

8. LATE EOCENE TO EARLY OLIGOCENE CALCAREOUS NANNOFOSSIL ASSEMBLAGES FROM SITES 699 AND 703, SUBANTARCTIC SOUTH ATLANTIC OCEAN¹

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ABSTRACT

Calcareous nannofossil assemblages were studied from Sites 699 and 703, drilled during ODP Leg 114 to the west and east, respectively, of the Mid-Atlantic Ridge in the subantarctic South Atlantic Ocean. Recovery at the two sites consists of an almost continuous sequence of upper Eocene-lower Oligocene sediments. This study describes the calcareous nannofossil assemblages at the transition between the Eocene and Oligocene and correlates these assemblages with those described in lower latitude sections. Quantitative analyses were performed on several important taxa in order to improve the biostratigraphic resolution and permit some paleoenvironmental interpretations. Several discrepancies were noted between the two sites and between the Eocene and Oligocene assemblages. The Eocene assemblages show a great number of species and warmer water conditions; the early Oligocene assemblages are less diversified and are indicative of cooler conditions. The Eocene/Oligocene boundary was not defined by planktonic foraminifers because of the strong dissolution, poor recovery, and drilling disturbances. On the other hand, the calcareous nannofossil assemblage allowed recognition of the interval where the Eocene/Oligocene boundary can possibly be placed.

INTRODUCTION

During Ocean Drilling Program (ODP) Leg 114 seven sites (698 through 704) were drilled in the subantarctic South Atlantic Ocean in the wide passageway that links the South Atlantic to the Weddell Sea basin (Fig. 1). The two major goals of Leg 114 were (1) to link regional tectonic events to the opening of the gateway that allowed antarctic cold waters to flow northward into the Argentine basin through the Falkland-Agulhas Fracture Zone and (2) to reconstruct the history of climatic conditions from the Late Cretaceous to the Holocene.

This paper describes the calcareous nannofossil assemblages at the transition between the Eocene and the Oligocene and establishes correlations with lower latitude assemblages. An almost continuous sequence of upper Eocene-lower Oligocene sediments was recovered at only two of the seven sites drilled: Site 699, located west the Mid-Atlantic Ridge on the northeastern slope of the Northeast Georgia Rise (51°32.537'S, 30°40.619'W), and Site 703, located east of the ridge on the Meteor Rise (47°03.042'S, 07°53.679'E). These sequences provide an excellent opportunity to study the biostratigraphic and biogeographic distribution of calcareous nannofossils at high latitudes. The upper Eocene-lower Oligocene sediments yield rich, but not diversified, calcareous nannofossil assemblages. Preservation ranges from moderate to poor, as a result of recrystallization and/or dissolution. Quantitative analyses were performed on several important taxa in order to improve biostratigraphic resolution and to permit some paleoenvironmental interpretations.

The distribution of calcareous nannofossils in the underlying and overlying sediments at these two sites, as well as at the other sites drilled during Leg 114, is presented by Crux (this volume).

Stratigraphic and biogeographic studies of high-latitude calcareous nannofossil assemblages from Eocene-Oligocene sediments have been conducted by Edwards and Perch-Nielsen (1975), Wise and Wind (1977), Haq et al. (1977), Wise and Mostajo (1983), Wise (1983), and Wise et al. (1982) for Deep Sea Drilling Project (DSDP) Legs 36 and 71 and by Edwards and Perch-Nielsen (1975) for DSDP Leg 29.

For detailed regional paleoenvironmental information on Paleogene paleoclimatic and paleoceanographic conditions, the reader is referred to Keigwin and Corliss (1986), Krashennikov and Basov (1986), Boersma et al. (1987), Kennett (1977, 1978), and Nocchi et al. (this volume).

METHODS

Approximately one sample per each core section from Holes 699A and 703A was studied. There are missing intervals in both holes, especially in the upper Eocene, which are due to poor recovery or to soupy materials. Smear slides were made for each sample and were examined under a light microscope at a magnification of 1500×. Abundances of individual nannofossil species are tabulated on the range charts in Tables 1 and 2. Estimates of the relative abundance of individual species in a given sample were made according to the following criteria:

A = Abundant: 1 specimen per 1 field of view.

C = Common: 1 specimen per 1 to 2 fields of view.

F = Few: 1 specimen per 2 to 10 fields of view.

R = Rare: 1 specimen per 10 to 100 fields view.

RR = Very rare: 1 specimen per more than 100 fields of view.

Reworking is rare in both holes and is characterized by Cretaceous and Paleocene specimens. A qualitative analysis of the state of preservation of the calcareous nannofossils was made using the following criteria:

G = Good: specimens exhibit no dissolution and/or overgrowth.

M = Moderate: specimens exhibit moderate dissolution and/or overgrowth.

P = Poor: specimens exhibit extreme dissolution and/or overgrowth.

Quantitative analyses were made on several important species using the method of Backman and Shackleton (1983)

¹ Ciesielski, P. F., Kristoffersen, Y., et al., 1991. *Proc. ODP, Sci. Results*, 114: College Station, TX (Ocean Drilling Program).

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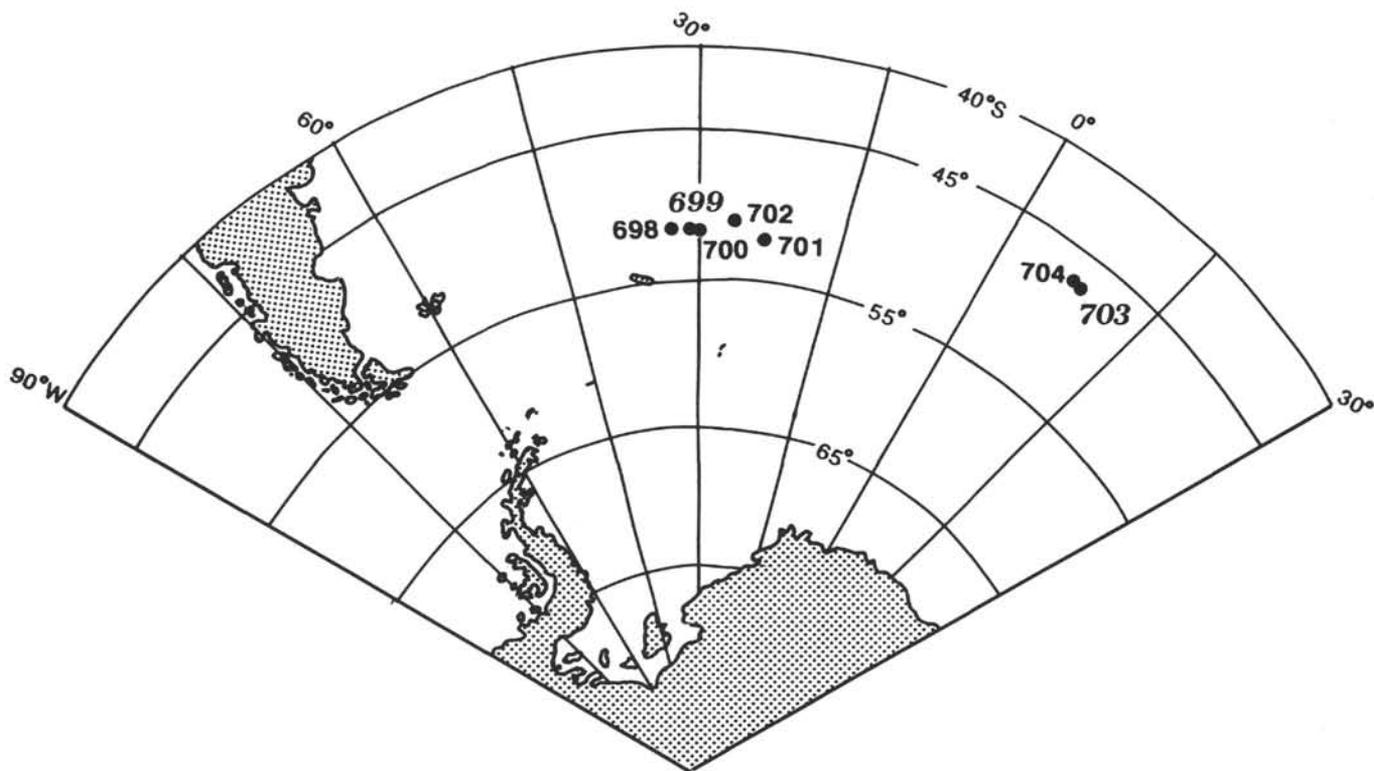


Figure 1. ODP Leg 114 site locations.

in which the abundance of each species is expressed as the number of specimens per square millimeter. The counts were performed on approximately 100 fields of view at a magnification of 1500 \times . Only a few samples were examined with the scanning electron microscope (SEM); for taxonomic purposes, Moshkovitz's (1974) technique was used, which allows the study of the same specimen in both the light microscope and SEM.

The species considered in this report are listed alphabetically by species epithets in the Appendix; the bibliographic references of these species are given in Loeblich and Tappan (1966, 1968, 1969, 1970a, 1970b, 1971, 1973), van Heck (1979a, 1979b, 1980a, 1980b, 1981a, 1981b, 1982a, 1982b), and Steinmetz (1985a, 1985b, 1986a, 1986b, 1987a, 1987b).

BIOSTRATIGRAPHY

High-latitude nannofloral assemblages are less diversified than low-latitude assemblages; for this reason, fewer markers are available for the biostratigraphic resolution of high-latitude sections. The standard zonation of Martini (1971) and the low-latitude zonation of Bukry (1973, 1975) and Okada and Bukry (1980) are quite difficult to apply to the Leg 114 material, mainly because several low-latitude index forms are very rare or even absent. Instead, the biostratigraphic zonal scheme of Wise (1983), which was defined for the Falkland Plateau region, was used here, although a few zones could not be applied in this study because of different species concepts.

Chiasmolithus oamaruensis Zone (= NP18)

Definition. Interval from the first occurrence (FO) of *Chiasmolithus oamaruensis* and the FO of *Isthmolithus recurvus*.

Remarks. The *Chiasmolithus oamaruensis* Zone is present in both holes, but at Hole 703A the lower boundary was not reached. Very rare specimens of *Discoaster barbadiensis*, *Discoaster saipanensis*, and *Bramletteius serraculoides* are

present only at Hole 699A. The assemblage is characterized mainly by *C. oamaruensis*, *Cyclicargolithus floridanus*, *Dictyococcites bisectus*, and *Dictyococcites scrippsae*. *Neococcolithes dubius* (a cool-water species; Siesser, 1975) is present only in Hole 703A and disappears within this zone.

Age. Late Eocene.

Isthmolithus recurvus Zone

Definition. Interval from the FO of *Isthmolithus recurvus* to the FO of *Reticulofenestra oamaruensis*.

Remarks. This zone is present in both holes. The specimens of *I. recurvus* at Site 703 are smaller compared with those at Site 699 and very badly preserved. Strong overgrowth completely masks the central area.

Age. Late Eocene.

Reticulofenestra oamaruensis Zone

Definition. Interval from the FO of *R. oamaruensis* to the last occurrence (LO) of *Discoaster saipanensis*.

Remarks. *Criboecium reticulatum* disappears within this zone in Sample 114-703A-15H-2, 130–131 cm, at a depth of 131.20 m below seafloor (mbsf). At Hole 699A the LO of *C. reticulatum* is just before the FO of *I. recurvus*. *C. reticulatum* is inferred to have an environmental preference for tropical to temperate conditions (Bukry, 1977) and has been found in sections from hemipelagic environments and open-ocean areas (Shafik, 1981). *C. reticulatum* was found at DSDP Site 511 (Wise, 1983), and its extinction level is before the LO of *D. saipanensis*. In low-latitude sections (Monechi, 1986; Coccioni et al., 1988; Premoli Silva et al., 1988) the extinction of *C. reticulatum* is also before the LOs of the disc-shaped discoasters, and it is correlated to the middle part of Zone P16 (Blow, 1969). Wei and Wise (in press) found that *C. reticulatum* becomes extinct earlier at high latitudes than at midlatitudes. In this study, the discrepancy between the two holes

Table 1. Calcareous nannofossil distribution and relative abundance in Hole 699A.

Age	Okada and Bukry (1980)	Wise (1983)	Core, section, interval (cm)	Abundance	Preservation	Reworking	<i>Birkelandia staurion</i>	<i>Blackites spinosus</i>	<i>Bramletteius serraculooides</i>	<i>Calcidiscus kingii</i>	<i>Chiasmolithus altus</i>	<i>Chiasmolithus oamaruensis</i>	<i>Chiasmolithus</i> sp.	<i>Clausiococcus fenestratus</i>	<i>Clausiococcus obrutus</i>	<i>Clausiococcus subdistichus</i>	<i>Coccolithus pelagicus-eopelagicus</i>	<i>Coronocyclus nitescens</i>	<i>Cribrocentrum reticulatum</i>	<i>Cyclicargolithus abisectus</i>	<i>Cyclicargolithus cf. abisectus</i>	<i>Cyclicargolithus cf. marismontium</i>	<i>Cyclicargolithus floridanus</i>	<i>Dicryococites bisectus</i>	<i>Dicryococites scrippsae</i>	<i>Discoaster barbadiensis</i>	<i>Discoaster deflandrei</i>	<i>Discoaster saipanensis</i>	<i>Discoaster</i> sp.	<i>Ericsonia formosa</i>	<i>Ericsonia</i> sp.	<i>Helicosphaera</i> sp.	<i>Isthmolithus recurvus</i>	<i>Pontosphaera plana</i>	<i>Reticulofenestra cf. dicyoda</i>	<i>Reticulofenestra daviesii</i>	<i>Reticulofenestra hallae</i>	<i>Reticulofenestra oamaruensis</i>	<i>Reticulofenestra samodurovii</i>	<i>Reticulofenestra umbilica</i>	Small <i>Reticulofenestra</i> sp.	<i>Spherolithus moriformis</i>	<i>Sphenolithus predistentus</i>	<i>Thoracosphaera sazea</i>				
early Oligocene	CP 17/18	<i>Chiasmolithus altus</i>	27X-1, 59-60	A	P	.	.	R	.	.	F	.	A	.	.	.	C	.	C	.	C	.	C	F	F	R	R	.	.	.	A	R				
			27X-4, 115-116	A	P	.	.	R	.	.	F	.	A	C	R	.	C	.	C	.	C	F	F	R	R	.	.	.	A	R			
	CP 16c	<i>Reticulofenestra daviesii</i>	27X-5, 60-61	A	P	.	.	R	.	.	C	.	A	.	.	.	C	F	.	C	.	C	.	A	F	F	R	R	.	.	.	A	A	R			
			27X-6, 60-61	A	P	.	.	R	.	.	F	.	A	A	F	.	C	.	C	.	A	F	F	R	R	.	.	.	A	A	R		
	CP 16b	<i>Blackites spinosus</i>	27X-7, 1-2	A	P	.	.	R	.	.	F	.	A	.	.	.	A	F	.	C	.	C	.	A	F	F	R	R	.	.	.	A	A	R			
			28X-1, 33-34	A	P	R	F	.	F	A	F	.	R	.	C	.	A	C	F	F	R	R	.	.	.	A	A	R	
			28X-CC	A	M	.	.	R	.	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	
			29X-1, 59-60	C	P	.	.	F	.	.	R	.	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	
			29X-2, 60-61	A	P	.	.	R	.	.	F	.	C	A	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	
			29X-3, 60-61	C	P	.	.	F	.	.	R	.	F	A	F	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	
			30X-1, 146-147	A	P	.	.	F	.	.	C	.	A	A	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	
			30X-2, 115-116	A	P	.	.	R	.	.	R	R	F	A	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
			30X-3, 87-88	C	P	.	.	R	.	.	R	R	F	F	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
			30X-3, 135-136	A	M	R	.	F	.	.	C	R	C	A	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
			31X-1, 22-23	C	P	.	.	R	.	.	R	.	F	C	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
			31X-2, 135-136	A	M	.	.	F	.	.	F	R	C	C	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
			31X-3, 138-139	A	M	.	.	F	.	.	F	R	C	C	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
			31X-4, 138-139	A	P	.	.	R	.	.	F	R	A	A	F	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
			31X-5, 138-139	A	M	.	.	R	.	.	F	R	A	.	F	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
			31X-6, 129-130	A	P	.	.	R	.	.	.	A	.	F	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
32X-1, 83-94			A	P	.	.	R	A	F	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	
32X-6, 103-104			A	P	R	A	F	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	
32X-CC	A	P	.	.	R	.	.	.	R	R	F	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R			
33X-1, 95-96	A	P	.	.	R	.	.	.	R	C	F	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R			
33X-3, 95-96	A	P	.	.	F	R	.	.	.	C	F	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R			
33X-5, 95-96	A	M	R	.	R	.	.	.	R	C	F	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R			
33X-CC	A	P	.	.	R	A	.	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R			
34X-CC	C	P	.	.	R	.	.	.	R	F	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R			
35X-1, 66-70	A	P	.	R	R	.	R	.	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R			
35X-3, 66-70	C	P	.	R	.	R	.	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R			
35X-5, 66-70	C	P	.	F	.	.	.	R	R	F	F	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R			
35X-CC	A	P	.	R	.	R	.	.	R	.	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R			
36X-1, 60-61	A	P	R	.	R	.	.	R	R	.	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R			
36X-3, 60-61	A	P	.	R	.	R	.	.	R	R	.	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R				
36X-5, 60-61	A	P	.	R	.	R	.	.	R	F	.	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R				
36X-CC	A	M	.	F	.	.	.	F	R	.	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R				
37X-CC	A	M	.	R	R	.	.	R	R	.	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R				
38X-CC	A	M	.	R	R	R	.	.	.	F	.	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R				

Note: Abundance: A = abundant; C = common; F = few; R = rare; RR = very rare. Preservation: M = moderate; P = poor. ? = doubtful species identification.

regarding the LO of *C. reticulatum* (at Site 699 it is before the FO of *I. recurvus*) possibly could be explained either by paleoenvironmental problems or by the effects of strong dissolution at Site 699.

Age. Late Eocene.

Blackites spinosus Zone

Definition. Interval from the LO of *D. saipanensis* to the LO of *I. recurvus*.

Remarks. The lower boundary of this zone is not well defined because of the scarcity of disc-shaped discoasters only rare to very rare *D. barbadiensis* and *D. saipanensis* were found in a few samples from Hole 699A; however, it could be tentatively placed in Sample 114-699A-35X-3, 66–67 cm. In Hole 703A placement of the base is uncertain, because of the absence of discoasters and a gap in the recovery. Within this zone several forms, such as *Ericsonia formosa*, *R. oamaruensis*, and *C. oamaruensis*, disappear and *Chiasmolithus altus* has its FO.

Age. Late Eocene–early Oligocene.

Clausicoccus fenestratus Zone

Definition. Interval from the LO of *I. recurvus* to the LO of *Clausicoccus fenestratus*.

Remarks. Wise (1983) used a very broad concept of *C. fenestratus*, which includes forms of *Clausicoccus subdistichus*, *Clausicoccus obrutus*, and *C. fenestratus* in this species, for the definition of this zone. In this study, the three species were separated on the basis of the different dimensions and the different structure of the central area. Only those forms with dimensions bigger than 6 μm and that show well-defined holes in the central area were considered as *C. fenestratus*.

Age. Early Oligocene.

Reticulofenestra daviesii Zone

Definition. Interval from the last common occurrence of *C. fenestratus* to the LO of *Reticulofenestra umbilica*.

Remarks. The *Reticulofenestra daviesii* Zone is easily recognizable in Hole 703A; on the contrary, poor recovery in Hole 699A obscured the base of the zone. Within this zone, transitional forms between *C. floridanus* and *Cyclicargolithus abisectus* appear; these are listed on the distribution chart as *Cyclicargolithus cf. abisectus*. The typical size of these forms is about 8 μm .

Age. Early Oligocene.

Chiasmolithus altus Zone

Definition. Interval from the LO of *R. umbilica* to the last common uphole occurrence of *C. altus*.

Remarks. Only the lower part of the zone was studied in both of the holes. The species diversity is very low; only 12 taxa were recognized. Reticulofenestrids and chiasmoliths dominate the assemblage.

Site 699

Site 699 is located on the northeastern slope of the Northeast Georgia Rise (51°32.537'S, 30°40.619'W) in a water depth of 3716 m. The section studied ranges in age from late Eocene, the *Chiasmolithus oamaruensis* Zone, to the late early Oligocene, the *Chiasmolithus altus* Zone. The approximately 100 m of sediments recovered includes a siliceous nannofossil ooze, which grades downward into nannofossil ooze, nannofossil chalk, and micritic chalk. The CaCO_3 content drops sharply in the upper Eocene–lower Oligocene interval at about 300 mbsf. This reduction is due to a decreasing abundance of planktonic foraminifers (see Nocchi et al., this volume) and an

increase in siliceous organisms. Nevertheless, calcareous nannofossils are always present and quite abundant. Unfortunately the recovery is quite poor: Core 114-699A-34X had no recovery and Cores 114-699A-25X through 114-699A-30X have a total recovery less than 50%. For this reason the resolution of events is low at these core intervals.

The Eocene nannofossil assemblage is more diversified than that of the Oligocene, and it is characterized by approximately 38 taxa, although sphenoliths, discoasters, and helicosphaerids are sparse and pentoliths are absent. The assemblage consists mainly of reticulofenestrids, placoliths, and chiasmoliths. Only single specimens of *Bramletteius serraculoides* and *Zygrhablithus bijugatus* are present in two samples. The upper Eocene interval is characterized by a succession of extinctions and appearances (Fig. 2); the LO of the disc-shaped discoasters occurs at Sample 114-699A-35X-3, 66–70 cm, at a depth of 319.60 mbsf. Core 114-699A-34X contains no sediments, and the assemblages from Cores 114-699A-33X and 114-699A-32X are the same except for the absence of discoasters. The upper part of the section studied is dominated by *Cyclicargolithus*, *Chiasmolithus*, and *Reticulofenestra daviesii*. The LO of *Reticulofenestra umbilica* defines the boundary between the *Chiasmolithus altus* Zone and the underlying *R. daviesii* Zone. The LOs of *Clausicoccus fenestratus* and *Isthmolithus recurvus* are coincident due to the poor recovery. Several fluctuations in abundance of *C. fenestratus* and the small *Ericsonia-Clausicoccus* were noted in the *Blackites spinosus* Zone. These fluctuations may be important for local correlation. It should be noted that *Chiasmolithus oamaruensis* disappears in the upper part of this zone. *Reticulofenestra hillae* is always less abundant than *R. umbilica* and becomes extinct just below it.

Site 703

Site 703, located on the Meteor Rise (47°03.042'S, 07°53.679'E) in a water depth of 1807 m, is between the Subtropical and the Antarctic convergences. This site received a significant biosiliceous input during the late Eocene and Oligocene. The interval studied from Hole 703A ranges in age from the late Eocene nannofossil Zone NP18 (*Chiasmolithus oamaruensis* Zone) up to the *Chiasmolithus altus* Zone. The thickness of the section is about 50 m (Cores 114-703A-17X to 114-703A-11H) and the dominant lithology is a foraminifer-bearing nannofossil ooze. Calcareous nannofossils are abundant throughout the section; preservation varies from moderate to poor.

The upper Eocene assemblage is characterized mainly by *Cyclicargolithus floridanus*, *Criboecentrum reticulatum*, *Reticulofenestra umbilica*, *Dictyococcites bisectus*, and *Dictyococcites scrippsae*. Discoasters and helicosphaerids are absent. The succession of events observed in the upper Eocene includes the LO of *Neococcolithes dubius* and the FOs of *Isthmolithus recurvus* and *Reticulofenestra oamaruensis*. The LO of *C. reticulatum* is just above the FO of *I. recurvus*. No data were recovered from Core 114-703A-14H, because it consists entirely of soupy sediments. The overlying Core 114-703A-13H contains the same assemblage with the addition of *C. altus*; several fluctuations in abundance of *I. recurvus*, *Clausicoccus obrutus*, and *Clausicoccus fenestratus* were also observed. *Ericsonia formosa* is quite rare and sporadic, but its extinction level appears to be at the top of Core 114-703A-13H (Fig. 3). *C. oamaruensis*, which is quite abundant in the upper Eocene, becomes quite rare and disappears at the same level as *E. formosa*. A succession of extinctions occurs in the upper Oligocene: *I. recurvus* in Sample 114-703A-12H-6, 21–22 cm, *C. fenestratus* in Sample 114-703A-12H-4, 2–4 cm, and *R. umbilica* and *Reticulofenestra hillae* in Sample 115-703A-

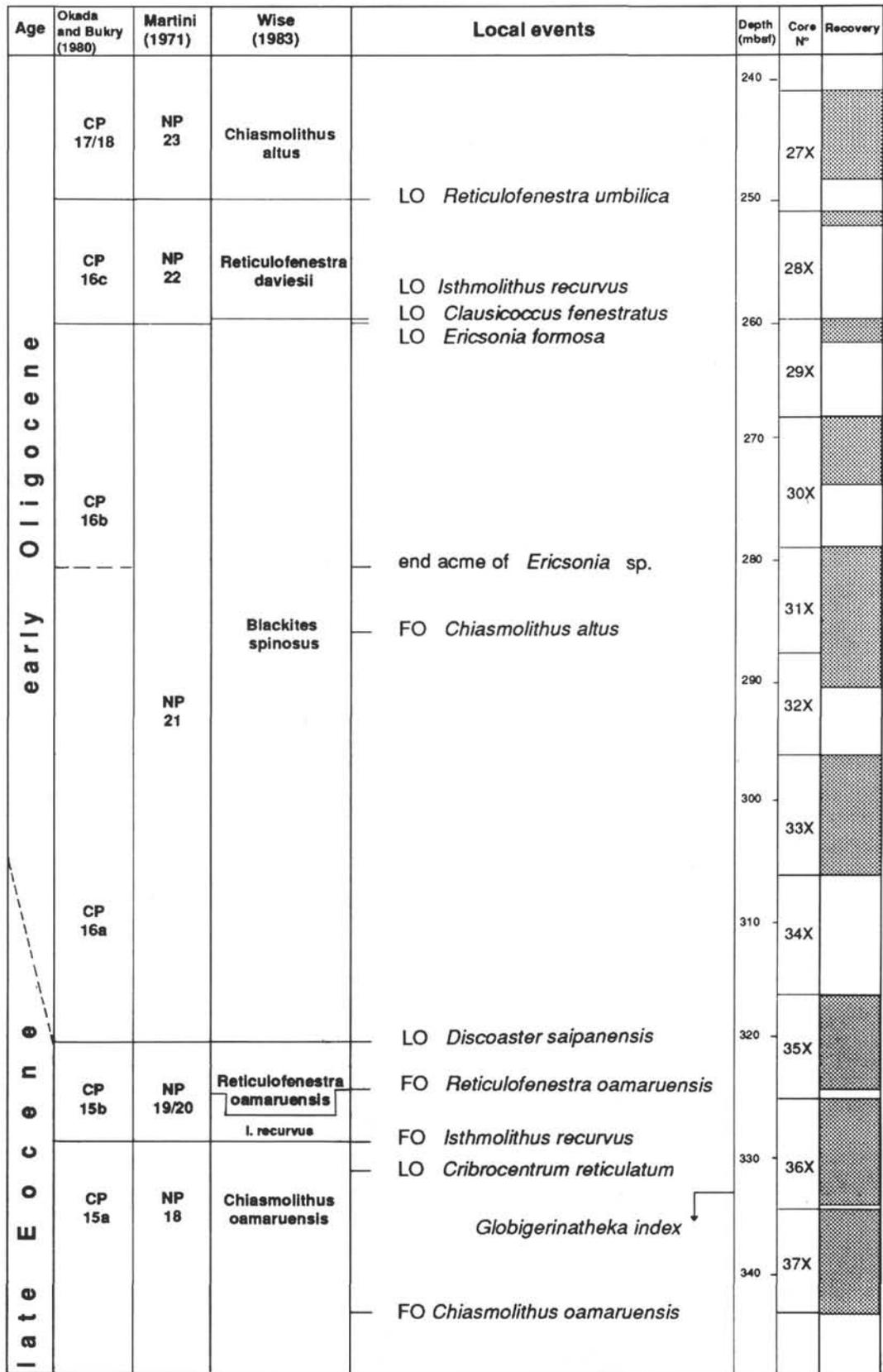


Figure 2. Major calcareous nannofossil events at Site 699 plotted against the zonations of Okada and Bukry (1980), Martini (1971), and Wise (1983).

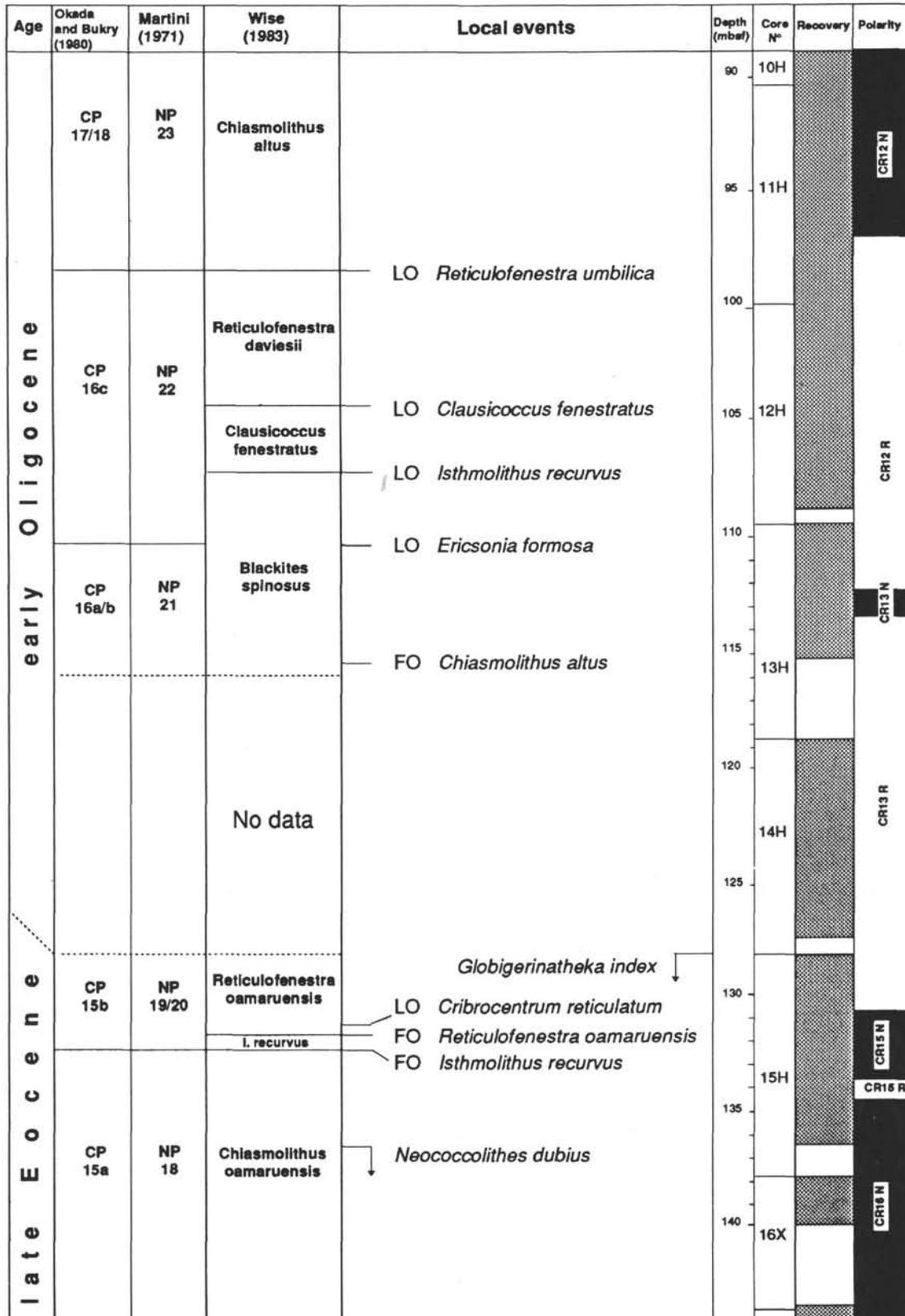


Figure 3. Major calcareous nannofossil events at Site 703 plotted against the zonations of Okada and Bukry (1980), Martini (1971), and Wise (1983) and the magnetostratigraphy (Ciesielski, Kristoffersen, et al., 1988).

11H-6, 28–32 cm. In the upper 10 m of the section studied, several fluctuations in the abundance of *C. altus* were also recognized. The number of species at the top of the sequence is very low; only 12 taxa were recognized in this interval.

ABUNDANCE PATTERNS

Detailed quantitative analyses of selected nannofossil species from the upper Eocene–lower Oligocene sediments of Sites 699 and 703 were performed in order to improve the biostratigraphic resolution, to gain some paleoenvironmental information, and to establish possible correlations between the biostratigraphy and magnetostratigraphy. The counting method used was that of Backman and Shackleton (1983; subsequently discussed by Backman, 1986). The plots presented in Figures 4 and 5 represent the abundances expressed as number of specimens counted per square millimeter unit area in the intervals investigated.

The abundance pattern of *Reticulofenestra umbilica* shows a general tendency toward progressive decline at both sites. This feature is quite evident at Site 703 whereas it is irregular at Site 699. It should be noted that the sharp decline is just above the FO of *Isthmolithus recurvus*. After this sharp decline several fluctuations were noted up to the extinction level. At Site 699 the increase and decrease of *R. umbilica* correlates well with the fluctuations of *Chiasmolithus* sp. and *Ericsonia* sp. One of the results of Backman's (1986) detailed study on the central opening/placolith length ratio of *R. umbilica* and *Reticulofenestra hillae* is that *R. hillae* may be considered an ecophenotype of *R. umbilica*; the author suggested, therefore, that the morphometric interrelationship between *R. hillae* and *R. umbilica* has a paleoenvironmental, rather than biostratigraphic, value. In particular, the increase of *R. hillae*, a reticulofenestrid species with a relatively smaller central opening size, might be linked to conditions of cooler temperature.

In the abundance plots (Figs. 4 and 5) the variations in abundance of *R. hillae* and *R. umbilica* are reported alongside each other. *R. hillae* is not very abundant in the Eocene, but increases in the lower Oligocene from Cores 114-699A-31X and 114-699A-32X, with a corresponding decrease of *R. umbilica*. Two recognizable peaks are at a core depth of about 280 mbsf. A cooler condition may also be suggested by the high abundance of *I. recurvus* and chiasmoliths. At the same depth, an increase in abundance of *C. fenestratus* was noted. At Site 703 the variations between the two morphovariants are not so clear as at Site 699, because of the lack of samples at the Eocene/Oligocene boundary; nevertheless, two peaks of *R. hillae* are present in Samples 114-703A-15H-2, 40–42 cm (upper Eocene), and 114-703A-13H-4, 74–75 cm. The two peaks correlate with an increase of *I. recurvus*, but there is no apparent correlation with *C. fenestratus*.

A tendency toward progressive decline has been noted in the abundance patterns of *Dictyococcites bisectus* and *Dictyococcites scrippsae*; the marked decrease in abundance occurs few samples above the extinction of disc-shaped discoasters. At Site 699 *I. recurvus* shows several fluctuations and has two peaks at the top of Cores 114-699A-31X and 114-699A-29X; it is always more abundant than at Site 703. Furthermore, in the distribution chart and abundance plots we distinguished *Clausicoccus subdistichus*, *Clausicoccus obrutus*, *C. fenestratus*, and *Ericsonia* spp.; in the latter we lumped together all the small *Ericsonia*-*Clausicoccus* in which we could not clearly recognize the central area.

C. subdistichus, *C. obrutus*, and *Ericsonia* spp. are not very abundant at Site 703, and only *C. fenestratus* shows a high increase in abundance just below and above the LO of *I. recurvus*, which clearly correlates with an increase in abun-

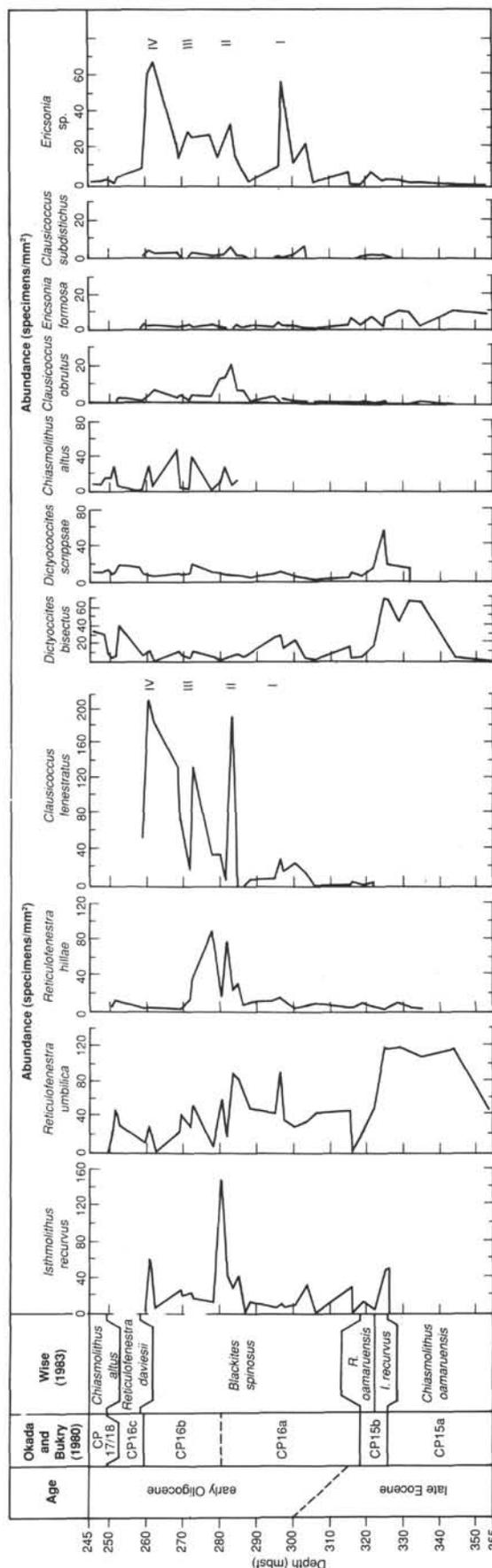


Figure 4. Abundance of selected nannofossil species in Hole 699A plotted for the zonations of Okada and Bukry (1980) and Wise (1983). Roman numerals identify the four peaks recognized in the abundances of *C. fenestratus* and *Ericsonia* sp.

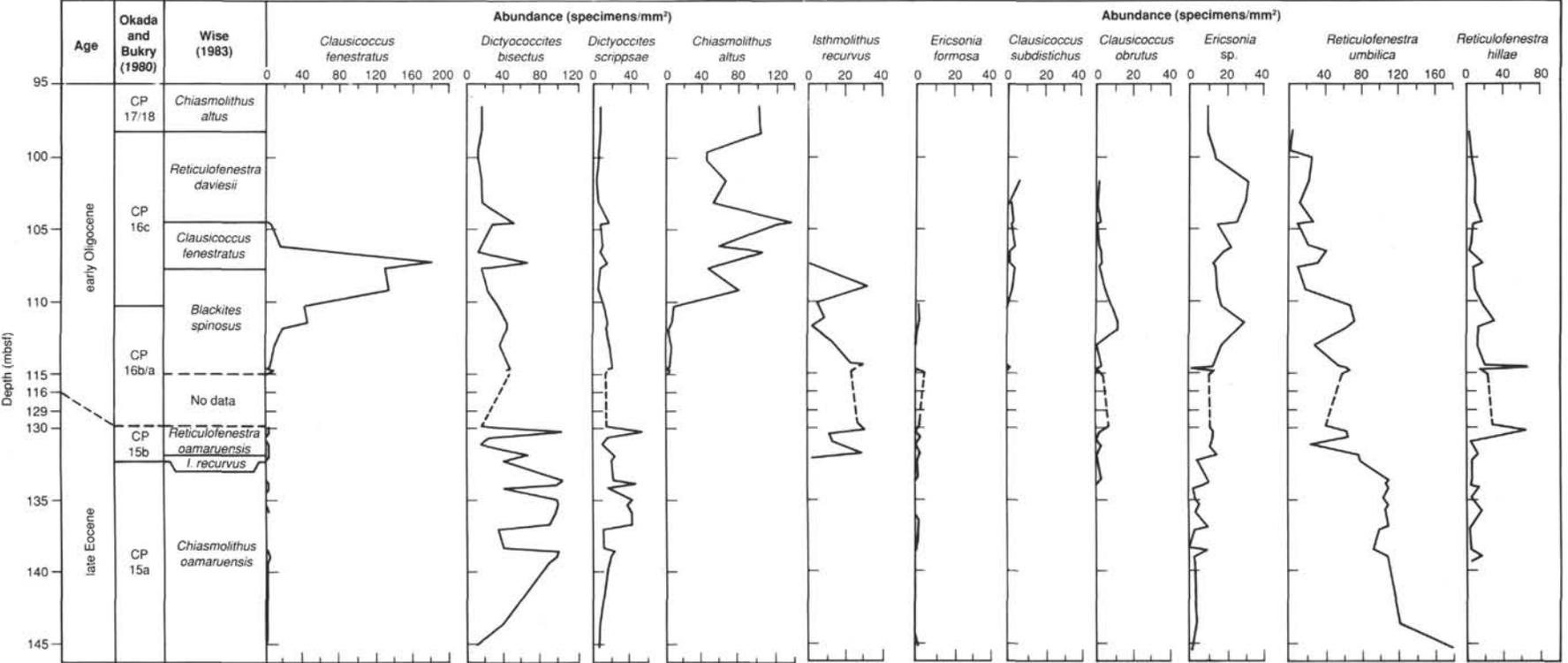


Figure 5. Abundance of selected nannofossil species in Hole 703A.

dance of *D. bisectus* and *C. altus*. At Site 699 *C. obrutus* and *C. subdistichus* are abundant and show several fluctuations. Four peaks are clearly recognizable in the lower Oligocene: (1) at about 300 mbsf; (2) at 280 mbsf, coincident with the peak of *I. recurvus*; (3) 10 m above at a depth of 270 mbsf; and (4) the largest peak at about 261 mbsf. At Site 703 the peaks of *Ericsonia* spp. and *C. fenestratus* are not so clear. The only detectable peak is that of *C. fenestratus* at a depth of about 107 mbsf (the extinction level of *I. recurvus*), which could be related to the last peak at Site 699.

In the abundance plots of Figures 4 and 5, *C. altus* includes only specimens with a well-recognized central area; the chiasmolith rims without a central area are lumped in *Chiasmolithus* sp. *C. altus* shows high abundances from its FO high into the section studied.

It is notable that *C. fenestratus*, a form very rare and discontinuously present in the upper Eocene, shows a sharp increase in abundance at the first occurrence of *C. altus* and continues with high abundance up to its extinction level. It was noted at Site 699 that in the same interval where the FO of *C. altus* was found, *I. recurvus*, *R. umbilica*, and *Ericsonia* spp. show a sharp increase in abundance. At Site 703 *C. fenestratus* and *C. altus* show a sharp increase in abundance in the upper part of the section.

EOCENE/OLIGOCENE BOUNDARY

The Eocene/Oligocene boundary is usually defined by planktonic foraminifers, by the extinction of *Hantkenina*, as equated by Nocchi et al. (1988) to the boundary between planktonic foraminiferal Zones P17 and P18 (Blow, 1969). The Eocene/Oligocene boundary could not be placed by planktonic foraminifers at the two studied sites because of drilling disturbances, incomplete recovery at Site 703, and the strong dissolution of planktonic foraminifers in the upper Eocene and lower Oligocene sediments at Site 699 (Nocchi et al., this volume).

On the other hand, the Eocene/Oligocene boundary, in terms of calcareous nannofossils, is usually taken at low latitude at the top of Zones CP15 and/or NP20 by the LO of *Discoaster barbadiensis* and *Discoaster saipanensis*. From several studies of low-latitude sections in Italy and Spain, it was observed that the extinction of disc-shaped discoasters is coeval with the extinction of *Globigerinatheka index* (Nocchi et al., 1986, 1988; Monechi, 1986). Moreover, it slightly predates the Eocene/Oligocene boundary defined by planktonic foraminifers, the extinction level of *Hantkenina* and *Cribohantkenina*.

In the Gubbio area the Eocene/Oligocene boundary, as far as the magnetostratigraphic correlation is concerned, occurs at the youngest polarity change within the reversed interval between Chrons 15 and 13. At high latitude the LO of *G. index* is best used to approximate the Eocene/Oligocene boundary. At Sites 703 and 699 it was very difficult to use this species. At Site 699 *G. index* disappeared earlier as a result of strong dissolution at the top of Core 114-699A-37X, and at Site 703 the LO of *G. index* occurred at the top of Core 114-703A-15H because no samples were available from Core 114-703A-14H. Thus, the Eocene/Oligocene boundary is even more difficult to recognize using calcareous nannofossils. The extinction of the disc-shaped discoasters is not very reliable, because these taxa are known to survive longer in tropical areas in comparison to the low to middle latitudes and are absent at high latitude. Discoasters are common in warm water/low latitude, but are rare or absent in cold water/high latitude. At Site 703 *D. barbadiensis* and *D. saipanensis* are absent, whereas at Site 699 the few specimens discontinuously present disappear

at Sample 114-699A-35X-3, 66–70 cm. Unfortunately, the reliability of this event is very low.

Detailed quantitative analyses performed at the Eocene/Oligocene boundary in the Umbrian sequences and at the South Atlantic sites show that the boundary may be recognized by the sharp increase in abundance of *Clausicoccus obrutus*/*Clausicoccus subdistichus* (Monechi, 1986; Backman, 1987) and, possibly, by a marked change in proportion between *Reticulofenestra umbilica* and *Ericsonia formosa*. Because of preservation problems at Site 699, *C. obrutus* and *C. subdistichus* are quite rare and all the small *Ericsonia*-*Clausicoccus* were grouped in *Ericsonia* spp. The abundance pattern of *Ericsonia* spp. shows several fluctuations, and the first sharp increase is at about 300 mbsf. A marked change in abundance in *R. umbilica* is detectable at about 315 mbsf. These two events possibly represent the Eocene/Oligocene boundary between 315 and 300 mbsf.

At Site 703 the Eocene/Oligocene boundary is difficult to place because of the absence of disc-shaped discoasters and the lack of recovery from Core 114-703A-14H between 129 and 117 mbsf. The paleomagnetic data from Clement and Hailwood (this volume) suggest that the Eocene/Oligocene boundary can be placed in the lowermost reversed interval of Chron 13, coincident with the decrease in abundance of *R. umbilica* and the increase in abundance of *C. obrutus* at 130 mbsf.

SUMMARY AND CONCLUSIONS

In this paper we have described the calcareous nannofossil assemblages from the upper Eocene and lower Oligocene section of high-latitude Sites 699 and 703. Several biostratigraphic events were recognized and correlated between the two sites, although some discrepancies exist in the succession of events and in the assemblages. Site 703 is characterized by the presence of species absent at Site 699, namely *Zygrhablithus bijugatus* (a holococcolith commonly preserved in water depths less than 1000 m; Edwards and Perch-Nielsen, 1975), *Bramletteius serraculoides* (warm-water taxa; Bukry, 1972) in the Eocene interval, *Sphenolithus moriformis* (a cosmopolitan form, not very abundant here), rare pontosphaerids (well known to prefer nearshore environments), and *Thoracosphaera saxea* common in the upper Eocene. Disc-shaped discoasters and warm-water taxa are absent. The LO of *Cribocentrum reticulatum* (a warm-water taxon) occurs later at Site 703 than at Site 699, where it disappears before the LO of *Isthmolithus recurvus*. In the nannofloral assemblage at Site 699 *Discoaster barbadiensis*, *Discoaster saipanensis*, *S. moriformis*, *B. serraculoides*, and *T. saxea* are present in scarce amounts and *Z. bijugatus*, *Neococcolithes dubius*, and the pontosphaerids are absent.

The differences in the calcareous nannofossil assemblages between the two holes in the upper Eocene interval may suggest warmer water conditions at Site 703 than at Site 699. During the early Oligocene the climatic conditions seemed more uniform, and the differences between the two holes are fewer. The Oligocene assemblage is characterized mainly by cool-water taxa and the diversity (number of species) is very low, with no more than 12 taxa.

Correlation with the magnetostratigraphy at Site 703 reveals some biostratigraphic discrepancies in the exit and entry of *Isthmolithus recurvus*. Crux (this volume) found rare *I. recurvus* lower, in Sample 114-703A-15H-CC, suggesting rare and sporadic occurrences within Chron C16N (~38–27 Ma). The first appearance of this species is in the lower part of CR15N, leading to a younger estimate than previously reported. Monechi (1986) reported this event in the Gubbio area at the very top of Chron 16, whereas Lowrie et al. (1982)

bserved this event within Chron 15N from another section in the Gubbio area; Backman (1987) observed the same event at site 523 immediately above Chron 17. In conclusion, the biostratigraphic value of *I. recurvus* seems to yield a very low reliability.

The Eocene/Oligocene boundary could not be placed precisely mainly because of poor sediment recovery. Nevertheless, its possible placement was determined within a narrow interval.

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APPENDIX

Calcareous Nannofossils in Alphabetical Order of Species Epithets

- Cyclicargolithus abisectus* (Müller, 1970) Wise, 1973
- Chiasmolithus altus* Bukry and Percival, 1971
- Discoaster barbadiensis* Tan, 1927
- Zygrhablithus bijugatus* (Deflandre in Deflandre and Fert, 1954) Deflandre, 1959
- Dictyococcites bisectus* (Hay, Mohler, and Wade, 1966) Bukry and Percival, 1971
- Helicosphaera compacta* (Bramlette and Sullivan, 1961) Hay and Mohler, 1967
- Reticulofenestra daviesii* (Haq, 1968) Haq, 1971
- Discoaster deflandrei* Bramlette and Riedel, 1954
- Reticulofenestra* cf. *R. dictyoda* (Deflandre in Deflandre and Fert, 1954) Stradner, 1968
- Neococcolithes dubius* (Deflandre in Deflandre and Fert, 1954) Black, 1967
- Coccolithus eopelagicus* (Bramlette and Riedel, 1954) Bramlette and Sullivan, 1961
- Clausicoccus fenestratus* (Deflandre and Fert, 1954) Prins, 1979
- Cyclicargolithus floridanus* (Roth and Hay in Hay et al., 1967) Bukry, 1971
- Ericsonia formosa* (Kamptner, 1963) Haq, 1971
- Reticulofenestra hillaie* Bukry and Percival, 1971
- Calcidiscus kingii* (Roth, 1970) Loeblich and Tappan, 1968
- Pedinocyclus larvalis* (Bukry and Bramlette, 1969) Loeblich and Tappan, 1973
- Cyclicargolithus* cf. *C. marismontium* (Black, 1964) Perch-Nielsen, 1985
- Sphenolithus moriformis* (Bronnimann and Stradner, 1960) Bramlette and Wilcoxon, 1967
- Coronocyclus nitescens* (Kamptner, 1963) Bramlette and Wilcoxon, 1967
- Chiasmolithus oamaruensis* (Deflandre in Deflandre and Fert, 1954) Hay, Mohler, and Wade, 1966
- Reticulofenestra oamaruensis* (Deflandre in Deflandre and Fert, 1954) Stradner and Edwards, 1968
- Clausicoccus obrutus* (Perch-Nielsen, 1971) Prins, 1979
- Coccolithus pelagicus* (Wallich, 1877) Schiller, 1930
- Pontosphaera plana* (Bramlette and Sullivan, 1961) Haq, 1971
- Sphenolithus predistentus* Bramlette and Wilcoxon, 1967
- Isthmolithus recurvus* Deflandre in Deflandre and Fert, 1954
- Criboecentrum reticulatum* (Gartner and Smith, 1967) Perch-Nielsen, 1971
- Discoaster saipanensis* Bramlette and Riedel, 1954
- Reticulofenestra samodurovii* (Hay, Mohler, and Wade, 1966) Roth, 1970
- Thoracosphaera saxea* Stradner, 1961
- Dictyococcites scrippsae* Bukry and Percival, 1971
- Bramletteius serraculooides* Gartner, 1969
- Blackites spinosus* (Deflandre and Fert, 1954) Hay and Towe, 1962
- Birkelundia staurion* (Bramlette and Sullivan, 1961) Perch-Nielsen, 1971
- Clausicoccus subdistichus* (Roth and Hay in Hay et al., 1967) Prins, 1979
- Discoaster tanii* Bramlette and Riedel, 1954
- Reticulofenestra umbilica* (Levin, 1965) Martini and Rizkowski, 1968

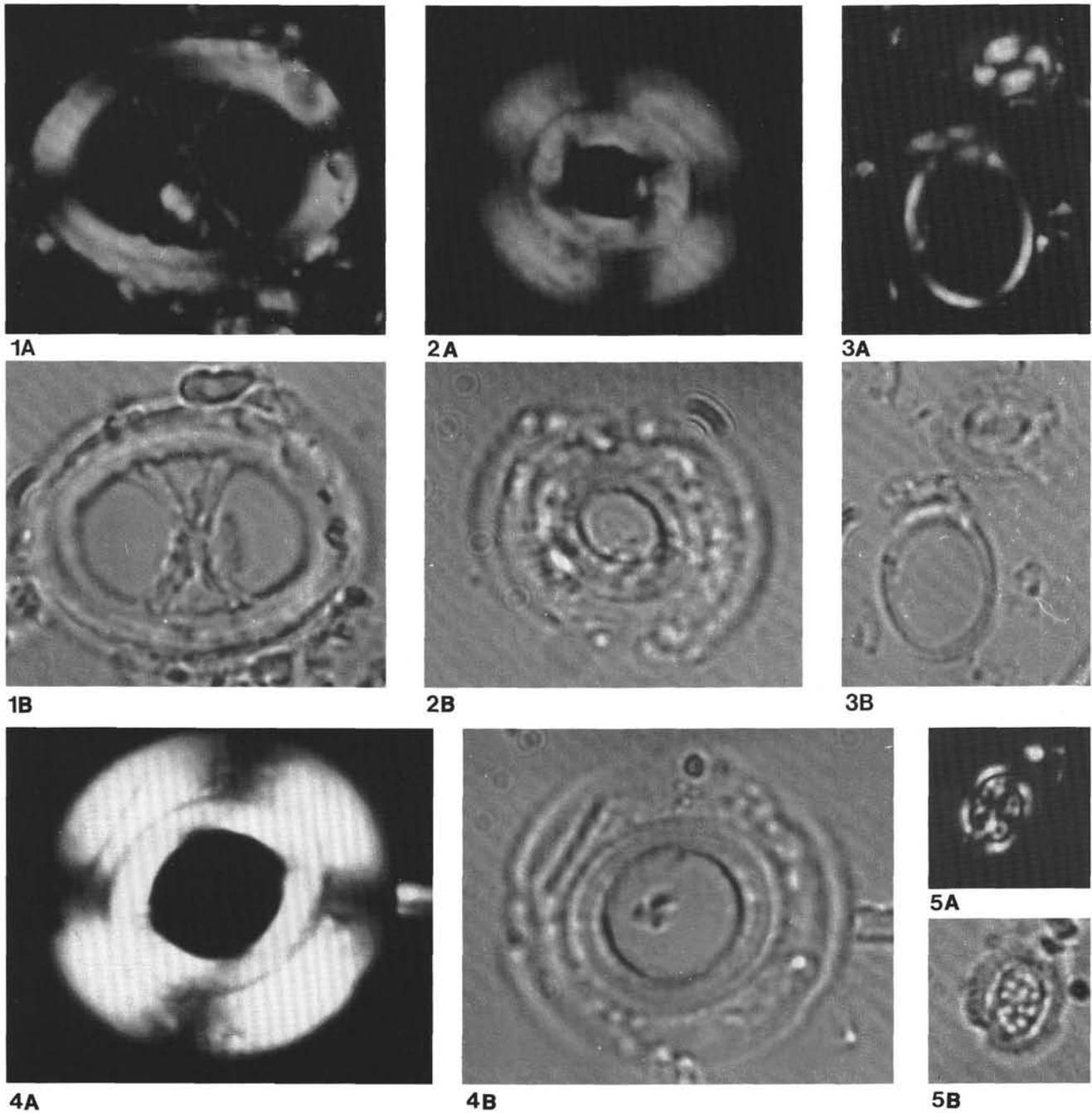


Plate 1. For all figures: A. cross-polarized light and B. transmitted light. 1. *Chiasmolithus oamaruensis*; Sample 114-703A-15H-5, 40–41 cm, upper Eocene. 2. *Reticulofenestra hillae*; Sample 114-703A-13H-4, 130–131 cm, lower Oligocene. 3. *Reticulofenestra oamaruensis*; Sample 114-703A-15H-2, 40–42 cm, upper Eocene. 4. *Reticulofenestra umbilica*; Sample 114-699A-29X-1, 59–60 cm, lower Oligocene. 5. *Clausiococcus fenestratus*; Sample 114-699A-31X-2, 135–136 cm, lower Oligocene.

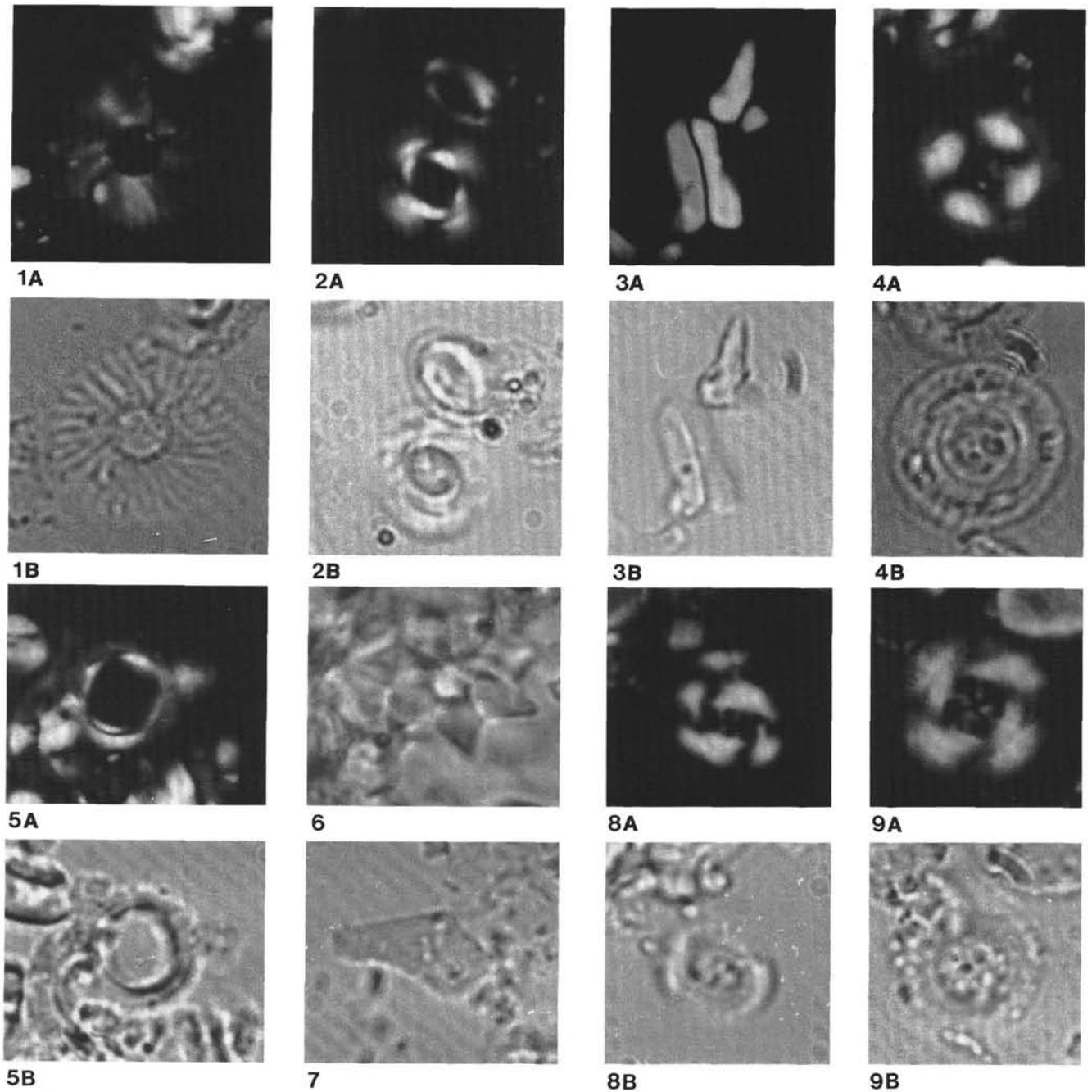


Plate 2. For all figures: A. cross-polarized light and B. transmitted light. 1. *Pedinocyclus larvalis*; Sample 114-703A-13X-3, 34–35 cm, lower Oligocene. 2. *Reticulofenestra* cf. *R. dictyoda*; Sample 114-699A-31X-3, 138–139 cm, lower Oligocene. 3. *Zygrhablithus bijugatus*; Sample 114-703A-15H-4, 116–120 cm, upper Eocene. 4. *Ericsonia formosa*; Sample 114-703A-15H-3, 40–42 cm, upper Eocene. 5. *Calcidiscus* cf. *C. kingii*; Sample 114-703A-15H-2, 80–84 cm, upper Eocene. 6. *Discoaster saipanensis*; Sample 114-699A-36X-3, 135–136 cm, upper Eocene (transmitted light). 7. *Bramletteius serraculooides*; Sample 114-703A-15X-6, 95–96 cm, upper Eocene. 8. *Reticulofenestra daviesii*; Sample 114-703A-13H-4, 130–131 cm, lower Oligocene. 9. *Cribocentrum reticulatum*; Sample 114-703A-15X-6, 95–96 cm, upper Eocene.