# 6. TAXONOMY, STRATIGRAPHY, AND PALEOCEANOGRAPHIC IMPLICATIONS OF PALEOCENE DIATOMS<sup>1</sup>

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# ABSTRACT

The taxonomy and stratigraphy of pelagic Paleocene diatoms from ODP Sites 698, 700, and 702 and DSDP Site 524 in the South Atlantic and DSDP Site 214 in the Indian Ocean are presented, as well as paleogeographic and paleoecologic implications. Eleven new species and one new variety are described and one new combination is proposed:

Coscinodiscus cruxii sp. nov. Grunowiella palaeocaenica var. alternans var. nov. Hemiaulus? beatus sp. nov. Hemiaulus? ciesielskii sp. nov. Hemiaulus? conicus sp. nov. Hemiaulus kristoffersenii sp. nov. Hemiaulus nocchiae sp. nov. Hemiaulus? oonkii sp. nov. Hemiaulus? velatus sp. nov. Triceratium gombosii sp. nov. Trochosira gracillima comb. nov. Trochosira marginata sp. nov.

Hole 700B provides one of the most continuous diatomaceous Paleocene profiles known. Stratigraphic ranges of diatom species from this and other Southern Hemisphere sites are calibrated against calcareous microfossil zones. The first-appearance datums of *Triceratium gombosii*, *Hemiaulus incurvus*, and *Triceratium mirabile* in Paleocene deep-sea sediments are useful for regional stratigraphic correlations.

Quantitative analysis of the biosiliceous microfossil groups (diatoms, silicoflagellates, radiolarians, and archaeomonadaceae) shows that preservation of diatoms is confined primarily to the upper Paleocene (planktonic foraminifer Zones P3 and P4 and calcareous nannofossil Zones upper NP5 to lower NP9). In the lower Paleocene only short intervals in Hole 700B are diatomaceous. A correlation between the degree of silica diagenesis and the calcium carbonate content of the sediment is not obvious.

Diatom species analysis reflects changes in the paleoenvironment between island-related upwelling conditions with highly diverse and well-preserved diatom assemblages and less productive periods resulting in less well-preserved diatom assemblages with a higher content of robust neritic diatoms.

# INTRODUCTION

Three holes drilled during Ocean Drilling Program (ODP) Leg 114 in the subantarctic southwest Atlantic recovered Paleocene diatomaceous sediments (Table 1). These sites form a west-east transect across the East Georgia Basin (Figs. 1 and 2). Site 698 lies on the eastern slope of the Northeast Georgia Rise, Sites 699 and 700 farther east on the northern slope of the Southeast Georgia Rise, and Site 702 is on the other side of the basin, on the Islas Orcadas Rise.

Just the uppermost part of the Paleocene, a clay- and zeolite-bearing chalk, was drilled in Hole 699A. Only the lowermost sample of this hole contained a few heavily etched fragments of Paleocene diatoms (Fig. 2). The diatomaceous sediments recovered at Holes 698A and 702B represent only a small part of the late Paleocene, mainly as a result of incomplete recovery and the presence of hiatuses (Figs. 2, 3, 5, and 8). A nearly continuous diatomaceous section through the upper Paleocene is available from Hole 700B with only the uppermost part (the upper part of calcareous nannofossil Zone NP9) barren of diatoms. In the lower Paleocene part of the profile diatom occurrence is restricted to short intervals, mainly as a result of silica dissolution and diagenesis.

Present knowledge of the stratigraphic ranges of diatom species in the Paleocene is based on reports from diatomaceous deposits in the USSR, for which "diatom-complexes" (assemblage zones) were defined by Krotov and Shibkova (1961), Gleser (1978), and Jousé (1979). From the Southern Hemisphere, stratigraphic ranges of a few species through the early Paleocene were reported from Deep Sea Drilling Project (DSDP) Site 208 in the southwest Pacific by de Prado (1981),

Table 1.	DSDP	and	ODP	sites	with	diatomaceous	Paleocene
sections.							

-	Loc	ation		Length of
Hole	Latitude	Longitude	Water depth (m)	Paleocene section (m)
698A	51°27.51'S	33°05.96'W	2138	57
700B	51°31.997'S	30°16.688'W	3601	100
702B	50°56.786'S	26°22.117'W	3083.7	52
208	26°06.61'S	161°13.27'W	1545	37
214	11°20.21'S	88°43.08'E	1671	57
327A	50°52.28'S	46°47.02'W	2400	61
524	29°29.055'S	3°30.74'E	4796	4

 <sup>&</sup>lt;sup>1</sup> Ciesielski, P. F., Kristoffersen, Y., et al., 1991. Proc. ODP, Sci. Results, 114: College Station, TX (Ocean Drilling Program).
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Figure 1. Location of studied DSDP and ODP sites in the southwest Atlantic. Map from Heezen and Tharp (1977).

de Prado and Ling (1981) and used for the definition of diatom zones. Harwood (1988) described diatoms from lower Paleocene sediments of the Sobral Formation on Seymour Island, eastern Antarctic Peninsula. While early Paleocene age diatomaceous sediments are scarce, late Paleocene diatomaceous sediments in the Southern Hemisphere are much more widespread and have been reported from the northern Indian Ocean (Vityaz Core 6744; Mukhina, 1976) and the South Atlantic (DSDP Sites 327 and 524). Using ranges of diatom species at these two last sites, Gombos (1977, 1984) developed a diatom zonation for the late Paleocene.

Both the zonations of Gombos (1977, 1984) and de Prado and Ling (1981) were established from a restricted knowledge of the ecology and paleogeographic distribution of diatom species in the Paleocene. As a consequence some of the species selected for zonal definitions (e.g., Odontotropis klavsenii and Stephanopyxis conici) are neritic species, thus making these schemes unsuitable for regional correlations of deep-sea sediments. The goal of this study, therefore, is to extend our knowledge of the stratigraphic ranges of diatom species in the Paleocene and their paleogeographic occurrence. For this purpose the well-preserved and diverse assemblages recovered at ODP Site 700 were analyzed in great detail and calibrated against the calcareous microfossil stratigraphy (Crux, this volume; Nocchi et al., this volume) as well as against the paleomagnetic reversal record determined at the same site (Hailwood and Clement, this volume). In addition, results from other ODP Leg 114 sites (698 and 702) and DSDP sites in the Southern Hemisphere (Table 1) that have diatomaceous Paleocene sediments and are dated by calcareous microfossils are used to select stratigraphically useful datums.

The stratigraphic occurrence of diatoms in the Paleocene sediments at these sites is shown in Figure 3.

# METHODS

The Paleocene sediments were so well indurated that samples could be taken only with hammer and chisel. But letting the samples stand overnight in a beaker with 10% HCl led to a slow, gentle, complete disintegration of the sediment without putting mechanical stress on the diatom valves. The samples then were surrendered to routine treatment by boiling in the 10% HCl solution with an equal amount of 30% H<sub>2</sub>O<sub>2</sub> added. Additional treatment of test samples with a mixture of concentrated sulfuric acid with potassium dichromate did not improve the cleaning and concentration of the diatoms. Diatoms were separated from clay by repeated washing of the samples in a 0.2 m sodium hexametaphosphate solution and by using their differing gravitational settling times (for details see Fenner, 1982). Sodium hexametaphosphate was found to better suspend clay than did sodium pyrophosphate.

Quantitative slides were prepared using the method of Battarbee (1973), in which randomly strewn slides can be produced giving statistically reproducible results. Hyrax (refractive index n.d. = 1.71; solvent: toluene) was used as the mounting medium.

Species identification and counting were done at  $1000 \times$  magnification using a Leitz Orthoplan photomicroscope with oil-immersion objective PL Apo Oel 100/1.32.

Estimates of preservation were made by integrating observations of the fragmentation and etching of diatom valves with the relative abundance of dissolution-resistant species (e.g., *Hemiaulus peripterus*, *Hemiaulus inaequilaterus*, *Stephano*-



Figure 2. A. Abundance of diatom valves and clinoptilolite crystals per gram sediment in the Paleocene sections recovered during ODP Leg 114. Calcareous nannofossil and planktonic foraminifer zone assignments from Crux (this volume) and Nocchi et al. (this volume). Zonal boundaries are drawn to indicate the core depth of the limiting samples. For core-catcher samples the maximum possible depth range was chosen. **B.** Relief of the west-east transect of Leg 114 sites across the East Georgia Basin.



Figure 3. Maximum possible stratigraphic range of diatomaceous sediments based on calcareous microfossil stratigraphy at the seven sites analyzed. Age assignment after Berggren et al. (1985). Age range in left column according to planktonic foraminifers; right column, calcareous nannofossils.

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*pyxis turris*, and *Coscinodiscus argus*). The categories differentiated are those generally used for stratigraphic studies: poor (P), moderate (M), good (G), and excellent (E).

For the abundance plots of diatom valves per gram sediment, a minimum of 300 diatom valves was counted. For the stratigraphic range charts and the lists of species occurrence, relative abundances are given according to the following scheme:

single (S) = <0.1%rare (R) = 0.1%-1% frequent (F) = 1%-10% common (C) = 10%-30% abundant (A) = 30%-50% dominant (D) = >50%

For abundance estimates a minimum of 1000 valves was checked.

# RESULTS

# **Diatom Abundance and Preservation**

In all three holes in which Paleocene diatoms are preserved, the sediment is an ash-bearing, clay-containing wellindurated chalk (CaCO<sub>3</sub> content >90%). The abundance of diatoms in the Paleocene section at the Leg 114 sites is illustrated in Figure 2.

From Figures 2 and 3 it is evident that the diatoms are mainly preserved in late Paleocene sediments ranging in age from planktonic foraminifer Zones P3 to P4 or calcareous nannofossil Zones upper NP5 to lower NP9. Toward the Eocene/Paleocene boundary the diatoms disappear, and they are scarce also in the early Paleocene age sediments. Late Paleocene oxygen isotope analyses of sediments from Site 690, farther south on Maud Rise, indicate that this was a period of relatively warm surface-water temperatures that extended far into the high southern latitudes and that the latitudinal temperature gradient was accordingly low (Shackleton, 1989). The occurrence of diatomaceous sediments in the late Paleocene was apparently controlled by local factors such as primary productivity, sedimentation rate, and sediment composition, which determine accumulation rates and the preservation potential of diatoms.

One of the factors that seems to have influenced opal-A preservation is the presence or absence of vitreous volcanic

ash in the sediments. In samples that contain more than 5% volcanic ash (Fig. 4) good diatom preservation was generally found. Otherwise, even where diatom abundance is higher than  $10^6$  or  $10^7$  diatom valves per gram of sediment, their preservation is only moderate, with the valves heavily etched and a high percentage of fragmented valves. Preservation is poor, causing low diatom diversity, where the abundance of diatoms drops below  $10^6$  valves per gram of sediment. In these samples the more dissolution-resistant skeletons of radiolarians, ebridians, and archaeomonadaceae (chrysophycean cysts) are enriched, whereas the abundance of silicoflagellates and diatoms is reduced. The latter groups are obviously less dissolution resistant.

The authigenic zeolite clinoptilolite is abundant in sediments where no opal-A skeletons are present and it occurs in low abundance in transitional intervals between diatom-rich and diatom-free sediments. Due to this inverse correlation and the sporadic occurrence of zeolitized diatom valves and radiolarian skeletons, the crystallization of clinoptilolite is thought to be related to an enrichment in silica in the pore water resulting from opal-A dissolution. Whether—and if so, how much, how far, and in what direction—diffusion of dissolved silica occurred in the sediments and what other factors influenced the reaction cannot be determined from the data available. Correlation of an increase and progression of silica diagenesis with a higher calcium carbonate content of the sediment was not observed.

# Diatom Assemblage Composition and Paleoecology

Diatom assemblages encountered at ODP Sites 698, 700, and 702 and DSDP Site 524 are pelagic and are dominated by chain-forming, planktonic species of the genera *Hemiaulus* (including *Hemiaulus*?), *Triceratium*, *Stephanopyxis*, *Sceptroneis*, *Grunowiella*, and *Trochosira*. Benthic, shallow-water species are extremely rare. Found very sporadically at Sites 214, 524, 698, and 700 were single fragments of valves of benthic species of the genera *Arachnoidiscus*, *Auliscus*, and *Aulacodiscus*. Only at Site 702 (paleodepth approximately 1500–1700 m) are these benthic species slightly more abundant, indicating a coastal environment and island nearby upslope for the late Paleocene. Neritic species, such as the *Stephanopyxis turris* species group, are common at all sites. Other neritic diatoms, such as the *Paralia sulcata* species



Figure 4. Paleocene abundance of biosiliceous components plotted against the calcium carbonate, volcanic ash, and clinoptilolite contents of the sediment at Hole 700B.

group, are also frequently present. But resting spore genera, such as *Acanthodiscus*, *Goniothecium*, *Odontotropis*, *Pseudopyxilla*, *Pterotheca*, and *Xanthiopyxis*, that are characteristic for shelf areas and shallow seas are rare. This species composition suggests an island environment with a narrow coastal belt and shelf areas upslope from the studied sites.

The high abundance of diatoms in the sediments suggests that upwelling occurred on the leeward flanks of these topographic highs. That these flanks were sites of high primary production is also supported by the intense bioturbation of these sediments. At Sites 698, 700, and 208 the most common trace fossils found were *Zoophycos*, *Planolites*, *Thalass-inoides*, and *Chondrites*. In the sediment recovered in Cores 114-702B-31X and 114-702B-32X the degree of bioturbation could not be determined because of the heavy drilling disturbance and poor recovery. The intensity of bioturbation in oxygenated deep-sea sediments can be assumed to be related to their original organic content. Such a correlation between diatom abundance and bioturbation is plausible, as silica and carbon export to the seafloor both are positively correlated to the amount of primary productivity.

The dominance of the diatom genera changes strongly from sample to sample (Tables 2 and 3), as can be best observed through the long diatomaceous section at Site 700. Samples rich in Grunowiella palaeocaenica and related species seem to have received increased pellet sedimentation. Even after completing the preparation procedure with boiling and washing, pellets consisting nearly exclusively of relatively delicate Grunowiella species were found (e.g., Pl. 11, Fig. 27). In the same samples the relatively delicate, small Trochosira species occur frequently to commonly, as do also the small, planktonic Triceratium species (e.g., T. mirabile and T. gombosii) and Trinacria deciusii. On the other hand, in samples in which large Trinacria species (e.g., T. senta and T. conifera) are frequent to common, the robust valves of Grunowiella gemmata are also frequent to common. These changes in assemblage composition could be interpreted to represent differing amounts of input from neritic environments related, for example, to sea-level fluctuations, periods of differing water turbulence and wind intensity, and changing nutrient availability and/or they could represent a different degree of opal-A preservation. It is difficult to evaluate these possibilities from extinct species, a uniform deep-sea lithology, and the common to dominant occurrence of dissolution-resistant valves of species such as Stephanopyxis turris, Coscinodiscus argus, Hemiaulus peripterus, Hemiaulus subacutus sensu Gombos, and Hemiaulus inaequilaterus in all samples studied.

For those core intervals in which the small, more delicate, planktonic species of *Grunowiella*, *Trochosira*, and *Triceratium* are common, the high abundance of diatom valves in the sediment (Fig. 4) and the frequent presence of pellets indicate very fertile, possibly upwelling, conditions. This morphotype, forming long chains (as at present, e.g., species of the genera *Chaetoceros*, *Nitzschia*, *Thallassiothrix*, *Thalassionema*, and *Thalassiosira*), is also typically common to dominant in present-day upwelling areas.

The other assemblage with large *Trinacria* species, *G. gemmata*, and *Paralia* spp. is obviously characterized by a higher percentage of robust neritic species. In these core intervals diatoms are less abundant and their preservation is poorer. Dissolution-resistant species are enriched, and etching and fragmentation of the valves is increased. This assemblage is interpreted here as the result of periods of lower primary productivity. It is well-known that decreased sediment accumulation, and thus a decreased burial rate, leads to

enhanced dissolution of the shells, thereby further concentrating the relatively robust, allochthonous, neritic diatoms. In addition, a higher amount of downslope-transported neritic diatom valves, relative to the autochthonous assemblage, may have been deposited.

Because of the scarcity of well-dated microfossil datums in the Paleocene, the calculation of sedimentation rates (Table 4) had to be integrated over nearly the entire late Paleocene and all of the early Paleocene. Thus, they do not provide sufficiently detailed information for a useful correlation with abundance fluctuations of diatoms in the sediment or for a test of the preceding interpretation. However, on a larger time scale a correlation between higher sedimentation rates and better preservation of diatoms can be demonstrated. At sites where early and late Paleocene age sediments are preserved (e.g., Sites 524 and 700), sedimentation rates are higher in the late Paleocene (the time interval from which most of the diatomaceous sediments are described) than in the early Paleocene, a period from which few, short intervals with diatomaceous sediments are known.

Thus, it seems that both (1) differing primary ecological conditions, changing between highly productive offshore upwelling conditions and less productive phases, resulting in different relative amounts of neritic input and (2) different sedimentation rates related to these changing ecological conditions are together responsible for the observed changes in assemblage composition and opal-A preservation.

# Stratigraphy

The occurrence of Paleocene diatom species and their relative abundance at the Leg 114 sites as well as at Sites 214 and 524 are listed in Tables 2 and 3. The species list provided by Gombos (1977) for DSDP Site 327 has been considered in the stratigraphic interpretation.

As all of the studied Paleocene sections are calcareous, planktonic foraminifer and calcareous nannofossil zones could be determined (Nocchi et al., this volume; Crux, this volume; Berggren et al., 1974; Bukry, 1974; Gartner, 1974; McGowran, 1974; Percival, 1984; Smith and Poore, 1984) and are used here to calibrate the diatom ranges. Both of the calcareous microfossil zonations agree in the stratigraphic placement of the Paleocene/ Eocene boundary and the Cretaceous/Tertiary boundary. The stratigraphic ranges of the most prominent and stratigraphically important planktonic diatom species at Holes 698A, 700B, 702B, and 214 are illustrated in Figures 5 through 8.

For Hole 700B the paleomagnetic polarity record (Hailwood and Clement, this volume) has been determined, as far as permitted by the fragmentation and disturbance of the cored sediment caused by rotary drilling. Accordingly, the paleomagnetic record is incomplete. This author sees several possible interpretations of the available reversal record; thus, diatom datum ages were not calibrated against magnetostratigraphy.

Of all the lower Paleocene sediments recovered during Leg 114, only short intervals in Hole 700B contain diatoms (Fig. 2). As a whole the early Paleocene diatom assemblages are clearly different from those of the late Paleocene. The early Paleocene assemblages are dominated by *Hemiaulus peripterus*, *Hemiaulus* sp. 1, *Hemiaulus* sp. 2, *Hemiaulus*? *beatus*, *Hemiaulus*? sp. 4, and *Rhizosolenia cretacea* (Fig. 6).

Planktonic foraminifers from Core 114-698A-12R indicate an early Paleocene age (Zone P1b, P1c), whereas calcareous nannofossils date the core as late Paleocene (probably the "Fasciculithus tympaniformis group" Zone). The diatom assemblage in this core is completely different from the early Paleocene diatom assemblages found in Hole 700B (Fig. 5).

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Core, section, interval (cm)	Ash	Acanthosphaeridium reticulatum	Preservation of diatoms	Acanthodiscus spp.	Actinophychus spp.	Anaulus spp.	Arachnotascus spp.	Rriocera snn	Chaetoceros? clavigerus	Coscinodiscus? aff. anissimovae	Coscinodiscus argus	Coscinodiscus cruxii	Coscinodiscus sp.	Ethmodiscus spp. (fragments)	Fenestrella barbadensis	Goniothecium spp.	Grunowiella gemmata	Grunowiella palaeocaenica var. palaeocaenica	G. palaeocaenica var. alternans	Hemiaulus affinis	Hemiaulus altus	Hemiaulus? beatus var.	Hemiaulus? aff. ciesielskii	Hemiaulus? conicus	Hemiaulus fragilis	Hemiaulus grassus	Hemiaulus elegans var. intermedia	Hemiaulus inaequilaterus Hemiaulus incisus	Hemiaulus incurvus	Hemiaulus kristoffersenii	Hemiaulus? oonkii	Hemiaulus nocchiae	Hemiaulus peripterus	Hemiaulus polymorphus var. charkovianus	Hemiaulus rossicus	Hemiaulus aff. speciosus	H. subacutus sensu Gombos (1977)	Hemiaulus? velatus	H. sp. F. Harwood (1988)	Hemiaulus sp. 1	Hemiaulus sp. 2	Hemiaulus sp. 3	Hemiaulus? sp. 4	Hemiaulus sp. 5	Hemiaulus sp.	Hemiaulus? sp.	Hyalodiscus ambiguus	Hyalodiscus sp. (oval) Historicans en	riyatoauscus sp.
114-698A- 10R-1, 66-67 10R-1, 129-130 10R-2, 35-36 10R-2, 75-76 10R-CC	- + (+) - (+)	s	P G P -						R	t t	с	F		s s			S R	C F	R				F		j.	R		F	S	R	F					R	R	F					F			F	F		
11R-CC 12R-1, 27-28 12R-1, 33-34 12R-1, 91-92 12R-CC 14R-1, 12-13	+ (+) - - (+)		M/G M/G - P -						R		R C			R			R	F			R	R F	F F R	F D	R	R C R		F R S R	RRS	C F R	F R R	R S				R	C R	F F F				R	F		R R	R	F	R	
214- 37-2, 50-51 38-3, 50-51 39-2, 50-51	+++++		P P P				5		R	s	R					s	F F	s s		s								F S		RS	24 a 4 7 1 1 1						F		s					R	R				
114-720B- 31X-CC 32X-1, 27–28 32X-CC	(+) - (+)	s	P/M M P/M	R		R	R S R		R	1	R F			R R S		S R	R R F	F F	F R		s s	S R	R S S			3	S R	R F R S	2		F S	R	F F F	F R	R S F		F	R R R		R	S R	R F	R F	R R	F R R		R R		
524A- 4-3, 87–89 4-3, 130–131 5-1, 130–131	1.1.1	1 1	G M P/M		s	s	R R R	F	R F F C		R		R		s		s	s		R			R R C			R F R		C F C	C F R	F F F			S R				F F								F F F		s	1	R

# Table 2. Occurrence of diatom species in the Paleocene section of Holes 698A, 214, 702B, and 524A.

#### Genus et species indet. (1) Fenner (1978) Triceratium areolatum f. minor Pseudostictodiscus angulatus Sphynctolethus hemiauloides Rhizosolenia hebetata var. Stephanopyxis marginata Stephanopyxis lavrenkoi Pseudopodosira simplex T. excavata f. tetragona Stellarima primalabiata S. turris var. internedio Trinacria simulacroides Trochosira aff. mirabilis Triceratuum cellulosum S. turris var. cylindrus Pseudopyxilla russica Pterotheca evernanni Rhizosolenia cretacea Pseudopodosira bella Pterotheca aculeifera Pterotheca kittoniana Trochosir'a marginata Odontotropis cristata Pterotheca carinifera Stellarima microtrias Triceratium gombosii Triceratium heibergü Sceptroneis ligulatus Triceratium mirabile Triceratium schulzii Triceratium species Pterotheca clavata Solium exsculptum Trinacria excavata 0 Stephanopyxis sp. Thalassiosira spp. Trinacria conifera Sceptroneis sp. 1 Trinacria deciusii Triceratium wittii Trinacria pileolus Xanthiopyxis sp. Odontotropis sp. Xanthiopyxis sp. Paralia sulcata Sceptroneis sp. Trinacria senta Trinacria aries Trochosira sp. Melosira sp. 1 Trinacria sp. Paralia sp. Core, section, interval (cm) 114-698A-10R-1, 66-67 10R-1, 129–130 10R-2, 75–76 10R-CC R CF R S CFC F R C F C R R S R S F S S S R R F F F 11R-CC R S S RR F R R RRR R 12R-1, 27–28 12R-1, 33–34 12R-1, 91–92 F S CC R С S C A R 12R-CC R F R 14R-1, 12-13 214-2 37-2, 50-51 38-3, 50-51 39-2, 50-51 R A R F S S S C F F C S S C F F F F S R R S RF R S F F S S S S S R S S s F 114-702B-SS S RSR R R R F S S S R F A F R D C A F R C F F F R R R R R 31X-CC R S R R R S R R S S R S R S R S R R R 32X-1, 27–28 32X-CC F S F S R R S R FFR RF F 524A-4-3, 87–89 4-3, 130–131 5-1, 130–131 R F R S S F F R R S R R R F F R R R R RSS F F R RF S S R R R F R R R S S R R R RRR R R R FR R S

#### Note: Relative abundance and preservation codes are listed in the text

Table 2 (continued).

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Core, section, interval (cm)	Ash	Acanthosphaeridium reticulatum	Preservation of diatoms	Anaulus spp.	Chaetoceros? calvigenus	Coscinodiscus argus	Coscinodiscus cruzii	Coscinodiscus sp.	Ethmodiscus spp. (fragments)	Eunotogramma spp.	Goniothecium spp.	Grunowiella gemmata	Grunowiella palaeocaenica var. palaeocaenica	G. palaeocaenica var. alternans	Hemiaulus affinis	Hemiaulus altus	Hemiaulus? beatus	Hemiaulus? ciesielskii	Hemiaulus? conicus	Hemiaulus? fragilis	Hemiaulus aff. grassus	Hemiaulus inaequilaterus	Hemiaulus inaequilaterus var.	Hemiaulus incisus	Hemiaulus incurvus	Hemiaulus kristoffersenii	Hemiaulus nocchiae	Hemiaulus? oonkii	Hemiaulus polymorphus var. charkovianus	Hemiaulus rossicus	Hemiaulus aff. speciosus	H. subacutus sensu Gombos (1977)	Hemiaulus? velatus	H. sp. F. Harwood (1988)	Hemiaulus sp. 3	Hemiaulus sp. 4	Hemiaulus sp. 5	Hemiaulus sp.	Hemiaulus? sp.	Hyalodiscus ambiguus	Hyalodiscus sp. (oval)	Hyalodiscus sp.	Melosira sp. 1
114-700B- 26R-1, 40-41 26R-1, 106-107 26R-2, 106-107 26R-CC 27R-1, 30-31	- - (+) (+) -	R	P P P/M	s	R F	F C	S R				R	C F F	S F	F F	R			R F			F		S F R C		R R	R F		R			R	F F	F C R			F F		R F				R	
27R-1, 120–121 27R-CC 28R-1, 130–131 28R-2, 16–17 28R-2, 130–131	(+) - - -		P/M P/M P/M P/M P		F R F	C R F			R	F			F F R		R			C R R F	F C C F	s	A		C R R F	R F R R	F R R S	F F F F F	R	R F R F R			R R R	F C F	F F C F F		R	F F R		F		R S R F		S S F R	
28R-3, 130–131 28R-4, 130–131 28R-CC 29R-1, 24–25 29R-2, 10–11	(+) - (+) -	S S	P P P P	FR	R F R	C F C F F	F				S R	R F F	F F F F C	F				S	R F F S		R F R F		F F R	R F F	R R F	F F F F F		F R F F				C R F R R	F R	R		R				R R		F	
29R-2, 122–124 29R-CC, 3–4 29R-CC 30R-1, 3.5 30R-1, 27–28 30R-1, 107	- - + (+) -	S	P P M/G M P	S R	R F R F R F	R R F F F F		R			s	F R S	F C A C C	R R R					F F F R	R	F F F	R	F F F F R	F R R	F F F R S	R F F R F	R R R	R F F C R R		S	R	F F F F R	R R F R		R R		R R	F F	s	R R F F		R R R R	R
30R-2, 7 30R-2, 27–28 30R-2, 97 30R-2, 120–121	(+) - -	s	P P P P		R	F F F						R F	C F C F	R R R		s	R			R F S	R F	R	F F F			F F F S	R	F R R R	R			F	R F F		F F	R	R	F		R F		R F	
30R-3, 27–28 30R-4, 27–28	(+)		P P			F			s			R	S C	R F									F R	R		R	R	R			R		F F		R R			S	R	F	R	F	

Table 3. Occurrence of diatom species in the Paleocene section of Hole 700B.

# PALEOCENE DIATOMS

Core, section, interval (cm)	Odontotropis cristata	Odontotropis sp.	Paralia sulcata	Pseudopodosira bella	Pseudopodosira simplex	Pseudopyxilla russica	Pseudostictodiscus angulatus	Pseudostictodiscus sp.	Pterotheca aculeifera	Pt. aculeifera vat. spinosa	Pterotheca kittoniana	Pterotheca clavata	Pterotheca sp. 1	Rhizosolenia cretacea	Rhizosolenia hebetata var.	Sceptroneis ligulatus	Sceptroneis sp. 1	Sceptroneis sp.	Sphynctolethus hemiauloides	Stellarima microtrias	Stellarima primalabiata	Stephanopyxis discrepans	S. turris var. cylindrus	S. turris var. intermedia	Stephanopyxis sp.	Triceratium cellulosum	Trinacria deciusii	Triceratium gombosii	Triceratium mirabile	Triceratium schulzü	Trinacria aries	Trinacria conifera	Trinacria excavata	Trinacria senta	Trinacria simulacroides	Trinacria sp.	Trochosira gracillima	Trochosira marginata	Trochosira radiata	Trochosira aff. mirabilis	Trochosira sp.	Xanthiopyxis aff. structuralis	Xanthiopyxis sp.	Genus et species indet. (1) Fenner (1978)
114-700B-																																												
26R-1, 40-41 26R-1, 106-107 26R-2, 106-107 26R-CC 27R-1, 30-31			F S F	R R F	R	s	R		S R S			S R	s	S	s	s	R R	S				R	s c c	F R C	R	s	R R				S R	R	s		S R		F	F		FF	F	s	F F F	S
27R-1, 120–121 27R-CC 28R-1, 130–131 28R-2, 16–17 28R-2, 130–131		S	R F C	s			R		R S		R	S S						S S R			R R		A F F C C	C F A F			F C C F	F F S	R S		F R F				R	R		S R F		F R R	R F F		F R F	s s
28R-3, 130–131 28R-4, 130–131 28R-CC 29R-1, 24–25 29R-2, 10–11		S	F C F	s s	S		s			F F S		R S S		s						R	R R F R R		C A C A A	F R R F F			F F F R		C F F F	S F F	FFFFF							F F F		F R F R	F F F F		F F R	S R
29R-2, 122–124 29R-CC, 3–4 29R-CC 30R-1, 3.5 30R-1, 27–28			S	R	R	s s	R			S R							R	S R	s		F F F F F F	S	D A A A A	F F F F F	R	S R	F R R C	R	C R R F F	F F F C R	FFFFR				R		S	F F R	S	R	F F F		S R R F	s
30R-1, 107 30R-2, 7 30R-2, 27–28 30R-2, 97				s	R R		R R S	F R	S R			S R R		R				R	R	s	F F F F		A A C	R F F R	R	R	C R F		F F F	F	R R F				s			R R F		F R	R F		F R F	R F
30R-2, 120–121 30R-3, 27–28 30R-4, 27–28	s		S S R	F R	S	S	S		S		s	S				s	R	S F F			F F F		D D D	F F F	s	S	F R R		C C C	F	R			R	S		S	F F R		F R	R F		R R R	S

Note: Relative abundance and preservation codes are listed in the text

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# Table 3 (continued).

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Table 3	(continued).

Core, section, interval (cm)	Ash	Acanthosphaeridium reticulatum	Preservation of diatoms	Acanthodiscus spp.	Anaulus spp.	Arachnoidiscus spp.	Chaetoceros? clavigerus	Coscinodiscus argus	Coscinodiscus bulliens	Coscinodiscus cruxii	Coscinodiscus uralensis	Ethmodiscus spp. (fragments)	Eunotogramma spp.	Goniothecium spp.	Grunowiella gemmata	Grunowiella palaeocaenica var. palaeocaenica	G. palaeocaenica var. alternans	Hemiaulus altus	Hemiaulus? beatus	Hemiaulus? ciesielskii	Hemiaulus elegans var. intermedia	Hemiaulus fragilis	Hemiaulus aff. grassus	Hemiaulus inaequilaterus	Hemiaulus incisus	Hemiaulus kristoffersenii	Hemiaulus nocchiae	Hemiaulus? oonkii	Hemiaulus peripterus	Hemiaulus polymorphus var. charkovianus	Hemiaulus rossicus	Hemiaulus aff. speciosus	H. subacutus sensu Gombos (1977)	Hemiaulus? velatus	H. sp. F. Harwood (1988)	Hemiaulus sp. 1	Hemiaulus sp. 2	Hemiaulus sp. 3	Hemiaulus? sp. 4	Hemiaulus sp. 5	Hemiaulus sp.	Hemiaulus? sp.	Hyalodiscus ambiguus	Hyalodiscus sp.	Udontotropis cristata Odontotronis sp.
114-700B- 30R-5, 27–28 30R-5, 80 30R-6, 27–28 30R-CC 31R-1, 50–51	(+) - (+) - (+)		P P/M P/M P/M P					R F				R			R R R	F F F F R	R F R R	R				R	R R	R F F F		F R R	R		F F C F			R	F R	FFFFF				R F F	R		S R		F R R	R	3
31R-2, 50-51 31R-2, 96-97 31R-3, 125-126 31R-4, 149-150 31R-5, 18-19	- (+) + + -	R	P/M P/M G M P/M		s s		s	R F R F F		R R R	s	R		s	F R R R	F F F R R	R R F		R F	R R	R	S R	R	S R	s s	s	R		F F A C	S S R S	S S		s	R R R F R		R R S R	R S S		R	R	R R	S	R R	s	
31R-5, 115–116 31R-6, 17 31R-6, 18–19 31R-6, 32 31R-6, 63	(+) - - -		M P P P M			s		F R R F		R R		R	R	s	C C R	F R F R			F F C F C	R		S R R							F C A F C	R	R	R		F R F F	S R	R R	R F R		F F F		F	F	R		
31R-7, 13–14 31R-CC 32R-1, 124–125 32R-2, 15–16 32R-2, 84–85	(+) (+) (+) - (+)	R	P M P P P		R			F F F	R	S R		S R	R S		F F S F	F F S R	F R		R R R	R									C F A S C	R F F	R R S			C F F R	S	R R F	R R R F	R	S		S F	F C	R		s s
31R-1, 114–115 34R-1, 119 34R-1, 150 34R-2, 19–20 34R-3, 15–16 34R-3, 62	(+) (+) - (+) (+) (+)		P M P M P	R				F F F F F	s	R		S		s s	R R R	F F R R	R R F R		R R R R				R		R			s	F A A A A A	R R F	R R R R			F R R R R		F F F R F R F R	R F R R R		F R R R		S	F			

# Table 3 (continued).

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Core, section, interval (cm)	Paralia sulcata	Pseudopodosira bella	Pseudopodosira simplex	Pseudopyxilla russica	Pseudopyxilla tempereana	Pseudostictodiscus angulatus	Pterotheca aculeifera	Pterotheca evermanni	Pterotheca clavata	Pterotheca kittoniana	Rhizosolenia cretacea	R. hebetata var.	Sceptroneis ligulatus	Sceptroneis sp. 1	Sceptroneis sp.	Sphynctolethus hemiauloides	Stellarima microtrias	Stellarima primalabiata	Stephanopyxis marginata	Stephanopyxis discrepans	S. turris var. cylindrus	S. turris var. intermedia	Stephanopyxis schulzii	Stephanopyxis sp. 1	Stephanopyxis sp. 2	Stephanopyxis sp.	Trinacria deciusii	Triceratium gombosii	Triceratium mirabile	Triceratium schulzii	Trinacria aries	Trinacria conifera	Trinacria pileolus	Trinacria senta	Trinacria simulacroides	Trinacria sp.	Trinacria gracillima	Trochosira marginata	Trochosira aff. mirabilis	Trochosira radiata	Trochosira sp.	Xanthiopyxis aff. structuralis	Xanthiopyxis sp. 2	Xanthiopyxis sp.	Genus et species indet. (1) Fenner (1978)
114-700B- 30R-5,27-28 30R-5, 80 30R-6, 27-28 30R-CC 31R-1, 50-51	R S R	R R F	S F				R S S		R R	S R	R R F			R	R R R F	R	R	R F R F			A D D A	CFRFC					F R	s s s	CCCCC	F R R	F R R			R R				R F	s		R F	R		R R R R	R R
31R-2, 50-51 31R-2, 96-97 31R-3, 125-126 31R-4, 149-150 31R-5, 18-19	R R F R	F F R S R	R R R	S R		R	F S S R	s s	F S	S S R R S	R R R S	R	S R S R	F F F R	F R		R R	F F	s	s s s	D A D C A	C C C F	s	s		R	R F S		R C C		R S R			R R S	s s	R R	R F	R F F	R F R	R R F S	F	s		R R R R	R S R R
31R-5, 115–116 31R-6, 17 31R-6, 18–19 31R-6, 32 31R-6, 63	R F R	F F R	F R R	R R	s	R	R R R	s		R R R S	R F R		s	C F F R	R R R	R		FS	s		A A C A A	F R F		F R	R		R R R		F	F F S	R	C S		R R	S R	R		R S		R	R S			R R R S	s s
31R-7, 13–14 31R-CC 32R-1, 124–125 32R-2, 15–16 32R-2, 84–85	R S R	R R R	R S	s		R S	s s	s	s	S	F S R	s s	s	R F F	R R R	R	R	R R	s		A D A S D	C F F		R S	R	s	R R R			s	R S	F F	s	R F F	R S	F F		R S			R S	s	S S	F S	s
33R-1, 114–115 34R-1, 119 34R-1, 150	R		R						s	R R	R R		R	R R			R R	R R			A A A	F	0			R	F F			F F		R	R	F R								R			R R
34R-2, 19–20 34R-3, 15–16 34R-3, 62	R		R					R		R R	F R			R R	R R F	R		R			C C A	R R R				R R R	F R			R F R	R			R R								s		R R	

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# Table 4. Paleocene sedimentation rates.

	Sediment (cm/10	ation rate 000 yr)	
Hole	late Paleocene	early Paleocene	Reference
327	0.8	-	Barker, Dalziel, et al. (1977)
524B	2.6	2.3	Tauxe et al. (1984)
698A	1-1.5		Ciesielski, Kristoffersen, et al. (1988)
700B	2-2.5	1.5-2.3	Ciesielski, Kristoffersen, et al. (1988)
702B	1.2	_	Ciesielski, Kristoffersen, et al. (1988)

Instead, it has the typical late Paleocene marker species *Hemiaulus incurvus*, *Hemiaulus oonkii*, *Hemiaulus inaequilaterus*, *Hemiaulus kristoffersenii*, and *Hemiaulus subacutus* sensu Gombos (1977). The presence of *Hemiaulus? conicus* and the absence of *Triceratium gombosii* in this core suggests an age equivalent to somewhere between the upper part of the calcareous nannofossil "*F. tympaniformis* group" Zone and lower NP8. Thus, in this case, the diatoms support the zonal assignment provided by calcareous nannofossils. In addition, Cores 114-698A-10R and 114-698A-11R are clearly late Paleocene in age. They contain the same late Paleocene diatom marker species and also *T. gombosii*, which places these cores into calcareous nannofossil Zone NP8. The diatom-containing sediments thus stretch throughout a similar stratigraphic interval as in Hole 700B.

In Hole 700B (Fig. 6) late Paleocene diatoms are preserved in sediments ranging from the base of the calcareous nannofossil "F. tympaniformis group" Zone to the top of NP8. The occurrence of the LAD of H.? beatus and the last abundant occurrence of Hemiaulus rossicus together with the FADs of T. mirabile and Trochosira radiata between 292 and 293 m below seafloor (mbsf) (Fig. 6) may be due to a hiatus or to dissolution effects.

At Site 702 (Fig. 7) on the Islas Orcadas Rise diatoms were found only in upper Paleocene sediments (Cores 114-702B-31X and 114-702B-32X). In analogy to the stratigraphic ranges of diatom species determined in Hole 700B, the presence of H. peripterus, Hemiaulus sp. 5, H. inaequilaterus, Trinacria senta, and T. mirabile and the absence of H. incurvus, H.? oonkii, and H.? conicus in the uppermost diatom-containing sample (114-702B-31X-CC) imply an age equivalent to somewhere within the range of the calcareous nannofossil "F. tympaniformis group" Zone and planktonic foraminifer Zone P3. The lowermost diatom-containing sample (114-702B-32X-CC) falls below the FADs of H. inaequilaterus and T. mirabile and contains H. peripterus and H. sp. 2. Nocchi et al. (this volume) dated this sample from planktonic foraminifers as P3a; calcareous nannofossils (Crux, this volume) indicate the "F. tympaniformis group" Zone.

At Site 214 (Fig. 8) only the glauconite- and ash-bearing calcareous sands of Cores 214-38 through 214-39 contain poorly preserved Paleocene diatoms. Their very different assemblage composition from those encountered at the Leg 114 sites reflects a neritic environment. Species of the genera *Stephanopyxis* and *Melosira* are dominant, and *Sceptroneis gemmata*, *T. senta*, and *Trinacria simulacroides* as well as *Aulacodiscus* spp. and *Solium exsculptum* occur frequently. A depositional environment not too far from land is also suggested by the occurrence of glauconite and shallow-water mollusks, as well as the remains of higher plants and spicules of shallow-water sponges, in the HCl-insoluble residue. The presence of *H. inaequilaterus*, *H.* sp. 5, *T. mirabile*, and *T. senta* together with the absence of marker species such as *H. incurvus* and *T. gombosii* and typical early Paleocene species



Figure 5. Stratigraphic ranges of selected diatom species in ODP Hole 698A. Calcareous microfossil stratigraphy after Crux (this volume) and Nocchi et al. (this volume). The cored depths of the analyzed samples and the limiting samples for the zonal boundaries are calculated following Ciesielski, Kristoffersen, et al. (1988); for core-catcher samples the maximum possible depth range is presented.

places these sediments in the lower part of the upper Paleocene, equivalent to somewhere within planktonic foraminifer Zone P3 and the calcareous nannofossil "F. tympaniformis group" Zone.

This author intentionally neither applied existing diatom zonations for the Paleocene nor proposed a new zonation. The two existing zonations, of Gombos (1977) and de Prado and Ling (1981), are based in part on neritic species and therefore are not of wide regional applicability. Although study of the Leg 114 sites has added a wealth of data to the Paleocene diatom record, additional basic stratigraphic information is still needed to sort out the diachronous datums. As shown in this study, the upper Paleocene FADs of the diatoms *H. incurvus*, *H. inaequilaterus*, *T. gombosii*, and *T. mirabile* as well as the LAD of *Hemiaulus* sp. 1 occur in the same stratigraphic position at all of the studied ODP and DSDP sites and therefore could be useful for stratigraphic correlation between South Atlantic and Indian Ocean sediments.

# TAXONOMY

In addition to the literature on Paleocene diatoms, the original samples of Grunow from Simbirsk and Franz Josefs Land were examined to ensure correct species identification. Furthermore, a large number of samples from the Fur Formation (= Mo-clay), Denmark, were studied, most of which were sent by K. Perch-



Figure 6. Stratigraphic ranges of selected diatom species in ODP Hole 700B. Paleomagnetic reversal record after Hailwood and Clement (this volume). Sample depths presented as in Figure 5.

Nielsen, while additional samples were collected by the author. The slides reviewed from Franz Josefs Land are W coll. Grunow 2247 a, b, c, and d and W. coll. Grunow 2248 a, b, c, and d. The slides from the Simbirsk deposits are W coll. Grunow 1570 c and BM 46288. The abbreviation W indicates that the slide is from the collection of the Naturhistorisches Museum, Vienna, Austria; the abbreviation BM, from the collection of the British Museum (Natural History), London, U.K.

For those species for which the original species description is inadequate (many of these species descriptions date from the late 19th century) or for those for which new taxonomic details were observed, a full description or additional taxonomic remarks are given. Otherwise, just the author and reference to the original description and illustration are given. For some species later, more accessible and more extensive descriptions and better illustrations are also cited.

Holotypes of species newly defined in this paper are deposited in the "Hustedt Collection" of the "Alfred Wegener Institut für Polarforschung," Bremerhaven, FRG. Following the listings in the "Index Herbariorum," this collection is referred to as the "Hustedt Collection, BRM."

> Genus ACANTHODISCUS Pantocsek, 1892 Acanthodiscus spp.

Only very rare resting spores belonging to this genus were found.

# Genus ANAULUS Ehrenberg, 1844 Anaulus sp.

Specimens belonging to this genus occur only rarely.

Genus ARACHNOIDISCUS Deane ex Shadboldt, 1852 Arachnoidiscus spp.

Only single-valve fragments of species belonging to this genus were found.

> Genus AULACODISCUS Ehrenberg, 1844 Aulacodiscus spp.

Only incomplete specimens of this genus were found at DSDP Site 214.

Genus CHAETOCEROS Ehrenberg, 1844 Chaetoceros clavigerus Grunow, 1884

Description. Grunow, 1884, p. 96, pl. 5(E), fig. 51.

Genus COSCINODISCUS Ehrenberg, 1838 Coscinodiscus argus Ehrenberg, 1838

Description. Hustedt, 1930, pp. 422–424, fig. 226; Hasle and Sims, 1986a, pp. 307–308, 310, 312, 317.

Coscinodiscus bulliens A. Schmidt, 1878 in Schmidt et al., 1874-(Pl. 9, Fig. 6)

Description. Schmidt et al., 1874-, pl. 61, figs. 11, 12.

#### PALEOCENE DIATOMS





# Coscinodiscus cruxii sp. nov. (Pl. 11, Fig. 26)

**Description.** The valve outline is circular. The valve is nearly flat, and curved only near the margin. There are six areolae in 10  $\mu$ m in the central part. The areolae decrease from the center toward the margin and are arranged in radial rows. An irregularly shaped, elongated hyaline area extends from the center to about halfway toward the margin. No processes could be observed in the light microscope.

Differential diagnosis. The elongate hyaline area is characteristic of this species and differentiates it from all similar ones.

Holotype. Specimen illustrated as Plate 11, Figure 26, from DSDP Sample 327A-7-2, 100-101 cm. The holotype is deposited in the Hustedt Collection, BRM.

This species is named after Dr. Jason Crux, in memory of good cooperation during ODP Leg 114.

# Genus ETHMODISCUS Castracane, 1886 Ethmodiscus spp.

Fragments of very large *Ethmodiscus*-like valves were listed under this genus.

Genus EUNOTOGRAMMA Weisse, 1854 Eunotogramma sp. (Pl. 9, Fig. 5)

**Remarks.** This species differs from *Eunotogramma variabile* Grunow by its coarser areolation and by the presence of a large hyaline area in each of the valve segments.

# Genus GONIOTHECIUM Ehrenberg, 1841

Valves of specimens belonging to this genus are very rare and were not identified to the species level. These species are interpreted as resting spores.

# Genus GRUNOWIELLA Van Heurck, 1892 Grunowiella gemmata (Grunow) Van Heurck (Pl. 11, Fig. 13)

**Description.** Grunow, 1866, p. 146; Grunow, 1884, p. 57, pl. 2, figs. 7, 8; Van Heurck, 1896, p. 332, fig. 88.

**Remarks.** Besides the species G. gemmata, in which the areolae on each side of the pseudoraphe oppose each other, a variety of this species was found (Pl. 11, Fig. 12) with the areolae placed intermittently. In Tables 2 and 3 both species are listed together under the name G. gemmata.

Grunowiella palaeocaenica Jousé, 1951 (Pl. 11, Figs. 1-4)





Figure 8. Stratigraphic ranges of selected diatom species at DSDP Site 214. Planktonic foraminifer zones after McGowran (1974) and Berggren et al. (1974); calcareous nannofossil zones after Gartner (1974) and Bukry (1974). Sample depths presented as in Figure 5.

**Remarks.** The valve is linear-lanceolate and heteropolar. One pole is slightly capitate, and the valve gradually narrows toward the other broadly rounded or truncate pole. The valve length can vary considerably. Most specimens are between 30 and 110  $\mu$ m long. The width of the valve in the central part is about 5  $\mu$ m. A narrow axial area separates two apical rows of areolae with six to seven areolae in 10  $\mu$ m. The capitate pole has a round to subround apical pore field, the pseudocellus. Between its straight base and the regular rows of areolae there is one labiate process. Because of these characteristics and because there is only one row of areolae between the axial area and margin, this species is included in the genus *Grunowiella*.

# Grunowiella palaeocaenica Jousé var. alternans var. nov. (Pl. 11, Fig. 11)

Description. The valve outline is narrowly lanceolate. The pole at which the apical pore field is located is slightly capitate. The other

pole is rounded. The narrow axial area separates two apical rows of areolae. The number of areolae is six to seven in 10  $\mu$ m.

**Differential diagnosis.** This variety differs from *G. palaeocaenica* var. *palaeocaenica* by the position of the areolae placed intermittently across the axial area rather than in pairs.

Holotype. Specimen illustrated as Plate 11, Figure 11, from ODP Sample 114-700B-34R-3, 15-16 cm. The holotype is deposited in the Hustedt Collection, BRM.

# Genus HEMIAULUS Heiberg, 1863, nom. cons.

A number of electron microscopic studies by Ross (1972), Ross et al. (1977), Hendey and Sims (1984), Hasle and Sims (1985), Sims (1986), and Ross and Sims (1980, 1985, 1987) were concerned with fossil and recent representatives of the subfamily Hemiauloideae Jousé, Kisselev, and Poretzkii. These studies of the complex of species of the Biddulphiaceae with linking spines have led to definitions of some new genera and the reestablishment of others. The new definitions of genera are mainly based on differences in the pseudo-celli, linking spines, and areolation and on the presence or absence of these. The terminology introduced by the preceding authors is followed here. Previously, following Schütt (1896) and Hustedt (1930), all of these genera-depending on their symmetry and number of elevations—had been included either in the genus *Hemiaulus* Ehrenberg or the genus *Trinacria* Heiberg.

Only limited studies with the scanning electron microscope (SEM) could be included in this study. Therefore, the new definitions of species are based on light-microscopic observation. All newly defined, *Hemiaulus*-related species have been placed in the genus *Hemiaulus* Heib. If the observations with the light microscope suggested that placement in a related genus, including *Riedelia* sensu Schrader and Fenner (1976), was more appropriate, the assignment to *Hemiaulus* is queried.

Hemiaulus affinis Grunow in Van Heurck, 1883 (Pl. 1, Fig. 10)

Description. Van Heurck (1883), pl. 106, figs. 10-11.

Hemiaulus altus Hajós, 1975 (Pl. 4, Fig. 3)

Description. Hajós (1975), p. 931, pl. 5, figs. 17-19.

Hemiaulus? beatus sp. nov. (Pl. 2, Figs. 1-3)

**Description.** Only the long, slender apical elevations of this species were found. They are straight to slightly curved and carry four narrow ridges that widen slightly to form bladelike ridges in the upper part. The ends of the ridges form the small spines at the top of the elevations. Between two such ridges one row of large areolae is present, characteristically disrupted once or twice by a nonareolated part. There are six to seven areolae in 10  $\mu$ m. Only fragments are known for the remainder of the valve, but these indicate that it is finely areolated.

**Differential diagnosis.** This species differs from *Hemiaulus? ciesiel-skii* by its large and well-aligned areolae on the apical elevations, which are like beads on a thread.

Holotype. Specimen illustrated as Plate 1, Figure 3, from ODP Sample 114-700B-31R-6, 18-19 cm. The holotype of this species is deposited in the Hustedt Collection, BRM.

## Hemiaulus? ciesielskii sp. nov. (Pl. 1, Figs. 5-6)

**Description.** The long, curved elevations of this species have about six rows of widely spaced areolae (four in 10  $\mu$ m) separated by longitudinal ribs. The elevations narrow at the top and end in a round platform surrounded by short spines. The valve part adjacent to the elevation is densely covered with rows of fine pores (14–15 in 10  $\mu$ m) radiating from the base of the elevation. The observed length of the elevations varies between 60 and 150  $\mu$ m.

**Differential diagnosis.** This species differs from *Rhizosolenia cretacea* by the size and arrangement of its areolae and the ring of small spines at the top of the elevation.

Holotype. Specimen illustrated as Plate 1, Figure 6, from ODP Sample 114-698A-10R-1, 129-130 cm. The holotype is deposited in the Hustedt Collection, BRM.

This species is dedicated to Dr. Paul Ciesielski, co-chief scientist for ODP Leg 114.

# Hemiaulus? conicus sp. nov. (Pl. 6, Figs. 3-6, 11; 1-2?)

**Description.** The apical elevations of this species are strongly elongate and conical, broadening toward the top, where they end in a platform flanked on one side by a broad, flat spine. As such long and slender parts of the diatom valve are prone to breakage, a complete valve was never found. The wide part of the apical elevation is areolated. The small areolae are arranged in parallel, longitudinal rows or are distributed more irregularly. In the same samples, where this apical elevation occurs, small circular, flat or slightly domed valves are also present (Pl. 6, Figs. 1–2). They are densely covered with irregularly distributed areolae of nearly equal size (approximately eight areolae in 10  $\mu$ m). Further study is needed to show whether these two valve types belong to one frustule or whether their identical stratigraphic ranges are coincidental. Until the relationship of these two types is proven, this species is left in the genus *Hemiaulus*.

Differential diagnosis. No similar species is known from the literature.

Holotype. Specimen illustrated as Plate 6, Figure 3, from ODP Sample 114-700B-28R-1, 130-131 cm. The holotype is deposited in the Hustedt Collection, BRM.

Hemiaulus elegans var. intermedia Grunow, 1884 (Pl. 4, Figs. 5, 7)

Description. Grunow, 1884, p. 67, pl. 2(B), figs. 51-52.

Hemiaulus? fragilis Grunow, 1884 (Pl. 1, Fig. 2)

Original description. A. Grunow (1884), p. 62, no illustration.

Synonym. Rhizosolenia sp. A, Harwood (1988), p. 87, pl. 19, fig. 9.

**Description.** The straight apical elevations of this species are relatively narrow and delicate and end at their top in three short narrow spines. The elevations are finely punctate. The puncta are arranged irregularly on the flattened sides of the elevation. Also, the central part of the valves seems to be finely punctate. Because the valves are so delicate, a complete one was never found.

**Remarks.** This species does not seem to belong to the genus *Hemiaulus* (Ehr.) Heiberg, but rather to the genus *Riedelia* sensu Schrader and Fenner (1976).

Hemiaulus aff. grassus Fenner, 1984 (Pl. 3, Figs. 3-6)

Description. Fenner, 1984, p. 332, pl. 1, fig. 7.

Hemiaulus (Corinna) elegans var. intermedia Grunow, 1884 (Pl. 4, Figs. 5, 7)

Description. Grunow, 1884, pp. 66-67, pl. 2(B), figs. 51-52.

Hemiaulus inaequilaterus Gombos, 1977 var. (Pl. 5, Figs. 5-9; Pl. 7, Figs. 3, 10; 4?)

Description. Fenner, 1985, p. 731, pl. 9, figs. 3-4.

**Remarks.** The variability of this species is large. Specimens are unsymmetrical in respect to the diameter and length of their apical elevations or the number of valve segments and to the position of the largest central segment. In addition, specimens that are nearly or fully symmetrical were found. Whether these different morphological types have differing stratigraphic ranges has yet to be determined.

> Hemiaulus incisus Hajós, 1976 (Pl. 10, Fig. 9)

Description. Hajós, 1976, p. 829, pl. 23, figs. 4-9.

Hemiaulus incurvus Shibkova in Krotov and Shibkova, 1959

Description. Krotov and Shibkova, 1959, p. 124, pl. 4, fig. 8.

Hemiaulus kristoffersenii sp. nov. (Pl. 6, Figs. 7, 13)

Synonym. Hemiaulus polymorphus var. morsianus sensu Mukhina 1976, p. 155, pl. 1, figs. 4-6, non Grunow, 1884. **Description.** The valve outline is lanceolate. At both apices a long, slender elevation projects upward. At its flat top a straight, triangular spine is located on the proximal side and a small spine at the distal side. The central part of the valve is divided into lobes by a number of sulci, involving the basal part of the apical elevations also. The central lobe is the largest and highest one, carrying in its center the labiate process. Valve face and mantle are densely covered with areolae arranged in radial rows. There are three to four areolae in 10  $\mu$ m. On the elevations areolation is sparse and irregular. A marginal ridge separates the valve face from the mantle and extends as a narrow keel to the top of the apical elevations. The high marginal ridge is characteristically structured by riblike thickenings.

**Differential diagnosis.** This species is very similar to *Hemiaulus lobatus* Greville, but differs from it by its irregularly areolated elevations and their prominent spine.

Holotype. Specimen illustrated as Plate 6, Figure 13, from DSDP Sample 75-524B-4-3, 87-89 cm. This holotype is deposited in the Hustedt Collection, BRM.

This species is dedicated to Dr. Yngve Kristoffersen, co-chief scientist on ODP Leg 114.

Hemiaulus aff. lobatus Greville, 1865

Description. Greville, 1865, p. 29, pl. 3, fig. 9.

# Hemiaulus nocchiae sp. nov. (Pl. 10, Figs. 10-11)

**Description.** The valve outline is lanceolate. At both apices rise long, straight elevations, subcircular in cross section. The valve face is segmented by deep sulci into lobes, of which the central one is the highest and carries the labiate process in its center. Shallow sulci are found at the base of the apical elevations and cause their lobed appearance. Valve face, mantle, and apical elevations are densely areolated. The areolae are arranged in lines radiating from the center. There are five to six areolae in 10  $\mu$ m, and the size of the areolae does not decrease toward the top of the apical elevations. Along each side of the valve face a shallow, marginal ridge is present, extending up the proximal side of the apical elevations and merging with the long straight spine on top. This spine can reach lengths of 20  $\mu$ m.

**Differential diagnosis.** This species differs from *Hemiaulus* sp. 5 by its finer areolation and the approximately equal size of the areolae on the valve face, mantle, and apical elevations. It differs from *Hemiaulus inaequilaterus* by its symmetrical segmentation, symmetrical apical elevations, and denser areolation.

**Holotype.** Specimen illustrated as Plate 10, Figure 11, from ODP Sample 114-700B-30R-4, 27-28 cm. The holotype is deposited in the Hustedt Collection, BRM.

This species is named after Dr. Marissa Nocchi, my colleague in the micropaleontology laboratory on ODP Leg 114.

# Hemiaulus? oonkii sp. nov. (Pl. 1, Figs. 11-14)

**Description.** The valve outline is oval. The mantle is relatively high, especially in specimens with a short apical axis, and shows a circumferential basal incision. The apical elevations are long and slender, commonly slightly widened in the middle part and narrowing in their upper part, which ends in two short spines. The central valve is covered with areolae arranged in radial rows (seven to eight areolae in 10  $\mu$ m). The tapering upper half of the elevations is only sparsely areolated.

**Differential diagnosis.** This species is similar to *Hemiaulus incisus* Hajós, but differs from it by the shape and areolation of its elevations. *H.? oonkii* differs from *Hemiaulus kittonii* Grunow by its coarser areolation and the structure of its elevations.

Holotype. Specimen illustrated as Plate 1, Figure 11, from ODP Sample 114-698A-11R-CC.

**Paratype.** Specimen illustrated as Plate 1, Figure 12, from ODP Sample 114-698A-11R-CC. The holotype and paratype are deposited in the Hustedt Collection, BRM.

This species was named after the captain of the *JOIDES Resolution*, Edwin G. Oonk, who ensured a safe journey during ODP Leg 114 under extreme weather conditions.

# Hemiaulus peripterus Fenner, 1984 (Pl. 7, Fig. 9)

Synonym. ?Periptera capra sensu Weisse, 1854, pl. 3, fig. A.

Description. Fenner, 1984, p. 332, pl. 1, figs. 8-9.

**Remarks.** The apical elevations are relatively thin and long and seem to break very easily. The top of the apical elevations carries a straight long spine, below the top of which some pores or areolae can be recognized. In well-preserved specimens a comblike structure, as in *Hemiaulus caracteristicus*, can be seen on the mantle.

Hemiaulus polymorphus Grunow var. charkovianus Jousé, 1955 (Pl. 8, Fig. 8-10)

Description. Jousé, 1955, p. 97, pl. 5, figs. 4-5.

**Remarks.** Under this name are listed specimens that are practically identical to *Hemiaulus rossicus*, differing from it only by the transverse costae widening at their base in both apical directions.

Hemiaulus rossicus Pantocsek, 1889 (Pl. 8, Figs. 11-14)

Synonyms. Hemiaulus polycystinorum Ehr. var.? simbirskiana Grunow, 1884, p. 65, pl. 2(B), figs. 44–45. Hemiaulus antarcticus Ehr? sensu Weisse, 1855, p. 242, pl. 1, fig. 18, non: Hemiaulus rossicus sensu Strelnikova (1974), p. 102, pl. 42, figs. 1–18.

**Description.** The valve outline is narrowly elliptical. The central part of the valve is segmented by deep transverse costae, which at their base are bent toward the apices, causing the characteristic hooklike appearance of the costae in girdle view. The number of areolae is seven to eight in 10  $\mu$ m. A labiate process is located slightly off center. The apical, cylindrical elevations are relatively short (not exceeding valve length) and commonly are of unequal length. Their tops are flat, with up to three marginal spines projecting upward. Some of the valves have an asymmetric outline (narrower at one apex than at the other) and segmentation (the central segment not always occupying exactly the middle part of the valve), so that the number or size of the lateral segments differs.

This species differs from the Late Cretaceous Hemiaulus polycystinorum Ehr. var. brevicornis Jousé (synonym: H. rossicus sensu Strelnikova, 1974) by its coarser areolation. Also found in the same samples are specimens in which the costae widen at their base in both apical directions. These may just be a variety of H. rossicus, but they have been listed here as Hemiaulus polymorphus var. charkovianus Jousé (see the preceding). Whether they are a separate species and have a stratigraphic range different from that of H. rossicus has yet to be verified.

> Hemiaulus aff. speciosus Jousé, 1951 (Pl. 8, Figs. 1-3)

Description. Jousé, 1951a, p. 55, pl. 3, fig. 5.

Hemiaulus subacutus sensu Gombos, 1977 (Pl. 8, Figs. 5-6)

Description. Gombos, 1977, p. 594, pl. 17, figs. 5-8.

Hemiaulus? velatus sp. nov. (Pl. 2, Figs. 4-8, 11)

**Description.** Along the slightly curved apical elevations run hyaline ridges, which form little spinelike protrusions at the top. In the upper part of the elevations two of these ridges widen to winglike features. Where the elevation is narrow, generally only one row of pores is found between these ridges. Where the ridges widen, the number of rows of pores also increases to two or even three. Depending from which side the elevation is observed, the winglike extensions may or may not be evident. From the top, in the middle of the widest part, a slit (up to 10  $\mu$ m long) divides the outer shell on one side. However, the slit does not open into the valve interior. It is occluded by a thin siliceous membrane perforated by pores. A complete valve was never found.

Differential diagnosis. No similar species was found in the literature. Holotype. Specimen illustrated as Plate 2, Figure 5, from DSDP Sample 327A-7-2, 100-101 cm.

**Paratype.** Specimen illustrated as Plate 2, Figure 8, from ODP Sample 114-700B-31R-CC. The holotype and paratype are deposited in the Hustedt Collection, BRM.

# Hemiaulus sp. F. Harwood, 1988 (Pl. 4, Fig. 10)

Description. Harwood, 1988, p. 84, pl. 13, fig. 13.

### Hemiaulus sp. 1 (Pl. 7, Figs. 5, 11-12)

**Description.** Only specimens with elevations carrying a robust, straight, upwardly directed spine were found. The elevations do not seem to have pores or areolae.

# Hemiaulus sp. 2 (Pl. 6, Figs. 8-9)

**Description.** The species listed under this name has straight, areolated elevations, broadening distinctly at their base and carrying a very robust spine at their top.

# Hemiaulus sp. 3 (Pl. 2, Fig. 12)

**Description.** The valve outline is lanceolate. The apical elevations are straight and the valve face nearly flat, which gives the valves of this species a rectangular appearance in girdle view. The valve is densely areolated, with six to eight areolae in 10  $\mu$ m. Toward the top of the elevations the size of the areolae decreases. The top is flat, and carries on its proximal side a conical spine. The margin has a basal incision.

# Hemiaulus? sp. 4

**Description.** This species is similar to *Hemiaulus? ciesielskii*, but differs from it by being more robust and having larger areolae than *H*.? *ciesielskii*.

# Hemiaulus sp. 5 (Pl. 4, Figs. 1, 8-9)

**Description.** The valve outline is lanceolate. The central part of the valve is segmented by deep sulci. The robust apical elevations end in a flat top that carries a large, slightly curved spine at its proximal side. The areolation is coarse: three to four areolae in 10  $\mu$ m.

Genus HYALODISCUS Ehrenberg, 1845

Hyalodiscus ambiguus (Grunow) Tempère et Peragallo, 1889-1895

Description. Grunow, 1879, p. 689, pl. 21, fig. 4 (as Podosira ambigua).

**Remarks.** Marginal processes (approximately 40 in one valve) were observed with SEM. These processes are arranged in one circle along the margin.

# Genus MELOSIRA Agardh, 1824 Melosira sp. 1

**Description.** This species is similar to *Melosira architecturalis*, but differs from it by having a central groove within the central hyaline area. This species is also found in early Eocene age sediments of the North Atlantic.

Genus ODONTOTROPIS Grunow, 1884 Odontotropis cristata (Grunow in Van Heurck) Grunow, 1884

Description. Grunow, 1884, p. 59, pl. 5(E), fig. 58.

#### Odontotropis sp.

Fragments of species belonging to this genus were found, of which only *Odontotropis cristata* could be determined to the species level. The rest is listed as *Odontotropis* sp.

Genus PARALIA Heiberg, 1863

Paralia concentrica Schmidt, 1892 in Schmidt et al., 1874-

Description. Schmidt et al., 1874-, pl. 176, figs. 47-49.

# Paralia sulcata (Ehr.) Cleve, 1873

**Description.** Grunow, 1884, p. 41, pl. 5, figs. 34–36. **Remarks.** No subspecies, varieties, or formae were differentiated. Genus PSEUDOPODOSIRA Jousé, 1949 Pseudopodosira bella Posnova et Gleser in Gleser and Posnova,

1964 (Pl. 1, Fig. 3)

Description. Gleser and Posnova, 1964, pl. 61, fig. 1.

Pseudopodosira simplex (Jousé) Strelnikova, 1974

Description. Strelnikova, 1974, pp. 51-52, pl. 2, figs. 10-11.

Genus PSEUDOPYXILLA Forti, 1909 Pseudopyxilla russica (Pantocsek) Forti, 1909

Description. Forti, 1909, p. 14, pl. 1, fig. 13.

Pseudopyxilla tempereana Forti, 1909 (Pl. 9, Fig. 3)

Description. Forti, 1909, pp. 28-29, pl. 1, fig. 11

Pseudopyxilla sp. (Pl. 9, Fig. 4)

Genus PSEUDOSTICTODISCUS Grunow, 1882 in Schmidt et al., 1874– Pseudostictodiscus angulatus Grunow, 1882 in Schmidt et al.,

1874–

Synonym. Pseudostictodiscus angulatus var. Grunow, 1882 in Schmidt et al., 1874-, pl. 74, figs. 24, 25.

Description. Schmidt et al., 1874-, pl. 74, figs. 26-30; Witt, 1886, pp. 165-166, pl. 6, fig. 15.

Pseudostictodiscus picus Hanna, 1927 (Pl. 7, Fig. 1)

Description. Hanna, 1927, p. 28, pl. 3, figs. 1-4.

Genus PTEROTHECA Grunow in Van Heurck, 1882 Pterotheca aculeifera (Grunow) Van Heurck, 1896

Description. Van Heurck, 1896, p. 430, fig. 151.

Pterotheca aculeifera var. spinosa Jousé, 1951 Description. Jousé, 1951b, p. 38, pl. 4, fig. 2.

Pterotheca clavata Strelnikova, 1974

Description. Strelnikova, 1974, pp. 115-116, pl. 57, fig. 35.

Pterotheca evermanni Hanna, 1927 (Pl. 2, Fig. 13)

Description. Hanna, 1927, p. 31, pl. 4, fig. 6.

Pterotheca kittoniana Grunow in Van Heurck, 1882 (Pl. 8, Fig. 7)

Synonym. Cladogramma simplex Hajós and Stradner in Hajós, 1975, p. 928, pl. 4, figs. 7, 8; pl. 28, fig. 5.

Description. Van Heurck, 1882, pl. 83, figs. 10, 11; pl. 83 bis, fig. 9-11.

**Remarks.** The two valves of this species are very different. One has a high mantle and siliceous ribs running from the base to the top of the mantle. This is the valve always illustrated under the name *P. kittoniana*. The other valve is only slightly convex. Its only structure is a spine, which rises from the center, and hyaline, bifurcating ribs, which radiate somewhat irregularly from the center toward the margin. In complete frustules this valve lies slightly sunk into the margin of the other valve. Because these two valves are so different they have not been recognized as valves of the same species. Consequently, they were even assigned to completely different genera: *Cladogramma* Ehr. and *Pterotheca* Grunow.

This species is known to range from the Late Cretaceous into the earliest Eocene.

# Pterotheca sp. 1 (Pl. 2, Fig. 10)

Description. This species resembles *Pterotheca aculeifera*, but differs from it by its lack of ribs.

# Genus RHIZOSOLENIA Ehrenberg, 1841 Rhizosolenia cretacea Hajós et Stradner in Hajós, 1975 (Pl. 1, Figs. 4, 9)

**Description.** Hajós, 1975, p. 929, pl. 7, fig. 1; pl. 31, figs. 4–6. **Remarks.** A complete valve of this species was never found. Only the curved apical elevations were found, which end in a characteristic, short, broad spine, which is bifurcate and slightly curved. The elevation is always curved. Its surface is structured by thick hyaline ribs (about eight), running from its base to the top, and furrows in between. SEM studies revealed a fine network of pores in each furrow. These pores are arranged in longitudinal rows. There are about 45 pores in 10  $\mu$ m. The pores of neighboring rows are not positioned opposite each other, but are offset to create a quincuncial pattern.

# Rhizosolenia hebetata Bailey, 1856 var. (Pl. 1, Figs. 1, 8)

Description. Bailey, 1856, p. 5, pl. 1, figs. 18-19.

**Remarks.** Scattered occurrences of robust fragments of a long straight spine and the uppermost part of the valve (calyptra) with a few coarse pores were found. There is no indication that the occurrence of these specimens is due to contamination. This observation thus extends the known range of the genus *Rhizosolenia* into the late Paleocene.

Genus SCEPTRONEIS Ehrenberg, 1844 Sceptroneis ligulatus Fenner, 1978

Synonym. Genus et species indet. (C) Gombos, 1977, p. 599, pl. 12, fig. 8.

Description. Fenner, 1978, p. 531, pl. 31, figs. 8-10.

## Sceptroneis sp. 1 (Pl. 11, Figs. 9-10)

**Description.** The valve outline is lanceolate. The pole at which the apical pore field is located is capitate; the other pole is rostrate. The narrow axial area divides the transapical rows of areolae, which in the central part of the valve consists of two areolae on each side. There are six areolae in 10  $\mu$ m and five to six transapical rows in 10  $\mu$ m.

Genus SOLIUM Heiberg, 1863 Solium exsculptum Heiberg, 1863

Description. Heiberg, 1863, p. 52, pl. 4, fig. 10; Ross and Sims, 1987, pp. 272-276, pl. 1, figs. 1-6; pl. 12, figs. 86-88.

Genus SPHYNCTOLETHUS Hanna, 1927 Sphynctolethus hemiauloides Sims, 1986 (Pl. 4, Figs. 2, 4)

**Description.** Sims, 1986, pp. 246–250, figs. 16–22, non figs. 64 and 65. The latter two illustrations probably show different species, which lack the patches of fine pores in the central segment of the mantle.

Genus STELLARIMA Hasle et Sims, 1986 Stellarima microtrias (Ehr.) Hasle et Sims, 1986

Description. Hasle and Sims, 1986b, p. 111, figs. 18–27; Grunow, 1884, p. 82, pl. 4, figs. 3–6.

# Stellarima primalabiata (Gombos) Hasle et Sims, 1986b

**Description.** Gombos and Ciesielski, 1983, p. 606, pl. 9, figs. 1–8. **Remarks.** The valve outline is circular. The valve is slightly convex. One labiate process is present slightly off center. The areolae are arranged in radiating rows forming fascicles and a secondary pattern of curved tangential lines. There are seven to eight areolae in 10  $\mu$ m.

> Genus STEPHANOPYXIS Ehrenberg, 1844 Stephanopyxis discrepans Hanna, 1927 (Pl. 10, Fig. 1)

Description. Hanna, 1927, p. 33, pl. 4, figs. 10-11; Hajós, 1975, p. 925, pl. 2, figs. 5-6.

Stephanopyxis ferox (Grev.) Ralfs in Pritchard, 1861 Description. Grunow, 1884, p. 37 (89).

Stephanopyxis lavrenkoi Jousé in Proshkina-Lavrenko, 1949 Description. Proshkina-Lavrenko, 1949, p. 40, pl. 10, fig. 9.

> Stephanopyxis marginata Grunow, 1884 (Pl. 10, Fig. 5)

Description. Grunow, 1884, p. 38 (90), pl. 5(E), fig. 17.

Stephanopyxis schulzii Steinecke in Schulz, 1935 (Pl. 10, Fig. 6)

Description. Fenner, 1985, p. 739, pl. 14, fig. 6.

Stephanopyxis turris var. cylindrus Grunow, 1884 Description. Grunow, 1884, p. 87, pl. 5(E), figs. 9, 14.

Stephanopyxis turris var. intermedia Grunow, 1884 Description. Grunow, 1884, p. 88, pl. 5(E), figs. 15–16.

> Stephanopyxis sp. 1 (Pl. 10, Fig. 3)

Stephanopyxis sp. 2 (Pl. 10, Fig. 2)

# Genus TRICERATIUM Ehrenberg, 1839

A separation of the genera *Triceratium*, *Trigonium*, and related genera was not done in this study, but all triangular species that do not belong in the genus *Trinacria* were listed under *Triceratium*.

Small, planktonic triangular species are common in the Paleocene diatom assemblages. For the time being, these species, which lack a pseudocellus at their apices and have no labiate process in the central part of the valve but have interstitial pores, are left within the genus *Triceratium*, although they probably represent a new genus. Detailed taxonomic studies with the SEM are necessary to define this group clearly. Of these small "*Triceratium*" species *T. mirabile* is known from the Paleocene diatomaceous deposits of the USSR. *T. gombosii* also seems to be restricted to the Paleocene and may have evolved from *T. mirabile*. But *T. schulzii* and *T. deciusii* have been described only from Late Cretaceous deposits up to now. The holotypes have not yet been studied, and it must remain open whether the species identifications in this study are correct and whether these two species do range into the Paleocene.

Triceratium areolatum f. minor Schmidt, 1890 in Schmidt et al., 1874-

Description. Schmidt et al., 1874-, pl. 150, fig. 23.

Triceratium cellulosum Greville, 1861

Synonym. Triceratium cf. tesselatum sensu Gombos (1977), p. 598, pl. 37, figs. 1–2.

Description. Greville, 1861, p. 44, pl. 4, fig. 14.

Triceratium gombosii sp. nov. (Pl. 1, Fig. 7; Pl. 9, Figs. 1-2)

Synonym. Triceratium gracillimum Hustedt sensu Gombos, 1977, p. 598, pl. 38, fig. 5.

**Description.** The valves are small and triangular, with slightly concave, crenate, undulated sides. The corners are separated from the central part of the valve by slightly curved sulci. The areolae are arranged in radial rows in some valves, leaving free a central hyaline area. There are 10-11 areolae in  $10 \ \mu$ m. No labiate process is present.

Differential diagnosis. This species differs from all other *Triceratium* species that have undulated sides (e.g., *T. crenulatum* Grove and Sturt and *T. sundbyense* Hustedt) by its small size and finer areolation.

Holotype. Specimen illustrated as Plate 9, Figure 1, from ODP Sample 114-698A-11R-CC. The holotype is deposited in the Hustedt Collection, BRM.

# Triceratium mirabile Jousé in Proshkina-Lavrenko, 1949 (Pl. 9, Figs. 7-10)

**Description.** Proshkina-Lavrenko, 1949, p. 166, pl. 62, fig. 5. **Remarks.** This small *Triceratium* species has a characteristic outline, created by the bulging, raised, central part of the valve. The central part carries one subcentral spine, which is usually broken off. At each apex a slitlike pore is present. There are no labiate processes. The central part and apical projections are separated by a sulcus. The areolae are arranged radially.

> Triceratium schulzii Jousé, 1949 (Pl. 9, Figs. 17-21)

Description. Jousé, 1949, p. 70, pl. 1, fig. 8; Jousé in Proshkina-Lavrenko, 1949, p. 161, pl. 58, fig. 3.

Triceratium wittii Schmidt, 1888 in Schmidt et al., 1874– Description. Schmidt et al., 1874–, pl. 93, fig. 2b.

Genus TRINACRIA Heiberg, 1863 Trinacria aries Schmidt, 1886 in Schmidt et al., 1874– Description. Schmidt et al., 1874–, pl. 96, figs. 14–17.

Trinacria conifera (Brightwell) Grunow, 1884

Description. Grunow, 1884, p. 68; Brightwell, 1856, p. 274, pl. 17, fig. 6.

Trinacria deciusii Hanna, 1927 (Pl. 9, Figs. 11-16)

Description. Trinacria deciusii Hanna, 1927, p. 36, pl. 5.

**Remarks.** This small triangular species has slightly concave sides. Sulci separate the raised central and apical portions of the valve face. The areolae are arranged in radial rows decreasing in size near the apices. Between the areolae, interstitial pores are present. There is one subcentral spine and no labiate process. There are no connecting spines at the raised apices. Thus, this species probably does not belong in the genus *Trinacria* but is left there until more accurate taxonomic studies are done. In the original description Hanna also did not describe or illustrate such spines.

> Trinacria senta (Witt) Sims et Ross, 1988 (Pl. 7, Fig. 8)

Description. Witt in Schmidt et al., 1874-, pl. 150, figs. 2-6; Sims and Ross, 1988, pp. 295-297, pl. 8; pl. 13, figs. 91-92.

Trinacria pileolus (Ehr.) Grunow, 1884

Description. Grunow, 1884, p. 68, pl. 2(B), figs. 59, 60.

Trinacria simulacroides Pantocsek, 1892

Description. Pantocsek, 1892, pl. 28, fig. 417; Pantocsek, 1905, p. 116.

Genus TROCHOSIRA Kitton, 1871 Trochosira aff. gracillima (Fenner) Fenner (Pl. 11, Figs. 22, 25)

Trochosira gracillima (Fenner) comb. nov.

Basionym. Pterotheca gracillima Fenner, 1978, p. 527, pl. 12, figs. 5, 6.

Synonym. Pterotheca sp. 3 Schrader et Fenner, 1976, p. 994, pl. 35, figs. 17, 18.

Description. Fenner, 1978, p. 527, pl. 12, figs. 5, 6.

**Remarks.** The genus *Pterotheca* is characterized by heterovalvar frustules. As in *T. gracillima* the frustule is isovalvar, and as it is closely related to *Trochosira trochlea* Hanna (Pl. 11, Fig. 15), this species is better placed in the genus *Trochosira*.

Trochosira aff. mirabilis Kitton, 1871 (Pl. 11, Figs. 19-20)

**Description.** Kitton, 1871, p. 170, pl. 14, figs. 8–9; Sims, 1988, pp. 251–252, figs. 15–21, 29–34.

**Remarks.** The observed valve diameter varied between 10 and 15  $\mu$ m. The valve face is covered with irregularly distributed small

granules. From the center of the valve rises a robust process, which looks at its base in cross section like a triangular star. In addition, a ring of marginal spines is present. The margin is covered with vertical ribs (about 18 in 10  $\mu$ m).

### Trochosira marginata sp. nov. (Pl. 11, Fig. 18)

**Description.** The valve outline is circular. The valve face is convex and perforated by equidistant, radial rows of loculate areolae, opening to the interior by a foramen and having external cribra. The areolae all are of equal size and leave free an irregularly shaped, flat central area. Near the margin the valve face is surrounded by a ring of connecting spines, which are arranged in clusters. The mantle is vertical. Just above the margin on the valve face, a ring of labiate processes is present. This is the most commonly found *Trochosira* species in the Paleocene sediments recovered during ODP Leg 114.

**Differential diagnosis.** This species differs from *T. coronata* Fenner, *T. spinosus* Kitton, and *T. ornata* Grunow (the latter two may be synonymous) because the circle of connecting spines is farther away from the valve center, at the marginal ridge.

Holotype. Specimen illustrated as Plate 11, Figure 18, from ODP Sample 114-700B-31R-3, 125-126 cm. The holotype is deposited in the Hustedt Collection, BRM.

## Trochosira radiata sp. nov. (Pl. 11, Figs. 14, 16-17)

Description. The valve outline is circular. The valve face is convex and the mantle vertical. Equidistant, radial rows of loculate areolae perforate the valve face and continue onto the mantle. These areolae are all of equal size and leave free an irregularly shaped, hyaline central area. The areolae have an external cribrum and internally a foramen. At the margin where the rows of areolae end, a ring of labiate processes is present. Characteristically for this species, on one valve thick ribs are found on top of the areolated valve face. These ribs radiate from the center and terminate at the margin in an upward-projecting short, thick spine. The number of the ribs can vary between six and eight. The second type of valves instead has long, radial rimmed furrows on the valve face, which terminate at the margin in a rimmed depression. This, as well as the furrows, is created by raised levees on top of the valve face. The furrows mirror the position of the radial ribs of the opposing valve in a chain of frustules.

**Differential diagnosis.** This species differs from *Trochosira polychaeta* by its radial system of connecting ribs and furrows extending over the whole valve face and having six to eight ribs/furrow.

Holotype. Specimen illustrated as Plate 11, Figure 14, from DSDP Sample 208-29-5, 100-101 cm. The holotype is deposited in the Hustedt Collection, BRM.

> Genus XANTHIOPYXIS Ehrenberg, 1844 Xanthiopyxis aff. structuralis Fenner, 1978 (Pl. 5, Fig. 1)

Synonym. Genus et species indet. (B) sensu Gombos, 1977, p. 599, pl. 40, figs. 2-3.

Description. Fenner, 1978, p. 536, pl. 24, figs. 1-5.

Xanthiopyxis sp. 1 (Pl. 5, Fig. 2)

Xanthiopyxis sp. 2 (Pl. 8, Fig. 4)

Genus et species indet. (1) Fenner, 1978 (Pl. 3, Fig. 2)

Description. Fenner, 1978, p. 537, pl. 34, figs. 16-19.

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Plate 1. Magnification 1500×. 1. Rhizosolenia hebetata var., Sample 114-702B-31X-CC. 2. Hemiaulus? fragilis, Sample 114-700B-31R-6, 32 cm.
3. Pseudopodosira bella, Sample 114-700B-30R-CC. 4. Rhizosolenia cretacea, B.M. 46288, Coll. Sturt, Simbirsk. 5, 6. Hemiaulus? ciesielskii, sp. nov. Fig. 5. Sample 114-698A-11R-CC. Fig. 6. Sample 114-698A-10R-1, 129–130 cm, holotype (two photographs of the same specimen in a different focus were mounted). 7. Triceratium gombosii sp. nov., Sample 384-6-4, 100 cm. 8. Rhizosolenia hebetata var., Sample 114-700B-31R-CC. 9. Rhizosolenia cretacea, Sample 114-700B-30R-6, 77–78 cm. 10. Hemiaulus affinis, Sample 214-32-4, 50–51 cm. 11–14. Hemiaulus? oonkii, sp. nov. Figs. 11, 13, 14. Sample 114-698A-11R-CC (Fig. 11. Holotype). Fig. 12. Sample 327A-6-4, 68 cm, paratype.



Plate 2. Magnification  $1500 \times$  if not otherwise listed. 1–3. Hemiaulus? beatus sp. nov. Fig. 1. Sample 114-700B-34R-1, 150 cm. Fig. 2. Sample 114-700B-34R-1, 119 cm. Fig. 3. Sample 114-700B-31R-6, 18–19 cm, holotype. 4–8. Hemiaulus? velatus sp. nov. Fig. 4. Sample 327A-6-2, 100–101 cm. Fig. 5. Sample 327A-7-2, 100–101 cm, holotype. Fig. 6. Sample 114-700B-30R-3, 27–28 cm, 950 $\times$ . Fig. 7. Sample 114-700B-30R-4, 27–28 cm. Fig. 8. Sample 114-700B-31R-CC, 900 $\times$ , paratype (two photographs of the same specimen in a different focus were mounted). 9. Hemiaulus? sp., Sample 114-700B-34R-3, 15–16 cm, 560 $\times$ . 10. Pterotheca sp. 1, Sample 114-700B-30R-CC. 11. Hemiaulus? velatus sp. nov., Sample 114-700B-34R-1, 76 cm, 900 $\times$ . 12. Hemiaulus sp. 3, Sample 114-700B-34R-1, 76 cm. 13. Pterotheca evermanni, Sample 114-700B-31R-2, 50–51 cm. 14. Hemiaulus sp., Sample 114-700B-30R-6, 27–28 cm.



Plate 3. Magnification  $1500 \times$  if not listed otherwise. 1. *Hemiaulus* sp., Sample 114-700B-31R-6, 18–19 cm. 2. Genus et species indet. (1) Fenner (1977), Sample 327A-7-2, 100–101 cm. 3–6. *Hemiaulus* aff. grassus. Figs. 3–5. Sample 524-4-3, 87–89 cm (Fig. 4. Two photographs of the same specimen in a different focus were mounted). Fig. 6. Sample 114-700B-34R-1, 119 cm. 7. *Hemiaulus* sp., Sample 114-700B-31R-2, 50–51 cm, 900×.



Plate 4. Magnification 1500×. 1. Hemiaulus sp. 5, Sample 214-38-3, 50-51 cm. 2. Sphynctolethus hemiauloides, Sample 208-29-5, 100-101 cm. 3. Hemiaulus altus, Sample 114-702B-31X-CC. 4. Sphynctolethus hemiauloides, B.M. 46288, Coll. Sturt, Simbirsk (two photographs of the same specimen in a different focus were mounted). 5. Hemiaulus elegans var. intermedia, Sample 114-700B-31R-2, 50-51 cm. 6. Hemiaulus sp., Sample 114-700B-30R-1, 27-28 cm. 7. Hemiaulus elegans var. intermedia, Sample 327A-5-5, 100-101 cm. 8, 9. Hemiaulus sp. 5. Fig. 8. Sample 208-31-3, 100-101 cm. Fig. 9. Sample 208-29-5, 100-101 cm. 10. Hemiaulus sp. F. Harwood (1988), Sample 208-30-1, 100-101 cm.



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Plate 5. Magnification 1500×. 1. Xanthiopyxis aff. structuralis, Sample 114-700B-34R-3, 15–16 cm. 2. Xanthiopyxis sp., Sample 114-700B-31R-6, 17 cm. 3. Triceratium sp., Sample 114-700B-32R-2, 83–85 cm. 4. Hemiaulus sp., Sample 327A-6-2, 100–101 cm. 5–9. Hemiaulus inaequilaterus. Fig. 5. Sample 114-698A-11R-CC. Figs. 6–8. Sample 524-4-3, 87–89 cm (Fig. 7. Two photographs of the same specimen in a different focus were mounted). Fig. 9. Sample 114-698A-11R-CC (two photographs of the same specimen in a different focus were mounted).



Plate 6. Magnification  $1500 \times$  if not listed otherwise. 1, 2. Genus et species indet., part of *Hemiaulus? conicus* sp. nov.? Fig. 1. Sample 114-700B-29R-2, 10–11 cm. Fig. 2. Sample 114-700B-30R-1, 3.5 cm. **3–6.** *Hemiaulus? conicus* sp. nov. Fig. 3. Sample 114-700B-28R-1, 130–131 cm, holotype (two photographs of the same specimen in a different focus were mounted). Fig. 4. Sample 114-700B-30R-1, 3.5 cm, 950  $\times$ . Fig. 5. Sample 114-700B-28R-3, 130–131 cm. Fig. 6. Sample 114-700B-30R-1, 53 cm. 7. Hemiaulus kristoffersenii, sp. nov., Sample 327A-7-2, 100–101 cm. **8**, **9.** *Hemiaulus* sp. 2. Fig. 8. B.M. 46288, Coll. Sturt, Simbirsk. Fig. 9. Sample 114-700B-34R-1, 119 cm. 10. Genus et species indet., Sample 114-700B-29R-1, 130–131 cm. **11.** *Hemiaulus? conicus* sp. nov., Sample 114-700B-29R-1, 24–25 cm. **12.** *Hemiaulus* sp., Sample 114-700B-31R-2, 50–51 cm. **13.** *Hemiaulus kristoffersenii* sp. nov., Sample 524-4-3, 87–89 cm, holotype (two photographs of the same specimen in a different focus were mounted).



Plate 7. Magnification 1500× if not listed otherwise. 1, 2. Pterotheca sp., Sample 114-700B-32R-1, 124-125 cm. Fig. 2. 900×. Fig. 3. Hemiaulus inaequilaterus var., 850×, Sample 524-4-3, 87-89 cm. 4. Hemiaulus inaequilaterus var.?, Sample 114-700B-30R-2, 97 cm. 5. Hemiaulus sp. 1, 900×, Sample 114-700B-34R-1, 150 cm. 6. Hemiaulus sp., Sample 114-700B-28R-CC. 7. Pseudostictodiscus picus, Sample 114-700B-30R-1, 53 cm. 8. Trinacria senta, 410×, Sample 214-38-3, 50-51 cm. 9. Hemiaulus peripterus, 960×, Sample 114-700B-31R-6, 32 cm. 10. Hemiaulus inaequilaterus var., Sample 524-4-3, 87-89 cm (two photographs of the same specimen in a different focus were mounted). 11, 12. Hemiaulus sp. 1. Fig. 11. Sample 114-700B-34R-1, 150 cm. Fig. 12. Sample 114-700B-34R-1, 119 cm.



Plate 8. Magnification  $1500 \times .$  1–3. Hemiaulus aff. speciosus. Fig. 1. Sample 114-698A-11R-CC. Fig. 2. Sample 114-700B-30R-1, 3.5 cm. Fig. 3. Sample 208-29-5, 100–101 cm. 4. Xanthiopyxis sp. 2, Sample 114-700B-34R-1, 76 cm. 5, 6. Hemiaulus subacutus sensu Gombos (1976), Sample 114-698A-11R-CC. 7. Pterotheca kittoniana, Sample 114-702B-32X-CC. 8–10. Hemiaulus polymorphus var. charkovianus. Figs. 8, 9. Sample 208-30-1, 100–101 cm (Fig. 9. Two photographs of the same specimen in a different focus were mounted). Fig. 10. Sample 114-700B-34R-1, 119 cm. 11–14. Hemiaulus rossicus. Figs. 11, 12. NHW 1570c, Coll. Grunow, Simbirsk. Fig. 13. Sample 114-700B-31R-6, 63 cm. Fig. 14. Sample 114-700B-34R-3, 15–16 cm.



Plate 9. Magnification 1500×. **1**, **2**. *Triceratium gombosii*. Fig. 1. Sample 114-698A-11R-CC, holotype. Fig. 2. Sample 384-6-1, 100-101 cm. 3. *Pseudopyxilla tempereana*, Sample 114-700B-31R-6, 18-19 cm. **4**. *Pseudopyxilla* sp., Sample 114-700B-34R-3, 15-16 cm. **5**. *Eunotogramma* sp., Sample 114-700B-31R-6, 63 cm. **6**. *Coscinodiscus bulliens*, Sample 114-700B-32R-1, 124-125 cm. **7-10**. *Triceratium mirabile*. Fig. 7. Sample 114-700B-30R-1, 53 cm. Fig. 8. Sample 114-700B-29R-CC. Fig. 9. Sample 114-700B-31R-2, 50-51 cm. Fig. 10. Sample 114-702B-31X-CC. **11-16**. *Trinacria deciusii*. Fig. 11. Girdle view, Sample 114-700B-28R-1, 130-131 cm. Fig. 12. Sample 114-700B-31R-6, 32 cm. Fig. 13. Sample 114-700B-31R-CC. Fig. 14. Sample 208-30-5, 100-101 cm. Fig. 15. Sample 114-700B-34R-2, 19-20 cm. Fig. 16. Sample 114-702B-32X-1, 27-28 cm. **17-21**. *Triceratium schulzii*. Fig. 17. Sample 114-700B-34R-2, 19-20 cm. Fig. 18. Sample 114-700B-34R-3, 15-16 cm. Fig. 19. Sample 114-700B-34R-1, 76 cm. Figs. 20, 21. Sample 327A-7-2, 100-101 cm.



Plate 10. Magnification 1500× if not indicated otherwise. **1.** Stephanopyxis discrepans, Vema 12-46, 630 cm. **2.** Stephanopyxis sp. 2, fragment, girdle band view, Sample 114-700B-31R-6, 17 cm. **3.** Stephanopyxis sp. 1, Sample 524-4-3, 87-89 cm. **4.** Genus et species indet., 900×, Sample 114-700B-32R-1, 124-125 cm. **5.** Stephanopyxis marginata, Sample 114-700B-31R-6, 63 cm. **6.** Stephanopyxis schulzii, Sample 114-700B-31R-5, 18-19 cm. **7.** Stephanopyxis turris var., Sample 114-700B-34R-3, 62 cm. **8.** Hemiaulus sp., Sample 114-702B-32X-1, 27-28 cm. **9.** Hemiaulus incisus, with resting spore, Vema 12-46, 630 cm. **10, 11.** Hemiaulus nocchiae sp. nov. Fig. 10. Sample 114-702B-31X-CC, 1200×. Fig. 11. Sample 114-700B-30R-4, 27-28 cm, 1200×, holotype (two photographs of the same specimen in a different focus were mounted).



Plate 11. Magnification 1500× if not indicated otherwise. **1–4.** *Grunowiella palaeocaenica* var. *palaeocaenica*. Fig. 1. Sample 114-698A-11R-CC (two photographs of the same specimen in a different focus were mounted). Figs. 2, 3. Sample 114-700B-30R-2, 97 cm. Fig. 4. Sample 114-700B-31R-2, 50–51 cm. **5–7.** *Grunowiella* sp. Fig. 5. Sample 114-700B-31R-2, 50–51 cm. Fig. 6. Sample 114-700B-30R-4, 27–29 cm. Fig. 7. Sample 208-27-5, 100–101 cm. **8.** *Sceptroneis* sp., Sample 114-700B-32R-1, 124–125 cm. **9, 10.** *Sceptroneis* sp. 1. Fig. 9. Sample 114-700B-32R-1, 124–125 cm. Fig. 10. Sample 114-700B-31R-4, 149–150 cm. **11.** *Grunowiella palaeocaenica* var. *alternans* var. nov., holotype, Sample 114-700B-34R-3, 15–16 cm. **12.** *Grunowiella gemmata* var., Sample 208-30-5, 100–101 cm. **13.** *Grunowiella gemmata*, Sample 114-700B-32R-1, 124–125 cm. **14.** *Trochosira radiata*, Sample 208-29-5, 100–101 cm, holotype. **15.** *Trochosira trochlea*, Sample 208-28-2, 100–101 cm (mid-Eocene). **16, 17.** *Trochosira radiata*, Sample 114-700B-31R-3, 125–126 cm. **18.** *Trochosira marginata*, Sample 114-700B-31R-3, 125–126 cm, holotype. **19, 20.** *Trochosira aff. mirabilis.* Fig. 19. Girdle view, Sample 114-698A-10R-1, 129–130 cm. Fig. 20. Sample 114-700B-31R-3, 125–126 cm. **22.** *Trochosira aff. gracillima*, Sample 114-700B-31R-3, 125–126 cm. **23.** *Hyalodiscus* sp., Sample 327A-7-2, 100–101 cm. **24.** *Grunowiella* sp., Sample 114-700B-30R-2, 97 cm. **25.** *Trochosira* aff. *gracillima*, Sample 114-700B-31R-2, 50–51 cm (two photographs of the same specimen in a different focus were mounted). **26.** *Coscinodiscus cruxii* sp. nov., holotype, Sample 327A-7-2, 100–101 cm. **27.** Pellet consisting nearly exclusively of valves of *Grunowiella palaeocaenica*, 750×, Sample 114-698A-10R-1, 129–130 cm.