transport, and the similarity of the preserved carbonate record at this site with the regional patterns known from other DSDP sites, may serve as guides to paleoceanographic interpretations.

The carbonate record of Site 462 corresponds well to the regionally observed patterns in the deep central Pacific, as shown in Figure 10. The paleodepth for Site 462 was determined by assuming a basement age of 160 m.y., and by back-tracking along a standard oceanic-crust-subsidence curve. The intrusion of the basaltic sill complex, of at least 550-meters thickness, is assumed to have occurred prior to the Campanian. It may have reset the exponentially decreasing subsidence curve during its intrusion, which would have resulted in a Campanian paleodepth a few hundred meters shallower than shown on Figure 10, at best, assuming significant reheating of the underlying lithosphere (see Larson and Schlanger, this volume). The similarity of the carbonate preservation at Site 462 to that at other sites of different tectonic and topographic setting suggests that the CCD variation observed in the central Pacific is of regional oceanic rather than local tectonic and topographic significance.

Additional support for such an interpretation may be derived from the rather intermittent occurrence of posi-

| Age | | Nannofossil Zone | Sample (interval in cm) | Sub-bottom Depth (m) | Abundance | Preservation | Etching | Overgrowth | Reworking | *Tetralithus aculeus* | *Lithraphidites alatus* | *Parhabdolithus angustus* | *Reinhardtites anthophorus* | *Parhabdolithus asper* | *Watznaueria barnesae* | *Lithraphidites carniolensis* | *Lucianorhabdus cayeuxii* | *Cruciellipsis chiastia* | *Markalius circumradiatus* | *Vagalapilla compacta* | *Cretarhabdus conicus* | *Biscutum constans* | *Cretarhabdus crenulatus* | *Prediscosphaera cretacea* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Maestrichtian | | *A. cymbiformis* | 7-1, 96–100 | 440.5 | C | P | 3 | 2 | r | | | | | | A | F | | | | | | | | |
| Campanian | late | *T. trifidus* | 3H-3, 75–79 | | F | P | 3 | 2 | | | | | | | A | R | | | | | | | | F |
| | | | 3H,CC | | C | P | 3 | 2 | | R | | | | R | A | | | | | | | | | R |
| | | | 8-1, 57–60 | 487.6 | C | P | 3 | 2 | | F | | | | | A | | | | | | | | | R |
| | | *T. gothicus* | 8-2, 128–134 | 489.8 | C | P | 3 | 2 | | C | | | | | A | F | | | | | | | | R |
| | | | 8,CC | 496.5 | R | P | 3 | 2 | | R | | | | | R | R | | | | | | | | |
| | | | 4H-3, 112–115 | | F | P | 3 | 2 | | | | | | | R | | | | | | | | | |
| | | *T. aculeus* | 4H,CC | | R | P | 3 | 2 | | R | | | | | R | | | | | | | | | |
| | early | *B. parca* | 9-1, 35–41 | 515.9 | F | P | 3 | 2 | | | | | | | A | F | | | | | | | | F |
| | | | 9-2, 70–76 | 517.2 | C | M | 2 | 1 | | | | | | | A | R | | | | | | | | F |
| | | | 9-4, 6–10 | 520.6 | C | P | 3 | 3 | | | | | | | A | R | | | | | | | | F |
| | | | 9-5, 80–84 | 522.3 | C | P | 2 | 3 | | | | | | | A | C | | | | | | | | R |
| | | | 10-1, 47–52 | 525.5 | B | | | | | (7 barren samples) | | | | | | | | | | | | | | |
| | | | 11-2, 6–9 | 536.1 | B | | | | | | | | | | | | | | | | | | | |
| | | | 11,CC | 544.0 | R | P | 3 | 3 | | | | | | | R | | | | | | | | | R |
| | | | 12-1, 5–6 | 544.1 | B | | | | | | | | | | | | | | | | | | | |
| | | | 12-1, 62–67 | 544.6 | B | | | | | | | | | | | | | | | | | | | |
| | | | 12-2, 2 | 545.5 | R | P | 3 | 3 | | | | | | | R | | | | | | | | | |
| Cenomanian? | | | 12-2, 4–6 | 545.6 | F | P | 3 | 2 | | ? | | | | | A | | | | R | | | | | R |
| | | | 12,CC | 553.4 | R | P | 3 | 3 | | | | | | | R | | | | | | | | | |
| | | | 13-1, 1–5 | 553.5 | C | P | 3 | 2 | | ? | | | | | A | | | F | | | | | | |
| | | | 13-1, 7 | 553.6 | F | P | 3 | 2 | | | | | | | A | F | | R | | | | | | R |
| | | | 13-1, 47 | 554.0 | B | | | | | (21 barren samples) | | | | | | | | | | | | | | |
| | | | 32,CC | 658.0 | B | | | | | | | | | | | | | | | | | | | |
| l. Aptian to e. Albian? | | | 40-1, 92 | 702.0 | R | P | 3 | 3 | | | | | | R | A | | | R | | | | | | |

Figure 8. Stratigraphic distribution of Mesozoic calcareous nannofossils in Hole 462A. Symbols as in Figure 5 (back pocket, this volume).

tive evidence for transport found in the lithology and the benthic deep-water foraminifers (Sliter, this volume). We have studied the nannofacies of the lowermost part of the Upper Cretaceous carbonate sequence which was recovered below the obviously transported volcaniclastic upper Campanian to lower Maestrichtian interval. The analyzed sequence consists of partially burrowed, interlayered claystones, marlstones, and limestones in Cores 54 and 55, from a sub-bottom depth of 509 to 522.5 meters. Within that interval, we have examined the nannofacies of 20 samples. Eleven of these samples, covering the characteristic lithologies, are discussed in detail below (see Table 2). Listed in Table 2 are the abundance of calcareous nannofossils, the inferred provenance (autochthonous or allochthonous) of benthic foraminifers (after Sliter, this volume), the per cent bulk calcium carbonate, and respective illustrations of the nannofacies.

We attempted to recognize differences in the nannofacies between intervals with apparently transported foraminifer assemblages and intervals with no evidence for transport in either the coarse fraction or the lithology. Features for transport might include changes in preservation of nannofossils, their average sizes, lami-

| Arkhangelskiella cymbiformis | Microrhabdulus decoratus | Zygodiscus diplogrammus | Cribrosphaerella ehrenbergii | Parhabdolithus embergerii | Lithastrinus floralis | Tetralithus gothicus | Lithraphidites helicoideus | Assipetra infracretacea | Rucinolithus irregularis | Stephanolithion laffittei | Chiastozygus litterarius | Rucinolithus magnus | Cyclagelosphaera margerelii | Watznaueria oblonga | Vagalapilla octoradiata | Tranolithus orionatus | Broinsonia parca | Manivitella pemmatoidea | Parhabdolithus regularis | Discorhabdus rotatorius | Corollithion signum | Prediscosphaera spinosa | Zygodiscus spiralis | Parhabdolithus splendens | Micula staurophora | Tegumentum stradneri | Vagalapilla stradneri | Cretarhabdus surirellus | Tetralithus trifidus | Eiffellithus turriseiffelii | Braarudosphaera sp. 1 | Cylindralithus sp. | Provenance of Benthic Foraminifers (from Sliter, this volume) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | Indigenous Only | Some Transported | Most Transported |
| | R | | | | | | | | | | | | R | R | | | | | | | | | | | F | | | C | r | | | F | | | + |
| | | C | C | | | R | | | | | | | | | | | | | | | | | R | | C | | | C | F | | | C | | | + |
| R | R | | R | R | | R | | | | | | | | | | | | | | | | | | | C | | | C | R | R | | F | | | + |
| | R | | R | | | C | | | | | | | | | | | | | | | | | | | C | | | F | C | R | | F | | | + |
| | | | R | | | C | | | | | R | | | | | | | | | | | | | | C | | | C | | | | F | | | |
| | | | | | | P | | | | | | | | | | | R | | | | | | | | R | | | | | | | | | + | |
| | | | | | | R | | | | | | | | | | | | | | | | | | | R | | | R | | | | | | | + |
| | | | | | | | | | | | | | | | | | | | | | | | | | R | | | | | | | | | | + |
| R | | F | F | | | | | | | | R | | | | | | R | F | | | | | | | C | | | C | | R | | F | + | | |
| R | | F | F | F | | | | | | | R | F | | | | F | F | F | | | | | F | | F | | | C | | F | R | F | | | + |
| | | | R | R | | | | | | | | | | | | | R | R | | | | | | | C | | | C | | | F | F | | + | |
| | | R | R | | | | | | | | R | | | | | R | R | F | | | | | | | C | | | C | | | | C | | | + |
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| | | R | | | R | | | | | | | | | | | R | | | | | | | | | | | | C | | F | | | + | | |
| | | | | | R | | | | | | | | | | | | | | | | | | | | | | | R | | | | | + | | |
| | | F | | R | C | | | | | | | | | | | | | C | | | | | | | | | | C | | R | | | + | | |
| | | F | | | C | | | | | | | | | | | | | C | | | | | | | | | | C | | | | F | | | |
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| | | | | R | R | | | | R | | | | | | | | | R | | | | | | | | | | R | | | | | | | |
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Figure 8. (Continued).

nations and preferred orientations, changes in the frequency of individual taxa and of coccospheres, degree of lithification, and possibly others.

The nannofacies was studied by Manivit with a scanning electron microscope (SEM), on broken surfaces of bulk samples. Methodology and terminology have previously been described by Noël (1968) and Noël and Melguen (1978). Differentation of clay and carbonate particles was done with the aid of an ORTEC energy-dispersive X-ray system. The following discussion of the individual studied samples proceeds from bottom to top and refers to the illustrations in Plates 1 to 6.

**Sample 462-55,CC (Plate 1, Figs. 4–6)**

The dark-gray, silty claystone has a carbonate content of 16% and is at the base of the latest Cretaceous carbonate interval. None of the eight samples from the underlying 12 meters of zeolitic claystones contained any carbonate microfossils or measurable carbonate contents. Only two poorly preserved planktonic foraminifers (*Heterohelix* sp. and *Hedbergella* sp.) were recovered from this sample in the 63- to 50-$\mu$m fraction. Rare and poorly preserved agglutinated benthic foraminifers are considered indigenous (Sliter, this volume).

Table 1. Calcareous-nannofossil taxa considered in this report.

**Cenozoic**

*Sphenolithus abies* Deflandre, 1954.
*Cyclicargolithus abisectus* (Müller, 1970) Bukry, 1973
*Ceratolithus acutus* Gartner and Bukry, 1974
*Discoaster asymmetricus* Gartner, 1969
*Discoaster barbadiensis* Tan 1927
*Discoaster berggrenii* Bukry, 1971
*Zygrhablithus bijugatus* (Deflandre, 1954) Deflandre, 1959
*Dictyococcites bisectus* (Hay, Mohler and Wade, 1966) Bukry and Percival, 1971
*Discoaster bollii* Martini and Bramlette, 1963
*Discoaster brouweri* Tan 1927
*Discoaster calcaris* Gartner, 1967
*Catinaster calyculus* Martini and Bramlette, 1963
*Gephyrocapsa caribbeanica* Boudreaux and Hay, 1967
*Triquetrorhabdulus carinatus* Martini, 1965
*Helicosphaera carteri* (Wallich, 1877) Kamptner, 1954
*Discoaster challengeri* Bramlette and Riedel, 1954
*Sphenolithus ciperoensis* Bramlette and Wilcoxon, 1967
*Catinaster coalitus* Martini and Bramlette, 1963
*Helicosphaera compacta* Bramlette and Wilcoxon, 1967
*Ceratolithus cristatus* Kamptner, 1950
*Chiasmolithus danicus* (Brotzen, 1959) Hay and Mohler, 1967
*Discoaster deflandrei* Bramlette and Riedel, 1954
*Discoaster diastypus* Bramlette and Sullivan, 1961
*Sphenolithus distentus* (Martini, 1965) Bramlette and Wilcoxon, 1967
*Crenalithus doronicoides* (Black and Barnes, 1961) Roth, 1973
*Discoaster druggi* Bramlette and Wilcoxon, 1967
*Discoaster exilis* Martini and Bramlette, 1963
*Cyclicargolithus floridanus* (Roth and Hay, 1967) Bukry, 1971
*Coccolithus formosus* (Kamptner, 1963) Wise, 1973
*Sphenolithus furcatolithoides* Locker, 1967
*Chiasmolithus grandis* (Bramlette and Sullivan, 1954) Radomski, 1968
*Chiasmolithus gigas* (Bramlette and Sullivan, 1954) Radomski, 1968
*Discoaster hamatus* Martini and Bramlette, 1963
*Sphenolithus heteromorphus* Deflandre, 1953
*Triquetrorhabdulus inversus* Bukry and Bramlette, 1969
*Fasciculithus involutus* Bramlette and Sullivan, 1961
*Heliolithus kleinpellii* Sullivan, 1964
*Discoasteroides kuepperi* (Stradner, 1959) Bramlette and Sullivan, 1961
*Discoaster kugleri* Martini and Bramlette, 1963
*Pseudoemiliania lacunosa* (Kamptner, 1963) Gartner, 1969
*Calcidiscus leptoporus* (Murray and Blackman, 1898) Loeblich and Tappan, 1978
*Discoaster lodoensis* Bramlette and Riedel, 1954
*Sphenolithus moriformis* (Bronnimann and Stradner, 1960) Bramlette and Wilcoxon, 1967
*Discoaster multiradiatus* Bramlette and Riedel, 1954
*Sphenolithus neoabies* Bukry and Bramlette, 1969
*Discoaster neohamatus* Bukry and Bramlette, 1969
*Chiasmolithus oamaruensis* (Deflandre, 1954) Hay, Mohler and Wade, 1966
*Gephyrocapsa oceanica* Kamptner, 1943
*Coccolithus pelagicus* (Wallich, 1877) Schiller, 1930
*Discoaster pentaradiatus* Tan 1927
*Sphenolithus predistentus* Bramlette and Wilcoxon, 1967
*Sphenolithus pseudoradians* Bramlette and Wilcoxon, 1967
*Reticulofenestra pseudoumbilica* (Gartner, 1967) Gartner, 1969
*Discoaster quinqueramus* Gartner, 1969
*Sphenolithus radians* Deflandre, 1952
*Helicosphaera recta* (Haq, 1966) Jafar and Martini, 1975
*Isthmolithus recurvus* Deflandre, 1954
*Helicosphaera reticulata* Bramlette and Wilcoxon, 1967
*Ceratolithus rugosus* Bukry and Bramlette, 1968
*Triquetrorhabdulus rugosus* Bramlette and Wilcoxon, 1967
*Discoaster saipanensis* Bramlette and Riedel, 1954
*Reticulofenestra samodurovii* (Hay, Mohler and Wade, 1966) Roth, 1970
*Helicosphaera sellii* (Bukry and Bramlette, 1969) Jafar and Martini, 1975
*Bramletteius serraculoides* Gartner, 1969
*Orthorhabdus serratus* Bramlette and Wilcoxon, 1967
*Zygodiscus sigmoides* Bramlette and Sullivan, 1961
*Chiasmolithus solitus* (Bramlette and Sullivan, 1961) Locker, 1968
*Coccolithus subdistichus* (Roth and Hay, 1967) Bukry, 1971
*Discoaster sublodoensis* Bramlette and Sullivan, 1961
*Discoaster surculus* Martini and Bramlette, 1963
*Discoaster tamalis* Kamptner, 1967
*Discoaster tanii* Bramlette and Riedel, 1954
*Cruciplacolithus tenuis* Hay and Mohler, 1967
*Discoaster trinidadensis* Hay, 1967
*Reticulofenestra umbilica* (Levin, 1966) Martini and Ritzkowski, 1968
*Discoaster variabilis* Martini and Bramlette, 1963
*Thoracosphaera* sp.
*Toweius* sp.

**Mesozoic**

*Tetralithus aculeus* (Stradner, 1961) Gartner, 1968
*Lithraphidites alatus* Thierstein, 1972
*Parhabdolithus angustus* (Stradner, 1963) Stradner, Adamiker and Maresch, 1968
*Reinhardtites anthophorus* (Deflandre, 1959) Perch-Nielsen, 1968
*Parhabdolithus asper* (Stradner, 1963) Manivit, 1971
*Watznaueria barnesae* (Black, 1959) Perch-Nielsen, 1968
*Lithraphidites carniolensis* Deflandre, 1963
*Lucianorhabdus cayeuxii* Deflandre, 1959
*Cruciellipsis chiastia* (Worsley, 1971) Thierstein, 1972
*Markalius circumradiatus* (Stover, 1966)
*Vagalapilla compacta* Bukry, 1969
*Cretarhabdus conicus* Bramlette and Martini, 1964
*Biscutum constans* (Gorka, 1957) Black, 1967
*Cretarhabdus crenulatus* Bramlette and Martini, 1964
*Prediscosphaera cretacea* (Arkhangelsky, 1912) Gartner, 1968

Table 1. (Continued).

**Mesozoic (Cont.)**

*Arkhangelskiella cymbiformis* Vekshina, 1959
*Microrhabdulus decoratus* Deflandre, 1959
*Zygodiscus diplogrammus* (Deflandre, 1954) Gartner, 1968
*Cribrosphaerella ehrenbergii* (Arkhangelsky, 1912) Deflandre, 1952
*Parhabdolithus embergeri* (Noël, 1958) Stradner, 1963
*Lithastrinus floralis* Stradner, 1962
*Tetralithus gothicus* Deflandre, 1959
*Lithraphidites helicoideus* (Deflandre, 1959) Deflandre, 1963
*Assipetra infracretacea* (Thierstein, 1973) Roth, 1973
*Rucinolithus irregularis* Thierstein, 1972
*Stephanolithion laffittei* Noël, 1957
*Chiastozygus litterarius* (Gorka, 1957) Manivit, 1971
*Rucinolithus magnus* Bukry, 1975
*Cyclagelosphaera margerelii* Noël, 1965
*Watznaueria oblonga* Bukry, 1969
*Vagalapilla octoradiata* (Gorka, 1957) Bukry, 1969
*Tranolithus orionatus* (Reinhardt, 1966a) Reinhardt, 1966b
*Broinsonia parca* (Stradner, 1963) Bukry, 1969
*Manivitella pemmatoidea* (Deflandre ex Manivit, 1965) Thierstein, 1971
*Parhabdolithus regularis* (Gorka, 1957) Bukry, 1969
*Discorhabdus rotatorius* (Bukry, 1969) Thierstein, 1973
*Corollithion signum* Stradner, 1963
*Prediscosphaera spinosa* (Bramlette and Martini, 1964) Gartner, 1968
*Zygodiscus spiralis* Bramlette and Martini, 1964
*Parhabdolithus splendens* (Deflandre, 1953) Noël, 1969
*Micula staurophora* (Gardet, 1955) Stradner, 1963
*Tegumentum stradneri* Thierstein, 1972
*Vagalapilla stradneri* (Rood, Hay and Barnard, 1972) Thierstein, 1973
*Cretarhabdus surirellus* (Deflandre, 1954) Reinhardt, 1970
*Tetralithus trifidus* (Stradner, 1961) Bukry, 1973
*Eiffellithus turriseiffelii* (Deflandre, 1954) Reinhardt, 1965
*Braarudosphaera* sp.
*Cylindralithus* sp.

The very fine, clayey sediment is irregularly compacted, with holes in places, and is poorly structured. Clay particles are concentrated in large amorphous zones or in lamellae of variable thickness and of irregular shape. Nannofossils are visible only occasionally on the surfaces and are often deeply buried in the clay matrix, making their determination difficult. A red zeolitic claystone clast from the core catcher contained a few transported benthic foraminifers, but no calcareous nannofossils and no carbonate.

### Sample 462-55-4, 55–59 cm (Plate 2, Figs. 4–6)

Pale brown, zeolitic marlstone contains 44% carbonate; rare deep-water benthic foraminifers, considered indigenous (Sliter, this volume); rare radiolarians; fish debris; and volcanic rock fragments.

Moderately etched and overgrown calcareous nannofossils dominate the nannofacies, despite the comparatively low carbonate content. Nannofossils are surrounded by a matrix of undulating clay laminae.

### Sample 462-55-2, 117–122 cm (Plate 1, Figs. 1–3)

Brownish-gray claystone with 21% carbonate, and common, poorly preserved, mainly small planktonic and benthic foraminifers. Most benthic foraminifers are considered allochthonous, originating in shallower areas (Sliter, this volume).

Moderately well-preserved nannofossils are embedded in finely flaked, apparently diagenetically formed clay particles. Numerous fragments of coccoliths are dispersed in the fine clay matrix. No coccospheres were detected.

### Sample 462-55-2, 71–73 cm (Plate 2, Figs. 1–3)

Tan, zeolitic marlstone contains 26% carbonate, common recrystallized radiolarians, little fish debris,

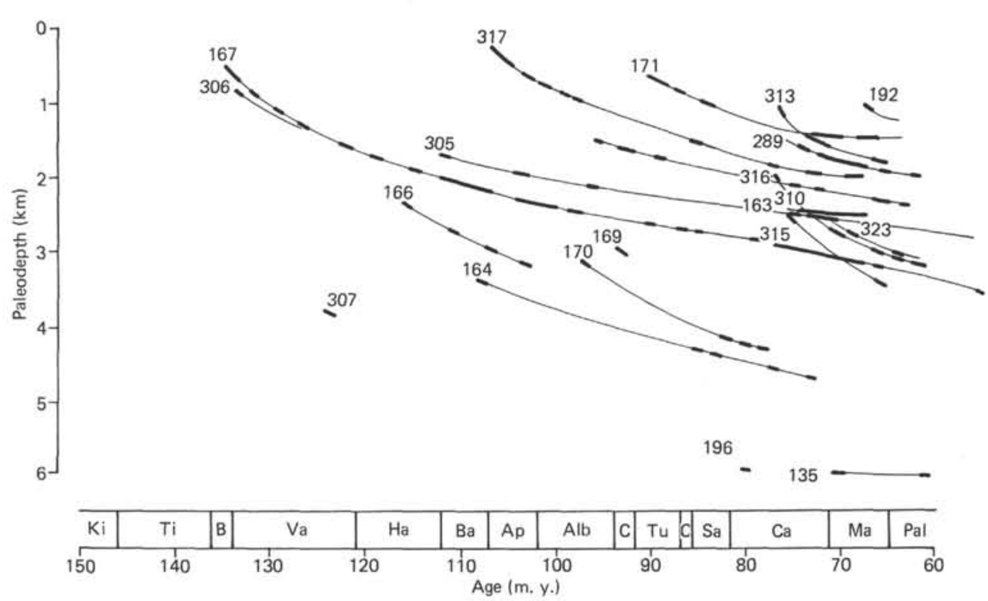


Figure 9. Back-tracked paleodepth of Pacific DSDP sites previously drilled on old oceanic crust (thin lines), and recovery of sediments (heavy lines). Modified from Thierstein (1979).

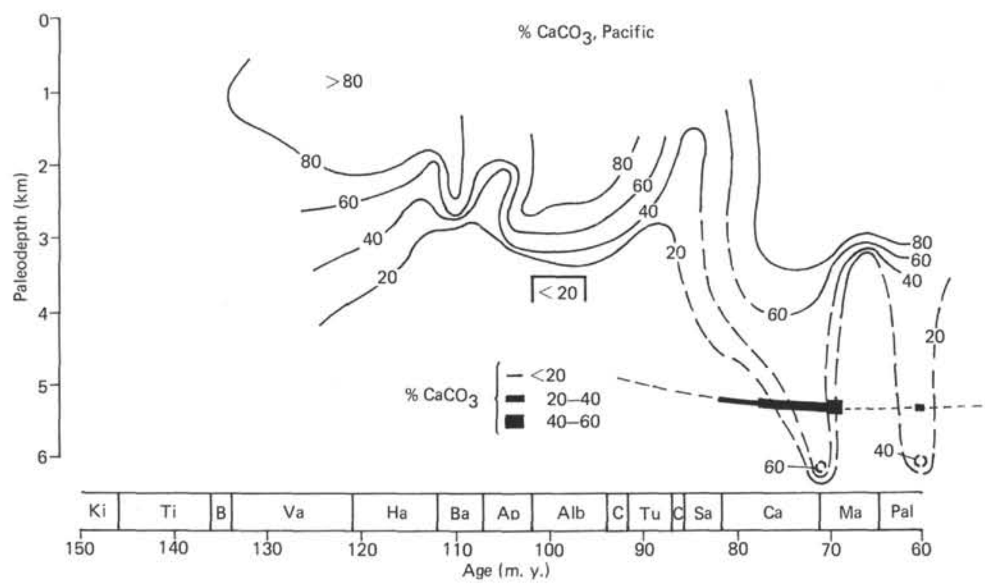


Figure 10. Mesozoic paleodepth and carbonate record of Site 462, and carbonate depositional patterns in the Pacific.

and few indigenous abyssal benthic foraminifers (Sliter, this volume).

Strongly etched and moderately overgrown nannofossils are dispersed in a compact clay matrix. Diagenetic dissolution of coccolith carbonate or diagenetic precipitation of clay minerals is evidenced by the occasional presence of coccolith imprints (e.g., Plate 2, Figs. 2, 3). No coccospheres were detected.

**Sample 462-55-2, 64–66 cm (Plate 4, Figs. 1–6)**

Dark brown, zeolitic clay contains 2% carbonate, rare silicified radiolarian casts, and few squashed benthic foraminifers.

Rare calcareous nannofossils observed in smear slides in occasional lithified clay clasts of over 50 $\mu$m were not found by SEM. The matrix consists of non-structured clay particles and pockets of cristobalite spherules.

**Sample 462-55-2, 61–64 cm (Plate 3, Figs. 1–3)**

Tan marlstone, with 55% carbonate, contains few planktonic foraminifers and few transported as well as rare indigenous deep-water benthic foraminifers, rare fish debris, and common, recrystallized radiolarians.

Common, moderately well-preserved calcareous nannofossils are dispersed in coccolith debris and clay matrix. Occasional coccospheres are present.

Table 2. Samples with nannofacies analysis, Site 462.

| Sample (interval in cm) | Sub-bottom Depth (m) | Age | Color of Sediment | Lithology | Abundance of Nannofossils | Provenance of Benthic Foraminifers (after Sliter, this volume) | $CaCO_3$ (%) | Illustration |
|---|---|---|---|---|---|---|---|---|
| 54-1, 39–45 | 509.39 | Late Campanian | White | Chalk with laminations | Frequent | Transported | 70 | Pl 6, Figs. 4 to 6 |
| 54-1, 123–126 | 510.23 | Late Campanian | White | Chalk with burrows | Common | Transported | 69 | Pl. 6, Figs. 1 to 3 |
| 54-2, 67–72 | 511.17 | Late Campanian | White | Chalk | Common | Indigenous only | 60 | Pl. 5, Figs. 3, 5, 6 |
| 54-3, 3–7 | 512.03 | Late Campanian | Grey | Chalk | Common | Transported | 60 | Pl. 5, Figs. 1, 2, 4 |
| 55-1, 85–89 | 514.35 | Early Campanian | Brown | Marlstone | Common | Transported | 50 | Pl. 3, Figs. 4 to 6 |
| 55-2, 61–64 | 515.61 | Early Campanian | Tan | Marlstone | Common | Transported | 55 | Pl. 3, Figs. 1 to 3 |
| 55-2, 64–66 | 515.64 | Early Campanian | Brown | Claystone | Very rare | Indigenous only | 2 | Pl. 4, Figs. 1 to 6 |
| 55-2, 71–73 | 515.71 | Early Campanian | Tan | Marlstone | Frequent | Indigenous only | 26 | Pl. 2, Figs. 1 to 3 |
| 55-2, 117–122 | 516.17 | Early Campanian | Grey | Marlstone | Abundant | Transported | 21 | Pl. 1, Figs. 1 to 3 |
| 55-4, 55–59 | 518.55 | Early Campanian | Brown | Marlstone | Abundant | Indigenous only | 44 | Pl. 2, Figs. 4 to 6 |
| 55,CC(A) | 522.50 | Early Campanian | Grey | Claystone | Rare | Indigenous only | 16 | Pl. 1, Figs. 4, 5, 6 |

### Sample 462-55-1, 85–89 cm (Plate 3, Figs. 4–6)

Brown marlstone contains 50% carbonate and common planktonic and benthic foraminifers of dominantly small size, and benthic foraminifers, probably transported.

Common to abundant, moderately to well-preserved calcareous nannofossils are embedded in flaky clay matrix. No coccospheres were observed.

### Sample 462-54-3, 3–7 cm (Plate 5, Figs. 1, 2, 4)

Gray, marly limestone contains 60% carbonate and few, poorly preserved planktonic and transported benthic foraminifers.

The nannofacies consists of abundant calcareous nannofossils embedded in a relatively coarse and porous matrix of mainly coccolith debris. Overgrowth features dominate over solution features. No coccospheres were observed.

### Sample 462-54-2, 67–72 cm (Plate 5, Figs. 3, 5, 6)

White, marly limestone with burrows has carbonate content of 60% and contains only indigenous, deep-water benthic foraminifers. Strongly etched and moderately overgrown calcareous nannofossils are tightly packed with carbonate debris and clay particles, apparently in preferred orientation. Nannofacies very different from that of Sample 462-54-3, 3–7 cm, despite identical bulk carbonate content.

### Sample 462-54-1, 123–126 cm (Plate 6, Figs. 1–3)

White marly limestone with darker laminations has a carbonate content of 69%. The coarse-fraction particles are all of relatively small size and include few planktonic and displaced (from up-slope) benthic foraminifers, rare radiolarians, and fish debris.

Common, moderately well-preserved and comparatively diverse calcareous nannofossils are found embedded in a matrix consisting mostly of nannofossil debris. Occasional coccospheres are present.

### Sample 462-54-1, 39–45 cm (Plate 6, Figs. 4–6)

Brown, marly limestone with darker and lighter burrows has a carbonate content of 70%. Coarse fraction consists of abundant recrystallized radiolarians, and few poorly preserved planktonic and benthic foraminifers, probably displaced from up-slope.

Moderately to well-preserved, relatively diverse calcareous nannofossils are found embedded in porous matrix of nannofossil debris and clay. Degree of recrystallization is variable. Partially intact coccospheres are encountered very commonly.

It becomes evident from the descriptions and illustrations of the nannofacies that there are no systematic differences on a presence–absence basis between the nannofacies of samples with apparently transported benthic foraminifers and those with only indigenous abyssal benthics. In samples with transported benthic foraminifers, coccospheres are encountered more frequently and more consistently, and nannofossil diversity is higher than in samples with only indigenous deep benthics. Dissolution experiments with Late Cretaceous nannofossil assemblages (Thierstein, 1980) have shown that a few solution-resistant taxa tend to become enriched rapidly in poorly preserved assemblages by dissolution of most of the other members of the assemblage, leading to a decrease in diversity. Rapid burial of particles in transported horizons should tend to preserve the higher diversity of shallower-water fossil assemblages, and indeed higher diversities are observed in samples with transported benthics than in those with only indigenous benthic foraminifers (see last column in Figs. 7 and 8).

## Campanian *Braarudosphaera* in the Nauru Basin

A unique morphotype of *Braarudosphaera* (sp. indet.) was found in the Campanian sediments of Cores 55 and 9A. All specimens are considerably overgrown, as illustrated in Plate 7. Overgrowth appears to occur preferentially along one of the cleavage planes of the individual trigonal calcite crystals of the pentalith, possibly aided by previous etching before burial. Asymmetric etching features on elements of pentaliths have been observed previously by Black (1972). The overgrowth of *Braarudosphaera* leads to buildup of the distal face and the development of a small central pit on the proximal side of the pentalith. The individual elements become radially asymmetric, and the sutures between the elements form an oblique, rather than perpendicular angle with the rotational-symmetry plane of the pentalith. *Braarudosphaera* (sp. indet.) are observed in samples with and without transported benthic foraminifers. The occurrence of *Braarudosphaera* in Holocene sediments is limited to well-preserved samples of less than 3 km water depth (Thierstein, 1980). Its apparent Recent preburial dissolution susceptibility and its occurrence in the Upper Cretaceous at Site 462 in samples with exclusively indigenous abyssal benthic foraminifers lend additional support to the interpretation of a descent of the CCD in the Pacific during the Campanian. The paleoecological and paleoceanographic implications of this first report of *Braarudosphaera* preserved in deep-sea sediments of Campanian age remain to be established.

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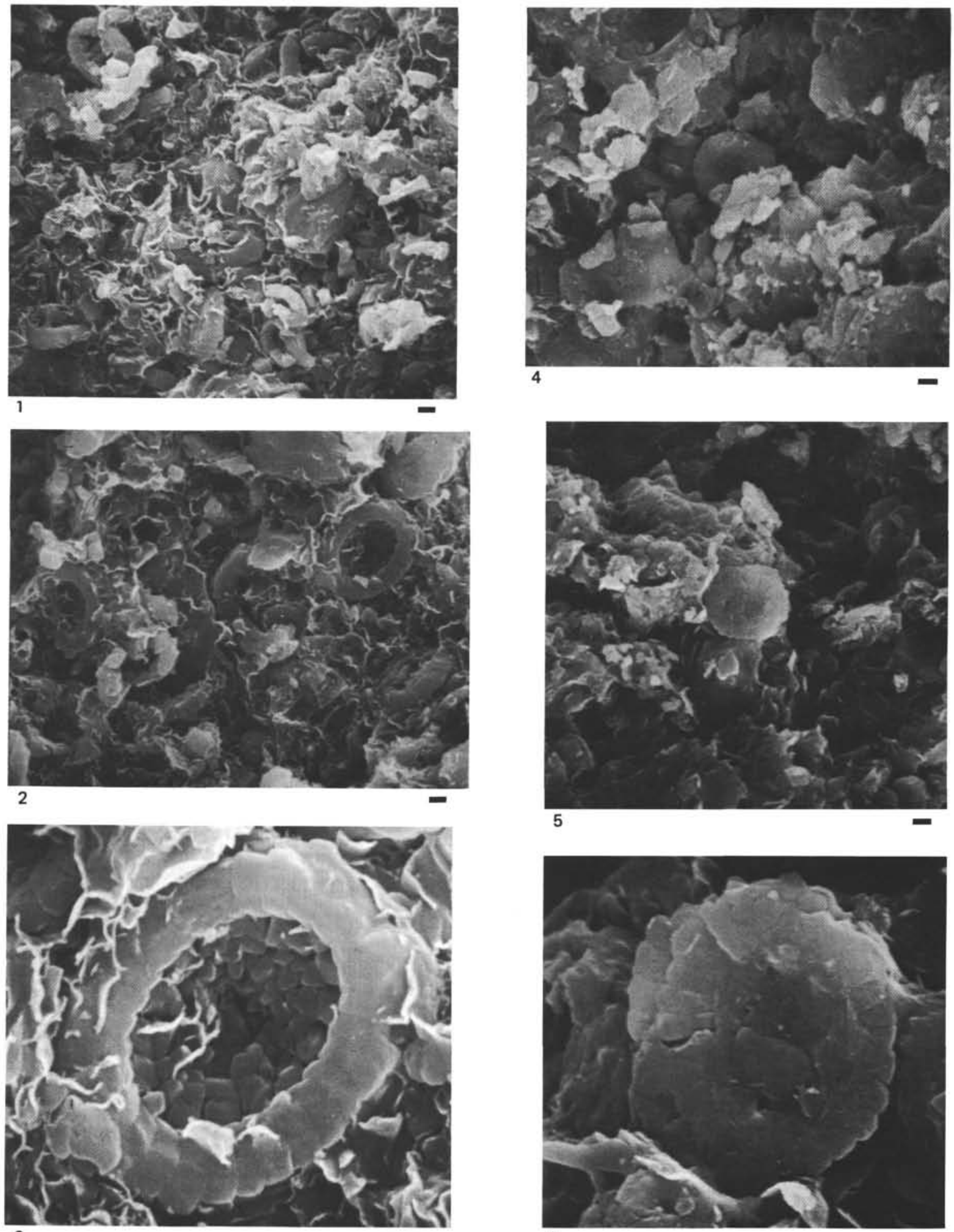

Plate 1. Scanning electron micrographs of lower Campanian nannofacies. Scale bars = 1 $\mu$m.

Figures 1–3. Sample 462-55-2, 117–122 cm. Marly claystone with transported benthic foraminifers. 1, 2. Abundant, moderately etched and slightly overgrown nannofossils embedded in finely dispersed clay matrix, ×3000. 3. Detail of 2, showing the proximal side of a slightly etched and overgrown coccolith, ×10,000.

Figures 4–6. Sample 462-55,CC. Zeolitic marlstone with indigenous deep-water benthic foraminifers only. 4. *Watznauria* spp. in a matrix of clay and overgrown carbonate particles, ×3000. 5. *Cretarhabdus* spp. in a splintered, porous clay matrix, ×3000. 6. Close-up of 5, showing etching and overgrowth of *Cretarhabdus* spp., whose central area structures are obscured by authigenic fused clay particles, ×10,000.

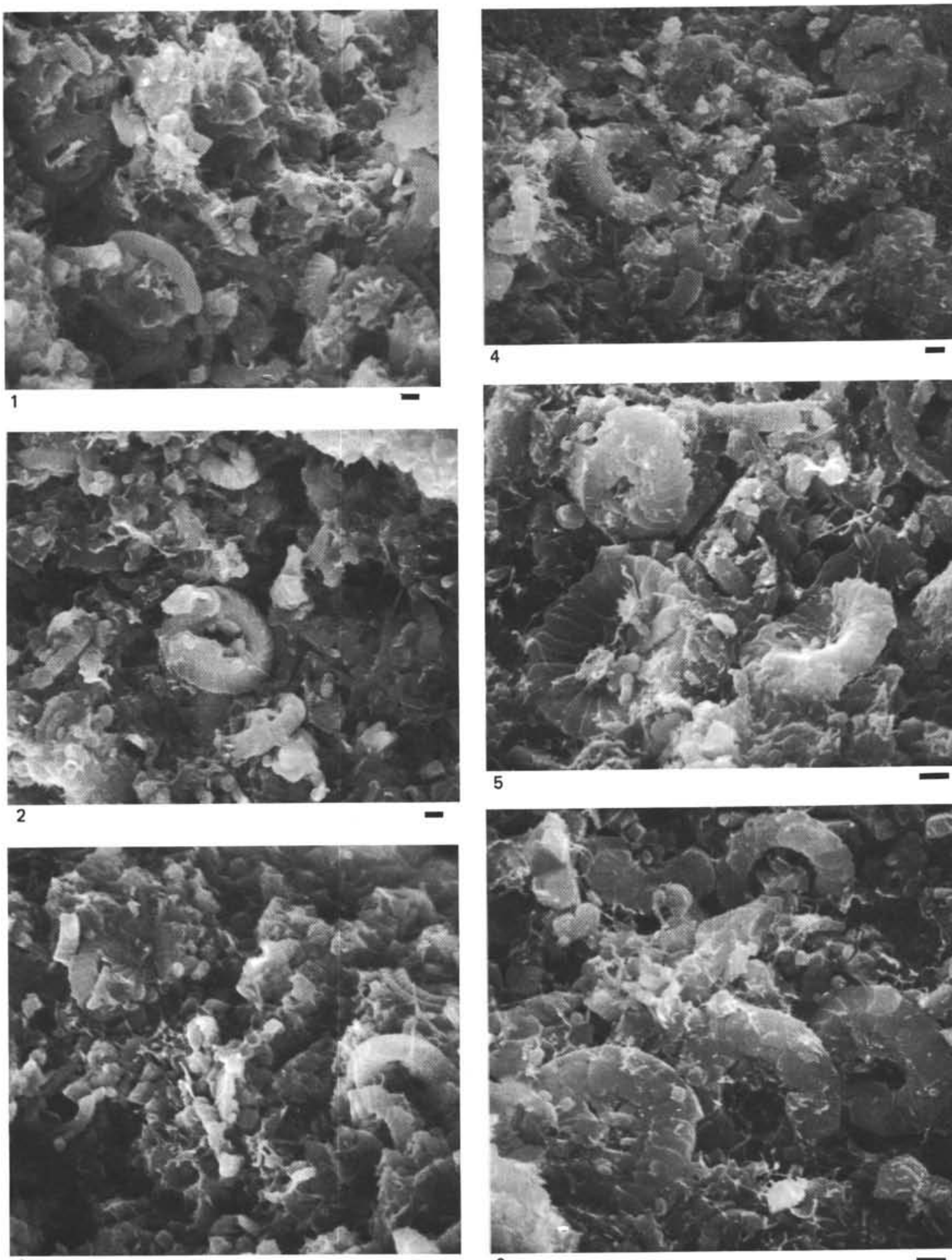


Plate 2. Scanning electron micrographs of lower Campanian nannofacies. Scale bars = 1 $\mu$m.

Figures 1–3. Sample 462-55-2, 71–73 cm. Tan, zeolitic marlstone with indigenous deep-water benthic foraminifers only. 1. Common, strongly etched and broken nannofossils embedded in clay matrix, $\times 3000$. 2. Imprint of nannofossil in clay matrix, above strongly dissolved *Watznaueria barnesae*, (distal view) $\times 3000$. 3. Nannofossil remains dispersed in compact clay matrix with numerous imprints of coccoliths in upper half of photograph, $\times 3000$.

Figures 4–6. Sample 462-55-4, 55–59 cm. Zeolitic marlstone with indigenous deep-water benthic foraminifers only. 4. Moderately well-preserved calcareous nannofossils dominating the fine clay matrix. Fine threads are probably hypha from post-recovery fungus growth, $\times 3000$. 5. Distal and proximal views of *Watznaueria barnesae* with signs of moderate overgrowth, $\times 5000$. 6. Placolith shields with central-area structures partially dissolved, embedded in fine-grained clay and coccolith-debris matrix, $\times 5000$.

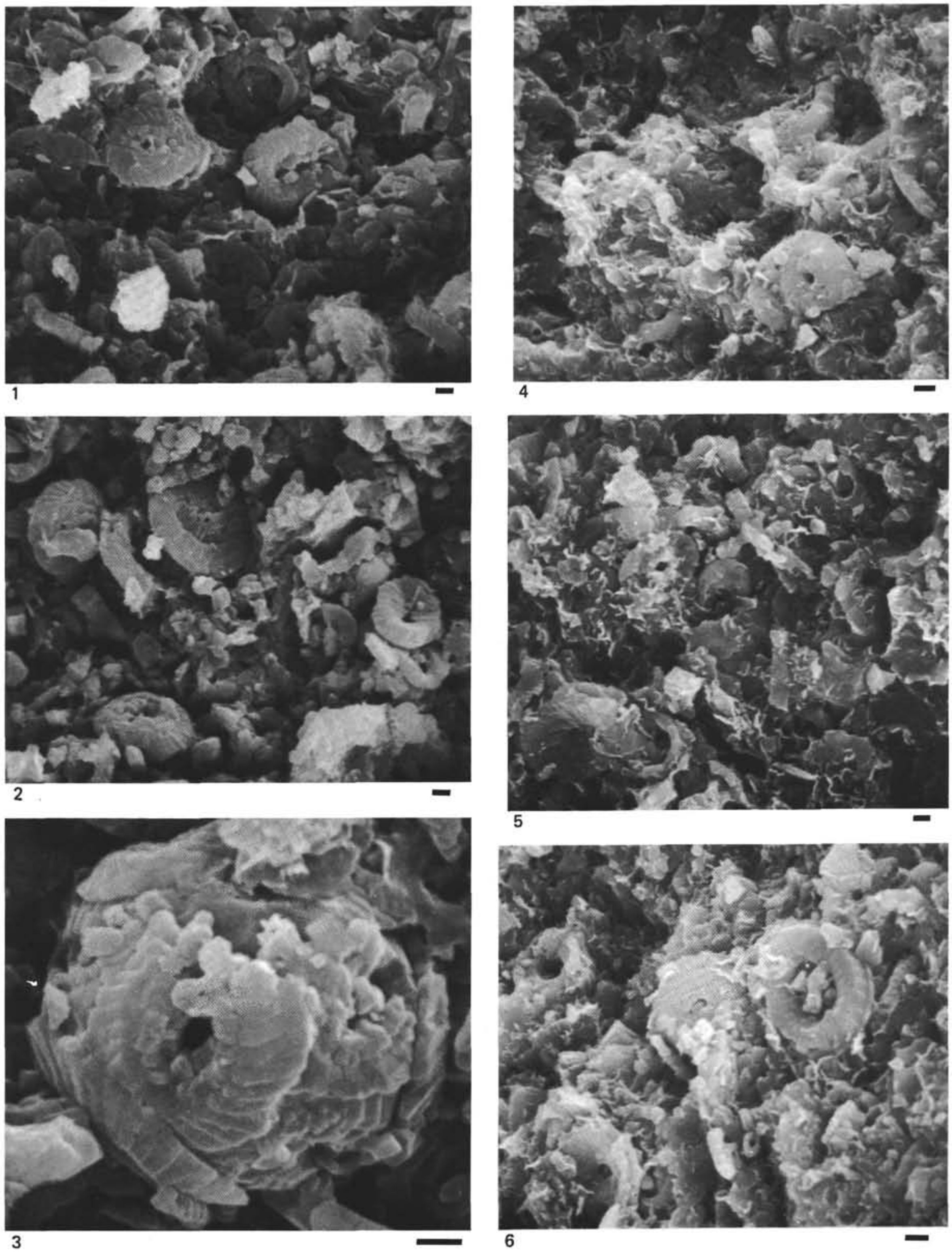


Plate 3. Scanning electron micrographs of lower Campanian nannofacies. Scale bars = 1 $\mu$m.

Figures 1–3. Sample 462-55-2, 61–64 cm. Tan marlstone with transported benthic foraminifers. 1. Common calcareous nannofossils of dominantly solution-resistant taxa, dispersed in matrix of clay and coccolith debris, ×3000. 2. Well-preserved *Cretarhabdus crenulatus* (distal view, upper center) and moderately well-preserved *Watznaueria barnesae* (distal views: upper left and lower left; proximal view: right center of micrograph), showing dissolution in central area and overgrowth of shield elements, ×3000. 3. Coccosphere of *Watznaueria barnesae* with partially dissolved coccoliths, ×8000.

Figures 4–6. Sample 462-55-1, 85–89 cm. Brown marlstone with transported benthic foraminifers. 4. Moderately well-preserved calcareous nannofossils packed in dense clay matrix, ×3000. 5, 6. Common, well-preserved, slightly overgrown calcareous nannofossils wrapped in flaky clay matrix, interspersed with coccolith debris, ×3000 (5), ×4000 (6).

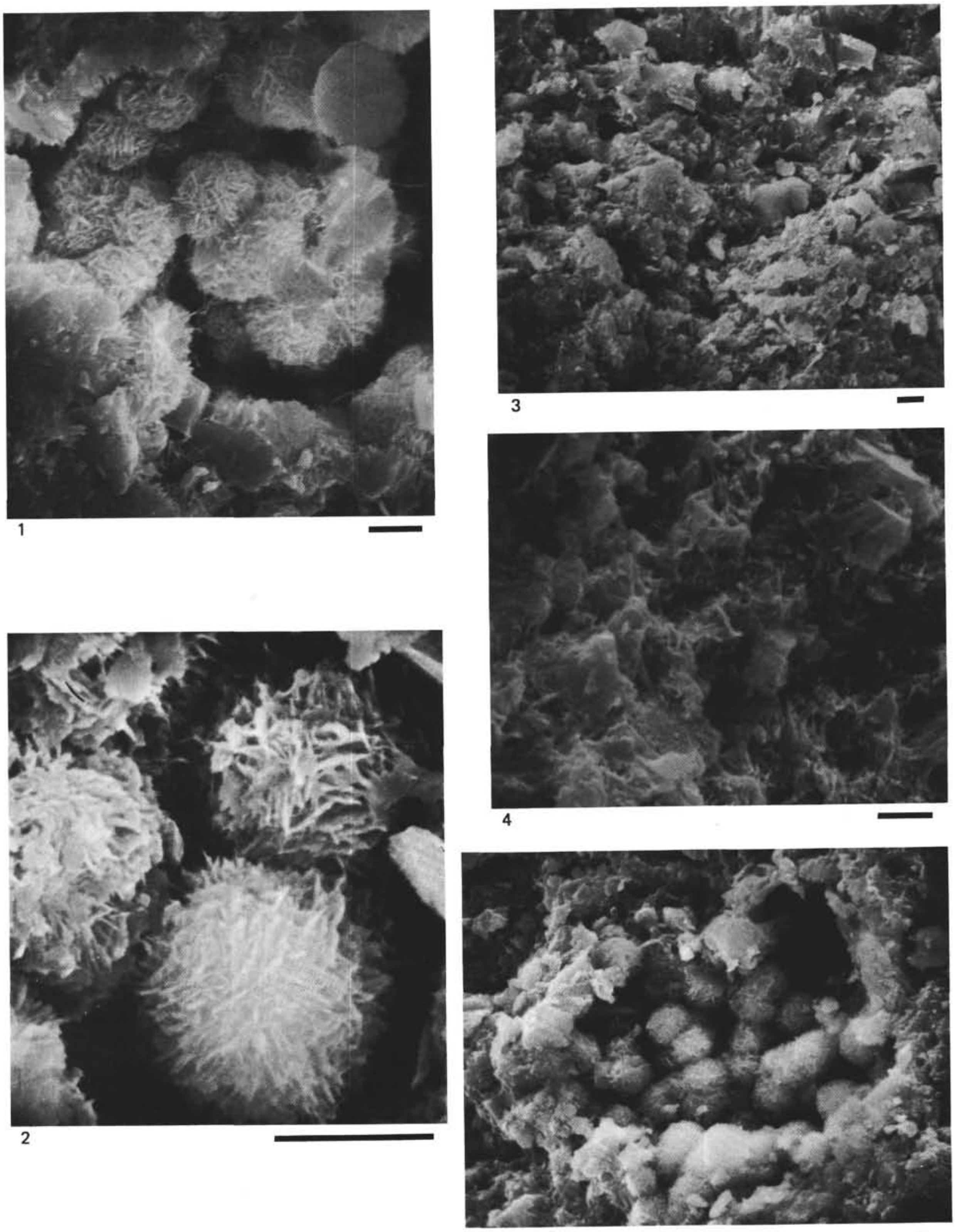


Plate 4. Scanning electron micrographs of lower Campanian nannofacies. Scale bars = 1 μm.

Figures 1–5. Sample 462-55-2, 64–66 cm. Dark-brown claystone with indigenous benthic foraminifers only. 1, 2, 5. Aggregates of cristobalite spherules developed diagenetically in fine clay matrix, ×2000 (1), ×6000 (2), ×1000 (5). 3, 4. Poorly structured clay matrix, ×1000 (3), ×2000 (4).

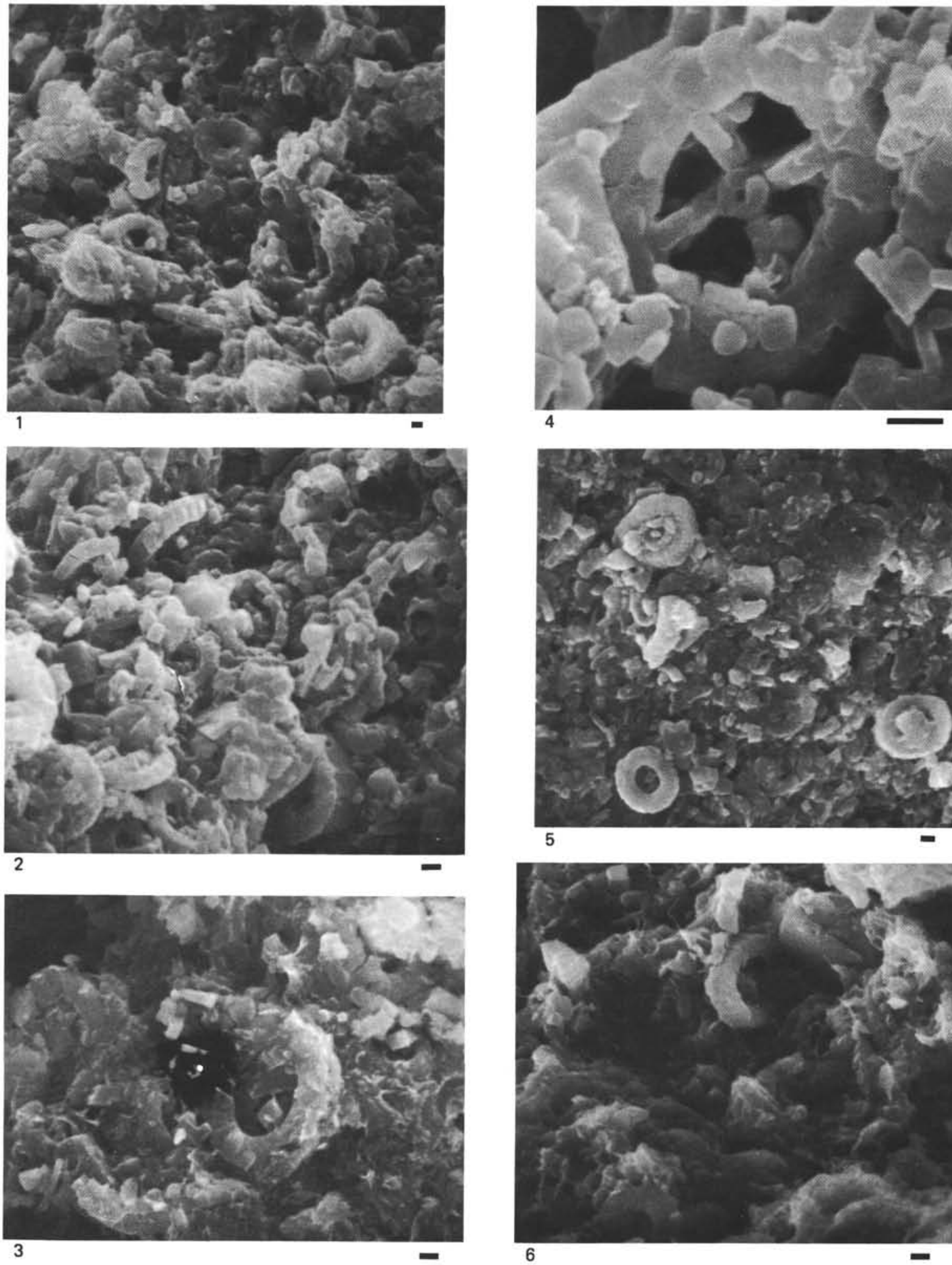


Plate 5. Scanning electron micrographs of upper Campanian nannofacies. Scale bars = 1 $\mu$m.

Figures 1, 2, 4. Sample 462-54-3, 3–7 cm. Marly limestone with transported benthic foraminifers. 1. Common, moderately overgrown calcareous nannofossils (mostly *Watznaueria barnesae*), embedded in rather porous coccolith debris and clay matrix, ×2000. 2. Moderately etched and overgrown nannofossils in porous matrix consisting dominantly of relatively coarse carbonate debris, ×3000. 4. Proximal view of *Prediscosphaera cretacea*, showing fusion of elements with carbonate debris by overgrowth, ×10,000.

Figures 3, 5, 6. Sample 462-54-2, 67–72 cm. Marly limestone with indigneous benthic foraminifers only. 3, 6. Few, strongly etched nannofossil shields are packed in dense matrix of clay particles and coccolith debris, ×3000. 5. Coccoliths and clay particles, showing preferred orientation, ×2000.

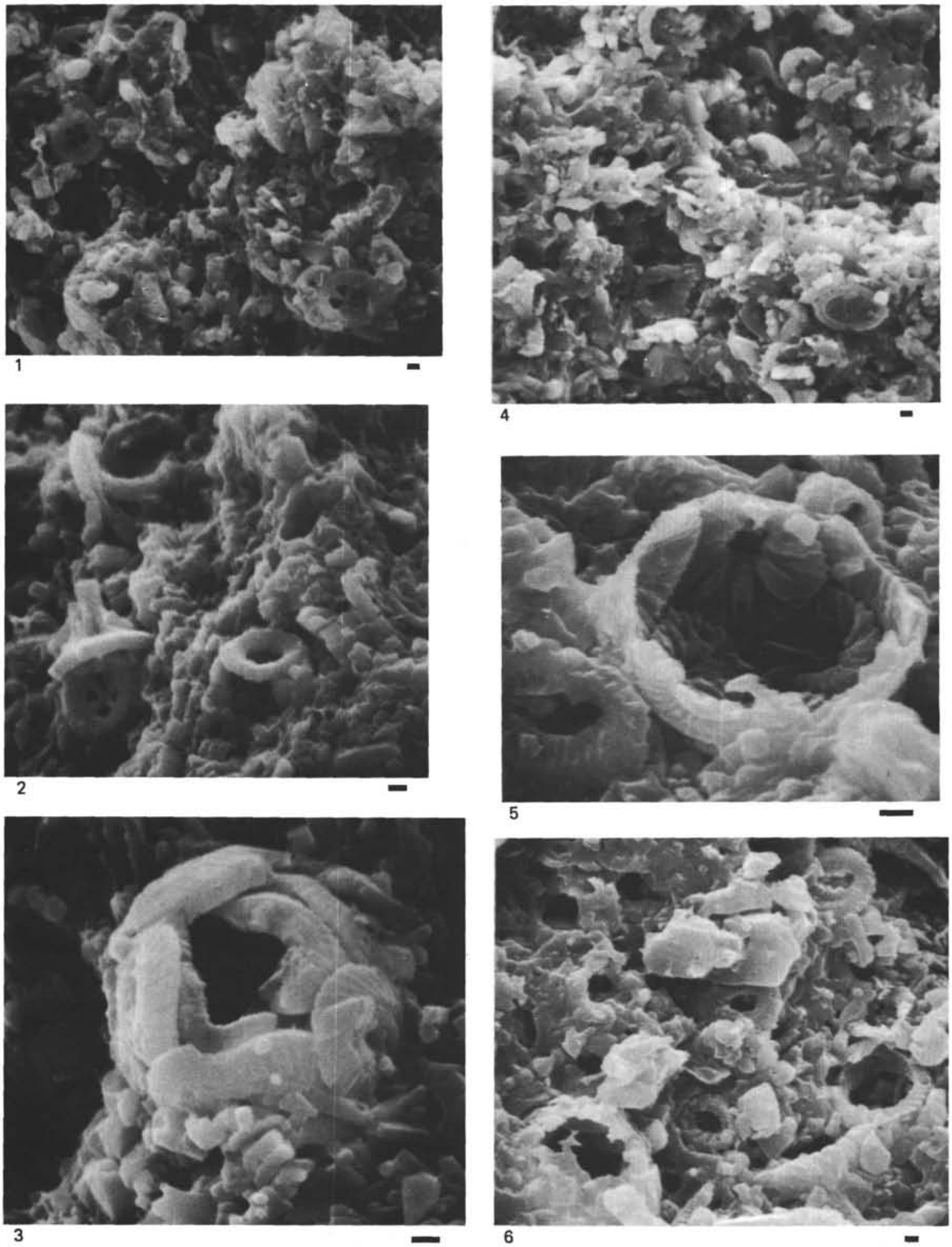

Plate 6. Scanning electron micrographs of upper Campanian nannofacies. Scale bars = 1 $\mu$m.

Figures 1–3. Sample 462-54-1, 123–125 cm. Laminated, marly limestone with transported benthic foraminifers. 1, 2. Nannofossils and nannofossil debris, making up the bulk of the sediment, solution-susceptible *Prediscosphaera cretacea* abundant, ×2000 (1), ×3000 (2). 3. Coccosphere of *Watznaueria barnesae*, partially dissolved, ×5000.

Figures 4–6. Sample 462-54-1, 39–45 cm. Burrowed marly limestone with transported benthic foraminifers. 4. Nannofossils and nannofossil debris dispersed in relatively coarse-grained clay matrix, ×2000. 5. Broken coccosphere of *Cyclagelosphaera margerelii*, showing overgrowth on proximal shields, *Watznaueria barnesae* in left lower corner strongly dissolved, ×6000. 6. Moderately well-preserved nannofossils dispersed in relatively coarse and porous carbonate debris and clay matrix, coccosphere of *Watznaueria barnesae* in lower left corner, ×2000.

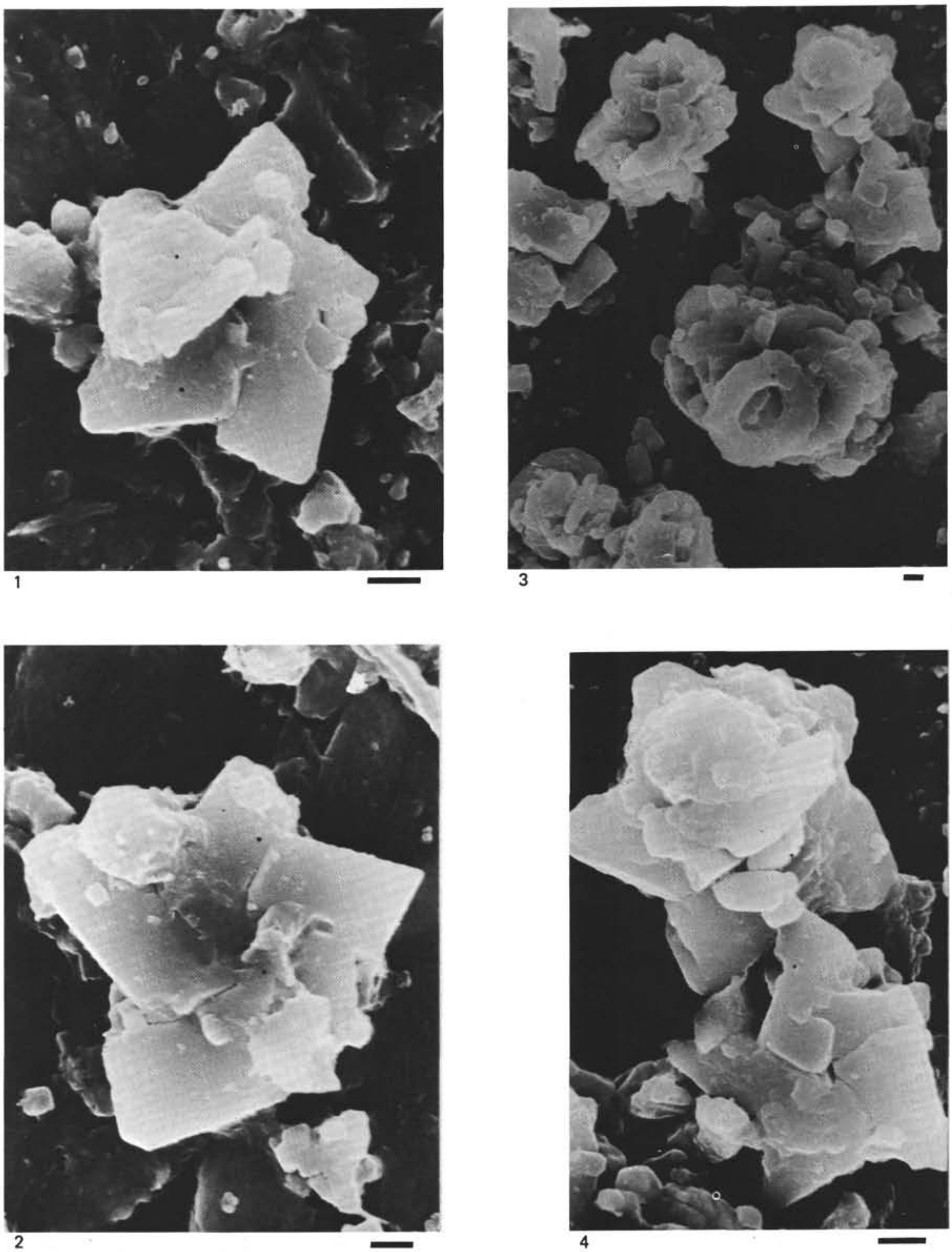


Plate 7. Scanning electron micrographs of early Campanian *Braarudosphaera* (sp. indet.) in disaggregated Sample 462-55-4, 37–40 cm. Scale bars = 1 $\mu$m.

Figure 1. Proximal view of pentalith, showing overgrowth of calcite crystals, incorporating carbonate debris and leading to radial asymmetry of pentalith, ×9800.

Figure 2. Proximal view of asymmetric pentalith showing central pit, ×7400.

Figure 3. Moderately well-preserved nannofossils with two specimens of *Braarudosphaera* (sp. indet.), ×3200.

Figure 4. Distal view of *Braarudosphaera* (sp. indet.) in upper part of of micrograph, showing sloping, re-calcified crystal surfaces; central part obscured by debris; proximal view of *Braarudosphaera* sp. indet.) in lower part of micrograph, with interlocking overgrowth features on some elements, ×8600.