2. Miocene Diatom Biostratigraphy at ODP Sites 689, 690, 1088, 1092 (Atlantic Sector of the Southern Ocean)*

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(Marine Micropaleontology, 45 (3-4), pp. 309-356, 2002)

2.1 Abstract

Four ODP sites located between 64°S and 41°S in the eastern Atlantic sector of the Southern Ocean were investigated to refine the Miocene diatom biostratigraphic zonation tied to the geomagnetic chronology. The Miocene diatom stratigraphy from two sites located on Maud Rise (ODP Leg 113) is revised considering the progress in diatom biostratigraphic research, diatom taxonomy and magnetostratigraphic age assignment during the past 10 years. A new diatom zonation was erected for Site 1092 (ODP Leg 177) located on Meteor Rise integrating a magnetostratigraphic interpretation of the shipboard data. This zonation was also applied to Site 1088 (ODP Leg 177) located on Astrid Ridge. The study is focused to Middle and Upper Miocene sequences. It reveals latitudinal differentiations in stratigraphic species ranges and species occurrence pattern that are related to latitudinal differences in surface water masses reflecting the climatic development of the Antarctic cryosphere. Considering the latitudinal differences, two stratigraphic zonations are proposed that are applicable to the northern and southern zone of the Southern Ocean, respectively. The southern Southern Ocean Miocene diatom biostratigraphic zonation consists of 16 zones in which 11 represent new or modified zones. The northern biostratigraphic zonation contains 10 diatom zones allowing a stratigraphic resolution in a range of 0.2 to 2 m.y. This paper also includes the taxonomic transfer of seven Miocene diatom taxa from genus *Nitzschia* Hassall to *Fragilariopsis* Hustedt.

*Reprinted from Marine Micropalaeontology, 45 (3-4), Censarek and Gersonde, Miocene Diatom Biostratigraphy at ODP Sites 689, 690, 1088, 1092 (Atlantic Sector of the Southern Ocean), pp. 309-356, 2002, with permission from Elsevier Science.

2.2 Introduction

First diatom zonation of Miocene strata has been proposed by McCollum (1975), based on Deep Sea Drilling Project (DSDP) Leg 28 cores recovered in the Pacific sector of the Southern Ocean. In the following years, Schrader (1976), Weaver and Gombos (1981) and Ciesielski (1983, 1986) refined the biostratigraphic zonations. The invention of the advanced hydraulic piston coring (APC) at the end of the 1980th allowed the recovery of undisturbed Neogene sections and the establishment of geomagnetic polarity records. Gersonde and Burckle (1990) have proposed the first Southern Ocean Miocene diatom stratigraphic zonation tied directly to a geomagnetic record. This was developed based on ODP Leg 113 Holes 689B and 690B recovered on Maud Rise, located in the southeastern realm of the Weddell Sea. Diatom species ranges and zones were tied to the geomagnetic record established by Spieß (1990) and the Geomagnetic Polarity Time Scale (GPTS) of Berggren et al. (1985) was used for absolute age assignments. Further refinement of this zonation came from the studies of Baldauf and Barron (1991) and Harwood and Maruyama (1992) based on sediment sequences recovered during ODP Legs 119 and 120 in the Indian sector of the Southern Ocean (Fig. 2.1). The latter authors also presented a comprehensive historical overview of the progress of Southern Ocean diatom biostratigraphic research. The GPTS established by Cande and Kent (1992) was used by Barron and Baldauf (1995) to compile Cenozoic biostratigraphic diatom zonations from high and low latitudes. A revised compilation of Gersonde et al. (1998) which also considered the absolute age assignments presented in the GPTS of Cande and Kent (1995) was the baseline for shipboard diatom biostratigraphic studies during Leg 177. However, Leg 177 shipboard investigations resulted in the preliminary revision of the Late Miocene diatom zonation (Shipboard Scientific Party, 1999c). Ramsay and Baldauf (1999) presented a recent and very comprehensive compilation of diatom biostratigraphic data obtained from 17 DSDP and ODP Sites located in the Southern Ocean. All data were adjusted to the GPTS of Cande and Kent (1995). The objective of this study was the development of a biochronological framework in which primary stratigraphical datums were validated and applied consistently throughout the Southern Ocean. In the present paper we reinvestigate the Miocene sequences from ODP Leg 113 Holes 689B and 690B recovered on Maud Rise (Fig. 2.2, Tab. 2.1), originally studied by Gersonde and Burckle (1990).

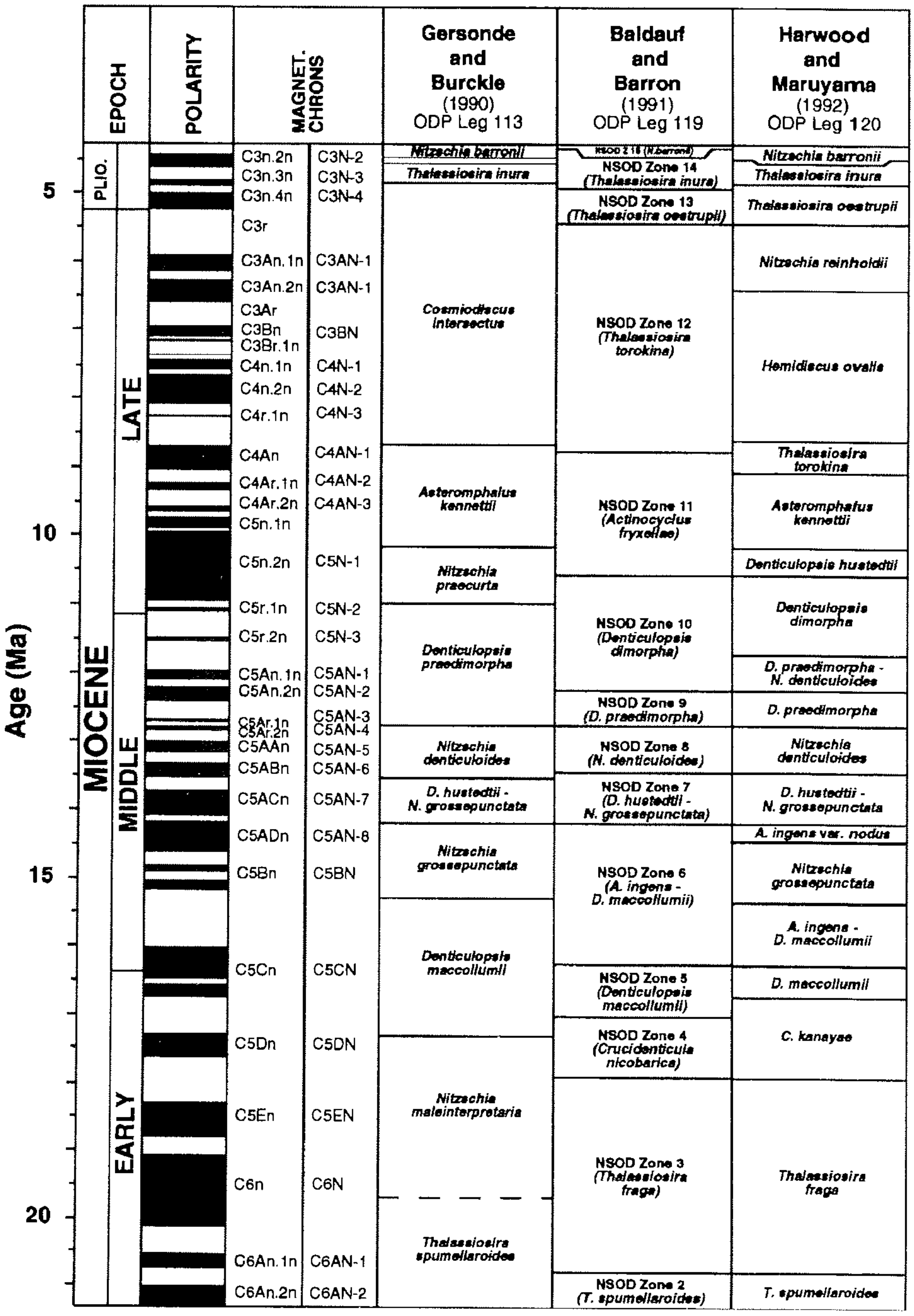
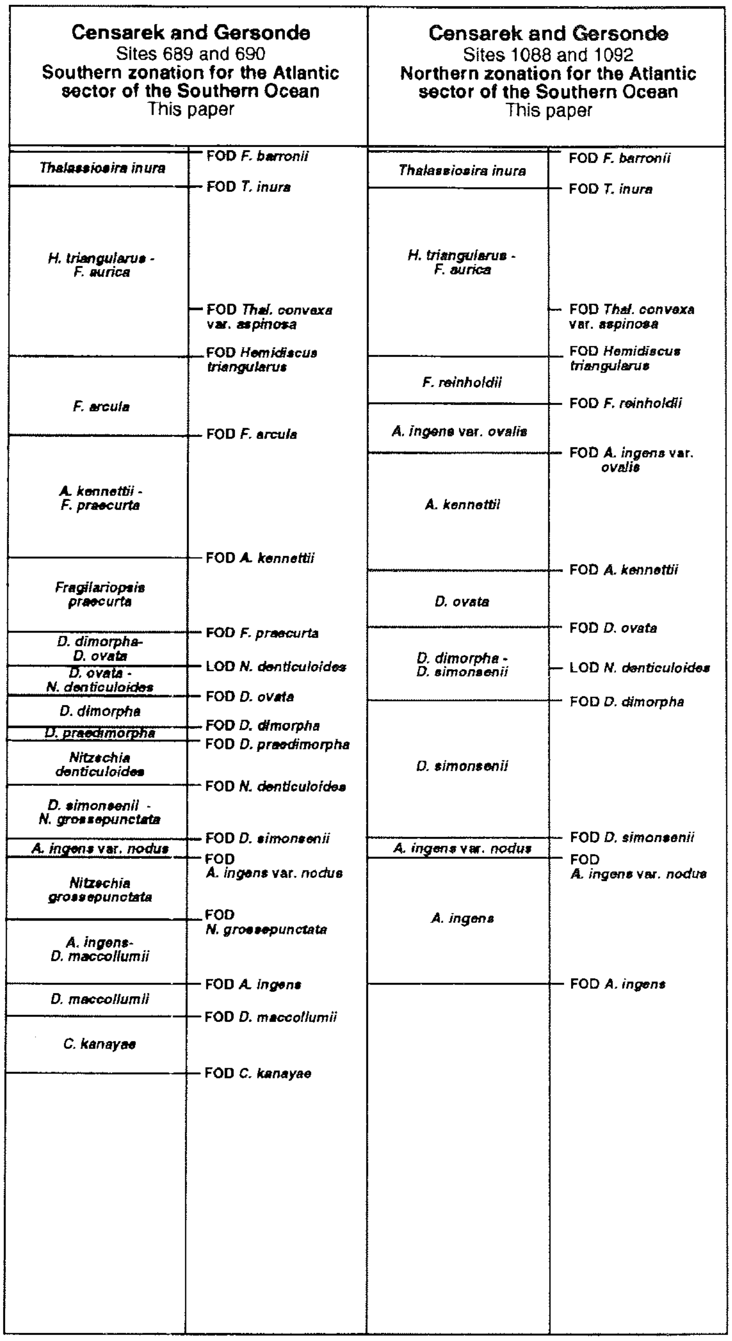


Figure 2.1 (both sides): Miocene diatom zonations from ODP Legs 113, 119 and 120 (Gersonde and Burckle, 1990; Baldauf and Barron, 1991; Harwood and Maruyama, 1992), which were tied to the Geomagnetic Polarity Time Scale of Cande and Kent (1995). Additionally the new southern and northern Southern Ocean diatom zonations are shown.



The designations of the geomagnetic polarity record is according to Cande and Kent (1992) (left column) and as proposed by Berggren et al. (1985) and Spieß (1990) (right column).

Considering the progress in diatom biostratigraphical research since 1990, revisions of age assignments of the geomagnetic record as well as revisions of the taxonomy of typical Miocene diatom species we propose an amended stratigraphic zonation for the late Early Miocene to the Late Miocene. We discuss the stratigraphic occurrence pattern of biostratigraphic marker species used as zonal definitions considering the results of previous studies of Leg 113, 114, 119 and 120. In contrast to Gersonde and Burckle (1990) and the following presentations of Ciesielski (1991), Baldauf and Barron (1991) and Harwood and Maruyama (1992), who based their study on abundance estimations of the taxa, we define the ranges of stratigraphic marker species upon the counting of up to 400 specimen per sample. We also considered the taxonomic refinements of taxa belonging to the genus *Denticulopsis*, proposed by Yanagisawa and Akiba (1990). This allowed the definition of ranges of three new *Denticulopsis* species in the Middle and Late Miocene. Out of these, two taxa were recognised as previously being included to *D. hustedtii*, and one is a new combination of different varieties close to *D. dimorpha*. The diatom zone and species ranges were dated based on the geomagnetic record established by Spieß (1990) according to the age assignments of the GPTS proposed by Berggren et al. (1995). As far as possible, the newly established zonation was also applied to the Leg 177 Sites 1092 and 1088, drilled in the area of the Antarctic Circumpolar Current (ACC) (Fig. 2.2, Tab. 2.1). Apparent latitudinal changes in species composition and abundance patterns, related to latitudinal differentiations of surface water masses, imposed the establishment of a modified zonation only applicable to the ACC realm. More comprehensive studies on the latitudinal variability of species abundance and occurrence patterns based on quantitative analyses of the diatom assemblages are presented in Censarek and Gersonde (subm. b). To improve and confirm the diatom biostratigraphic interpretation at Site 1092 a correlation to magnetostratigraphic datum points was needed. In the absence of shore-based magnetostratigraphic data sets for the Middle and Lower Miocene sections of Site 1092, we propose a preliminary interpretation based on the shipboard magnetic inclination data (Shipboard Scientific Party, 1999b). We also consider five available magnetostratigraphic datum points of the shipboard interpretation (Shipboard Scientific Party, 1999b), that have been approved by the shipboard paleomagnetists J. Channell and J. Stoner (Channell, pers. comm. 2000). At Site 1088 the complete lack of magnetostratigraphic data is due to magnetic inclinations that remained less than expected for this site location and declinations that were highly scattered (Shipboard Scientific Party, 1999a).

Unfortunately, the diatom biostratigraphy of Miocene sections recovered during Leg 114 in the realm of the ACC has never been published appropriately, except for a data report presented by Ciesielski (1991). We considered these data together with geomagnetic records presented by Clement and Hailwood (1991) and Hailwood and Clement (1991b). To refine our latest Miocene zonations we considered shipboard stratigraphical results obtained at Sites 701 and 704 (Ciesielski and Kristoffersen et al., 1988; Ciesielski, 1991), also using additional sample sets from these sites.

2.3 Material and methods

Samples for the biostratigraphic investigations were taken during Leg 113 (January to March 1987) and Leg 177 (December 1997 to February 1998) aboard JOIDES Resolution and postcruise in the Lamont and Bremen ODP core repositories. All sites considered in this study were drilled by the Advanced Hydraulic Piston Corer (APC) or the Extended Core Barrel (XCB) systems. The sample spacing in Holes 689B and 690B results in a maximum resolution up to 150 k.y. For the Leg 177 Sites 1088 and 1092, where two resp. four holes have been drilled, a resolution up to 50 k.y. is reached.

For quantitative and qualitative diatom study, microscope slides with randomly distributed microfossils were used. The cleaning of raw material and the preparation of permanent mounts for light microscopy follows the standard technique developed at the Alfred Wegener Institute (Gersonde and Zielinski, 2000). The resin for the slides was Mountex (nd = 1.67) except for samples from Site 1088 Meltmount (nd = 1.662) was used. Up to 400 diatom specimen were counted per sample using a Zeiss "Axioskop" microscope with apochromatic optics at a magnification of 1000×. Light photomicrographs were made with an AVT-Horn b/w camera coupled with a Mitsubishi video copy printer system.

The counting followed the concepts proposed by Schrader and Gersonde (1978). Detailed data sets of counting results are presented in a separate paper focusing to the paleoceanographic significance of diatom species distribution (Censarek and Gersonde, subm. b).

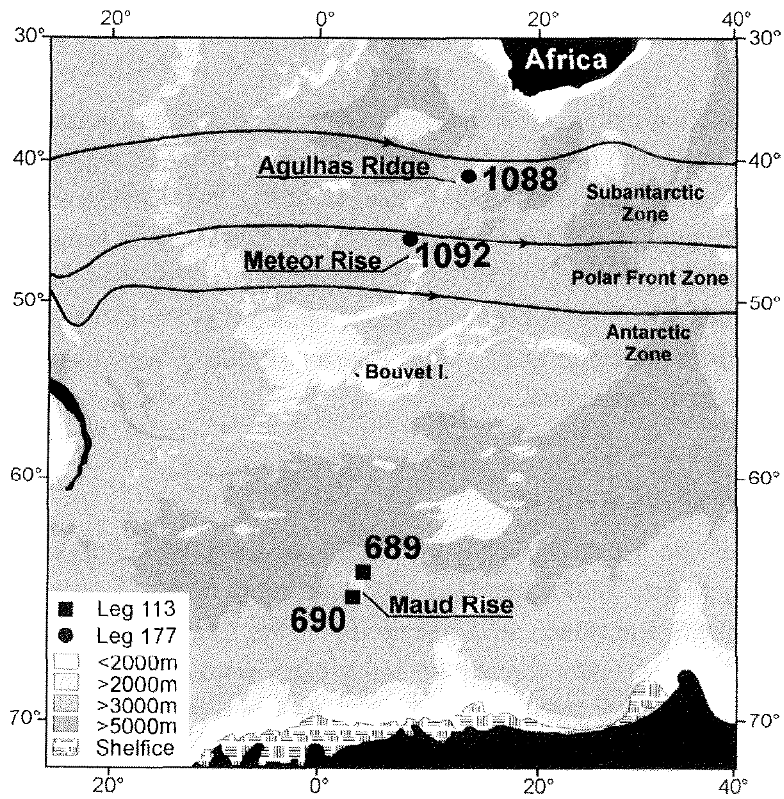


Figure 2.2: Location of Sites 689, 690, 1088 and 1092. Frontal zones according to Peterson and Stramma (1991).

Table 2.1: Location of investigated ODP sites and hydrographic settings.

Leg-Site/Holes	Latitude	Longitude	Water-depth	Location	Location/Hydrography	Investigated-section
113-689B	64°31.01'S	03°05.99'E	2080 m	Maud Rise	Weddell Sea/Antarctic Zone	11-62 mbsf
113-690B	65°09.63'S	01°12.30'E	2914 m	Maud Rise	Weddell Sea/Antarctic Zone	13-50 mbsf
177-1088B-C	41°08.16'S	13°33.77'E	2082 m	Agulhas Ridge	Southeast Atlantic Ocean/ Subantarctic Zone	34-224 mcd
177-1092A-D	46°24.70'S	07°04.79'E	1974 m	Meteor Rise	Southeast Atlantic Ocean/Polar Front Zone	60-211 mcd

For stratigraphic purposes absolute valve counts were converted to abundance classes following the ODP-style: D = dominant (>60% of total assemblage), A = abundant (30%-60%), C = common (15%-30%), F = few (3%-15%), R = rare (< 3%) and T = trace (species encountered only sporadically).

Spread sheets showing the site by site stratigraphic occurrences of selected diatom species are available from a data report (Censarek and Gersonde, subm. a), also accessible at *www-odp.tamu. edu/publications*. The diatom preservation was classified "good" when lightly silicified forms are present and no alteration of frustules could be observed, "moderate" when lightly-silicified diatoms are still present but with some alterations and "poor" if only some strongly silicified often fragmented diatoms could be observed.

The definition and nomination of zones is in accordance to the International Stratigraphic Guide (Steininger and Piller, 1999; Salvador, 1994). We tried to rely our zonal boundary definitions as much as possible on the First Occurrence Datum (FOD) of taxa that are well defined and easily to identify. The use of Last Occurrence Datum (LOD) may result in stratigraphic misinterpretation due to reworking of older species into younger sediment.

Depth assignments of zonal boundaries, species ranges and unconformities presented as mbsf (meters below sea floor) or mcd (meters composite depth) were calculated as the midpoint between the core depths of samples below and above these events or boundaries. Tiepoints for the establishment of mcd at the Leg 177 sites are presented in the individual site chapters in Gersonde et al. (1999). Zonal boundary ages, ages of species ranges and age ranges of disconformities were calculated assuming constant sedimentation rates between the various geomagnetic and biostratigraphic data points. The second digit of the calculated absolute age assignments of the stratigraphic was rounded up or down to a 0.05 m.y. step. Exceptions are such events that can directly be tied to a magnetostratigraphic event.

For paleomagnetic measurements at Site 1092 the shipboard pass-through magnetometer was used (Shipboard Scientific Party, 1999c). The measurements were made every 5 cm allowing a stratigraphic resolution of 3 k.y. Detailed shipboard paleomagnetic sampling and measurement methods of Leg 177 sites were documented in the Initial Reports (Shipboard Scientific Party, 1999c). The paleomagnetic polarity was determined directly from stable 25 mt demagnetised inclinations. Negative inclination values less than -45° were interpreted as normal polarity, positive values greater than 45° as reversed polarity. The bimodal grouping of polarity values results in a normal and reversed polarity pattern, illustrated as black/white pattern in Figure 2.10.

2.4 Definition of lower Pliocene/Miocene Diatom Zones

The latitudinal differentiation of the hydrographic parameters of Southern Ocean surface waters results in apparent latitudinal differentiations of the composition of diatom assemblages and the occurrence of stratigraphic markers. Considering this differentiation we propose two diatom biostratigraphic zonations that are applicable for the northern and the southern zone of the Southern Ocean, respectively (Fig. 2.1). The southern Southern Ocean diatom zonation (SSODZ) is based on the reinvestigation of Sites 689 and 690 (Maud Rise) and also considers previous stratigraphic results of Baldauf and Barron (1991) and Harwood and Maruyama (1992) from the Indian sector of the Southern Ocean. All sites from these studies bearing Miocene sequences are located south of the present Polar Front, except Site 737 located on the northern Kerguelen Plateau. At Site 737 diatoms have consistently been recovered in Middle Miocene through Lower Pliocene and Quaternary sediments (Baldauf and Barron, 1991). Unfortunately, the geomagnetic record obtained in the Miocene of Site 737 is rather incomplete, due to poor sediment recovery (Sakai and Keating, 1991). The northern Southern Ocean diatom zonation (NSODZ) is primarily based on the results obtained from Site 1092 located close to the Subantarctic Front (Fig. 2.2). Additional geomagnetic data from ODP Leg 114 Sites 699, 701 and 704 (Hailwood and Clement, 1991a, b; Clement and Hailwood, 1991), which have been combined with diatom occurrence data from the same sites (Ciesielski and Kristoffersen et al., 1988; Ciesielski, 1991) have also been considered. Ranges of selected Miocene diatom species and the SSODZ and NSODZ, are correlated to the geomagnetic time scale of Berggren at al. (1995) and presented in Figure 2.3.

2.4.1 Definition of southern Southern Ocean diatom biostratigraphic zonation (SSODZ)

***Thalassiosira inura* Partial Range Zone**

Authors: Gersonde and Burckle (1990), revised by Baldauf and Barron (1991) as NSOD Zone 14 (*T. inura* Partial Range Zone), revised herein.

Definition of top: FOD of *Fragilariopsis barronii.*

Definition of base: FOD of *Thalassiosira inura.*

Age: Early Pliocene, ca. 4.9 - ca. 4.5 Ma.

Paleomagnetic correlation: This zone ranges from the uppermost portion of Subchron C3n.3r close to the base of Subchron C3n.3n to the interval between the top of C3n.2n and the lowermost portion of Subchron C3n.1r.

Discussion: Gersonde and Burckle (1990) placed the FOD of *F. barronii*, which defines the top of the zone, approximately into the middle of Subchron C3N-2 (Fig. 2.1). Baldauf and Barron (1991) report in their revision of the zonal description (NSOD Zone 14, *Thalassiosira inura* Zone) erroneously a correlation of the FOD of *F. barronii* to Chron C3AN-2 instead to Subchron C3R-1 (=C3n.1r). This can be deduced from the diatom occurrence pattern presented in their range chart for Site 745 and the magnetostratigraphic data presented by Sakai and Keating (1991) from the same site. Also the stratigraphic occurrence pattern of *F. barronii* at Site 745, presented by Baldauf and Barron (1991) in their figure 6, does not coincide with the range chart data. We propose to place the FOD of *F. barronii* within the interval between the top of C3n.2n and the lowermost portion of Subchron C3n.1r on the base oft Sites 689, 690 and 695 (Gersonde and Burckle, 1990) and Site 745 (Baldauf and Barron, 1991).

There are however indications, that the FOD of *F. barronii* may be diachronous, having an older FOD in the northern area of the Southern Ocean (see discussion in NSODZ section). Taxonomic problems relate to this taxon because earlier (Weaver and Gombos, 1981; Ciesielski, 1983; Barron, 1985a) it was erroneously identified as *Nitzschia angulata* (= the extant *Fragilariopsis rhombica*) are discussed in Gersonde (1991).

Gersonde and Burckle (1990) defined the base of this zone based on the FOD of *T. inura*, which was placed at the base of Subchron C3n.3n (Fig. 2.1), as recorded from Site 695. This is in accordance with the findings of Baldauf and Barron (1991) from Site 745. However, in their zonal description Baldauf and Barron (1991) erroneously indicated a wrong paleomagnetic assignment (C3AR-2) for the base of the *T. inura* Zone and a wrong species range is shown in figure 6. Based on a comparison of the range chart data of Baldauf and Barron (1991) and the geomagnetic polarity record, presented in the stratigraphic summary of Site 745 (Barron et al., 1991), the FOD of *T. inura* at Site 745 can be placed at or very close to the base of C3n.3n.

Considering the confusion about the FOD of *T. inura* and previous problematic species identification (see discussion in Gersonde, 1991), more stratigraphic investigations are needed to strengthen the stratigraphic range of this taxon and thus the base of the *Thalassiosira inura* Zone.

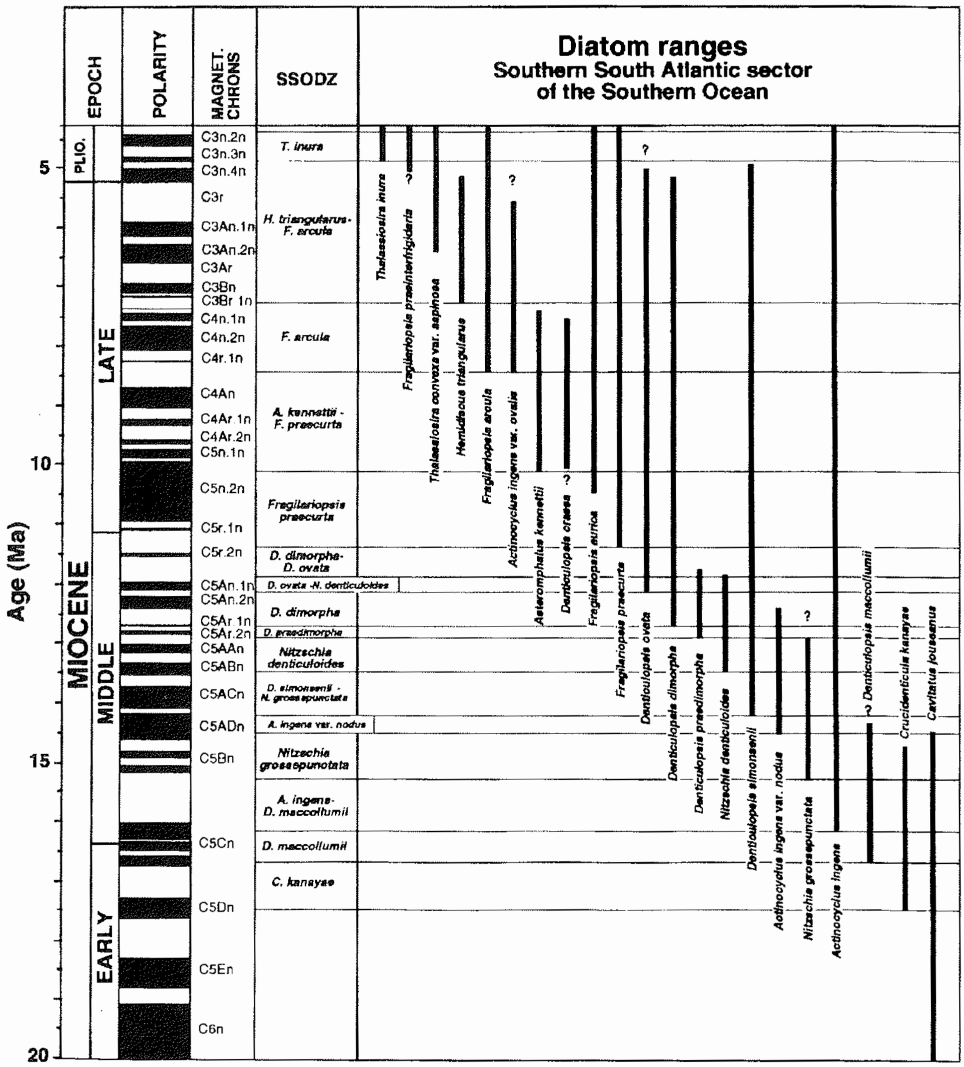
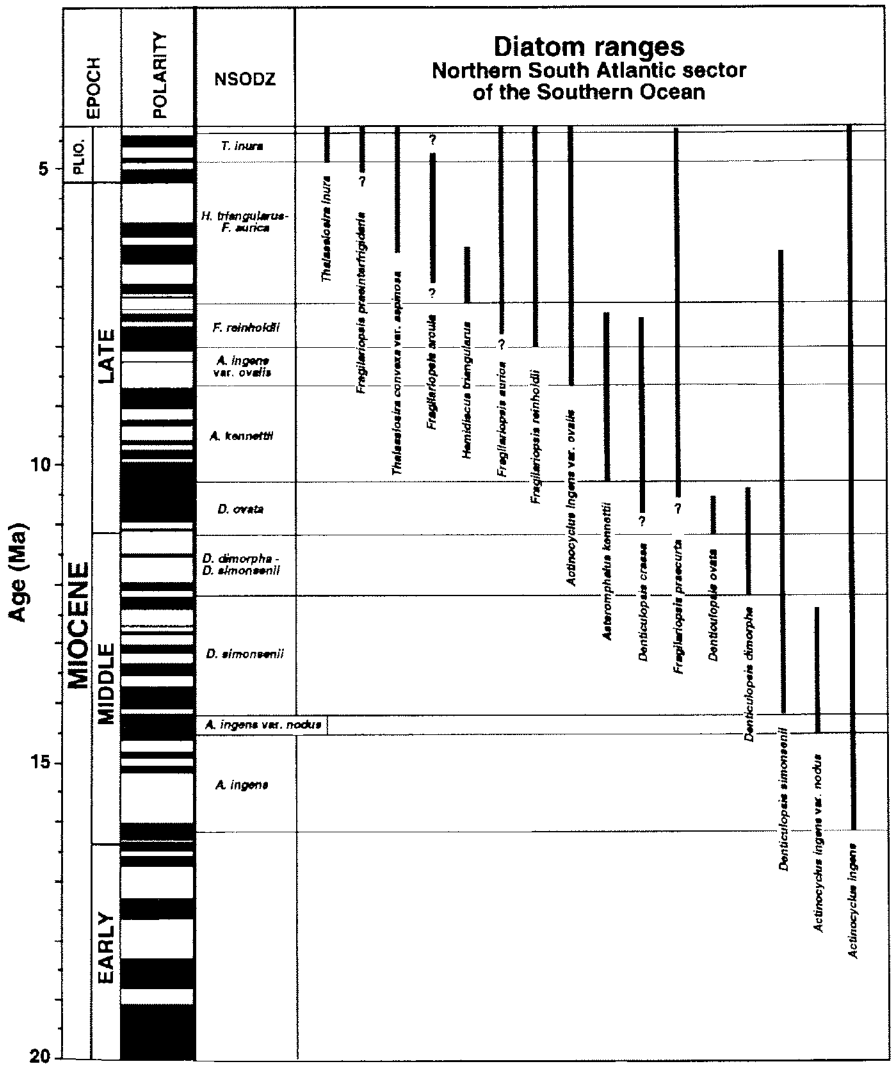


Figure 2.3 (both sites): Ranges of selected Miocene diatom species, diatom zonations as herein defined correlated to the GPTS of Berggren at al. (1995). SSODZ/NSODZ = Southern/Northern Southern Ocean diatom zonation.


Diatom ranges
Northern South Atlantic sector
of the Southern Ocean
EPOCH
POLARITY
NSODZ
Age (Ma)
5
10
15
20
PLIO.
MIOCENE
LATE
MIDDLE
EARLY
T. inura
H. triangularus - F. aurica
F. reinholdii
A. ingens var. ovalis
A. kennettii
D. ovata
D. dimorpha - D. simonsenii
D. simonsenii
A. ingens var. nodus
A. ingens
Thalassiosira inura
Fragilariopsis praeinterfrigidaria
Thalassiosira convexa var. aspinosa
Fragilariopsis arcula
Hemidiscus triangularus
Fragilariopsis aurica
Fragilariopsis reinholdii
Actinocyclus ingens var. ovalis
Asteromphalus kennettii
Denticulopsis crassa
Fragilariopsis praecurta
Denticulopsis ovata
Denticulopsis dimorpha
Denticulopsis simonsenii
Actinocyclus ingens var. nodus
Actinocyclus ingens

Hemidiscus triangularus-Fragilariopsis aurica **Partial Range Zone**

Authors: Censarek and Gersonde, herein.

Definition of top: FOD of *Thalassiosira inura.*

Definition of base: FOD of *Hemidiscus triangularus.*

Age: Late Miocene to Early Pliocene, 7.3 - ca. 4.9 Ma.

Paleomagnetic correlation: The zone ranges from the upper part of Subchron C3Br.2r up to the uppermost portion of Subchron C3n.3r close to the base of Subchron C3n.3n.

Discussion: In its upper part this zone is equivalent to the NSOD Zone 13 (*Thalassiosira oestrupii* Zone) and in its lower portion it covers the upper part of the NSOD 12 Zone (*Thalassiosira torokina* Zone), both proposed by Baldauf and Barron (1991). Harwood and Maruyama (1992) replaced the NSOD 12 Zone by the *Nitzschia reinholdii* and the *Hemidiscus ovalis* zones (Fig. 2.1). Within the *N. reinholdii* Zone, Harwood and Maruyama (1992) distinguished two subzones and defined the subzone boundary by the joint occurrence of the last occurrence (LO) of *Neobrunia mirabilis* and the LOD of *H. triangularus* near the top of Subchron C3AN-1 (Fig. 2.1).

In Southern Ocean sediments the FOD of *T. oestrupii* has only been documented from Holes 737A and 745B (Baldauf and Barron, 1991) and was cited to an age of 5.1 Ma. According to the chronology of Berggren et al. (1985), used by Baldauf and Barron (1991), this would fall within the lower reversed interval of Chron C3 at or close to the Miocene/Pliocene boundary. This is in conflict to the data presented in the Leg 119 range charts presented by Baldauf and Barron (1991), which indicate a younger age of the *T. oestrupii* FOD. Considering the paleomagnetic interpretations of Sakai and Keating (1991), the FOD falls close to the lower boundary of Subchron C3n.4n. According to Berggren et al. (1995) this datum is located in the lowermost Pliocene around 5.2 Ma. In our study we could not confirm the FOD of *T. oestrupii* because the first stratigraphic occurrence of this taxon is not documented at Sites 689 and 1092 due to the occurrence of a disconformity (Figs. 2.4, 2.10). At Site 690 the FO of *T. oestrupii* was found in the *T. inura* Zone (Fig. 2.6). Considering the generally rare occurrence pattern of *T. oestrupii* in our records and the unclear age determination of its FOD presented by Baldauf and Barron (1991), we decided not to consider the FOD of *T. oestrupii* as a stratigraphic marker until more reliable data are available.

In addition, we decided not to consider *Thalassiosira miocenica* and *Thalassiosira torokina,* whose FODs define the base of the *N. reinholdii* Zone of Harwood and Maruyama (1992) and the base of the NSOD Zone 12 (*T. torokina* Zone) of Baldauf and Barron (1991), respectively, because of their scattered occurrence pattern (Censarek and Gersonde, subm. a). The nominate taxa of our *H. triangularus-F. aurica* Zone can easily be identified and their range is documented by a continuous occurrence pattern.

The FOD of *H. triangularus* has been identified in Hole 689B (Fig. 2.4) and could be assigned to an age of 7.3 Ma (upper part of Subchron C3Br.2r). A similar age assignment was found by the study of Hole 704B, ODP Leg 114 considering the paleomagnetic data presented by Hailwood and Clement (1991b). However, the stratigraphic range of *H. triangularus* does not cover the total range of the *H. triangularus-F. aurica* Zone (Fig. 2.4). In Hole 689B the LO of this species correlates to the upper lower part of Subchron C3n.4n, while at Site 1092 the LO was found to correlate to the middle of C3An.2n. The middle and upper portion of the *H. triangularus-F. aurica* Zone is characterised by the presence of *F. aurica* in the absence of *T. inura*. The FOD of *F. aurica* can be placed around 10 Ma, in the upper portion of the *F. praecurta* Zone (Figs. 2.4, 2.6). Other useful marker species in the *H. triangularus-F. aurica* Zone are *Thalassiosira convexa* var. *aspinosa* and *Fragilariopsis praeinterfrigidaria.T. convexa* var. *aspinosa* has its FOD in the lowermost portion of Subchron C3An.2n at around 6.5 Ma (interpolated in Hole 689B), while in Hole 690B the first occurrence (FO) of this species is at a hiatus (18.7 mbsf) which covers Subchron C4n.1n to the lower part of Subchron C3n.4n (Fig. 2.6). This datum is corroborated by the study of Hole 746A (Leg 119), where it was correlated to the lower middle portion of Chron C3An.2n (Baldauf and Barron, 1991). At Site 704 (Leg 114) the FO of *T. convexa* var. *aspinosa* can be placed into the lower portion of Chron C3An (Ciesielski, 1991; Hailwood and Clement, 1991b). The FO of *Fragilariopsis praeinterfrigidaria* was recorded from Hole 745B (Leg 119) to correlate to the upper portion of Subchron C3n.3n (Baldauf and Barron, 1991). At Site 699 (Georgia Rise) the FO of this species falls into Chron C3An, whereas at Site 704 (Meteor Rise) the FO of a taxon labelled as *Fragilariopsis* aff. *praeinterfrigidaria* was placed somewhere in the lower portion of the Gilbert Chron (Ciesielski, 1991; Hailwood and Clement, 1991a, b). In Hole 695A the base of the stratigraphic range of the species was placed in the upper part of Chron C3n.3n (Gersonde and Burckle, 1990). This differs from the results of the investigation at Sites 689 and 690, where the FO is found in Chron C3n.4n and in the upper portion of C3n.3r, respectively (Figs. 2.4, 2.6). It thus can be summarised that the FOD of *F. praeinterfrigidaria* was found in the lower portion of the Gilbert Chron, except at Site 699, where an older age for this event was marked. More data are needed to constrain this age assignment and to check if the occurrence pattern of the taxon is diachronous in the Southern Ocean.

Fragilariopsis arcula Partial Range Zone

Authors: Censarek and Gersonde, herein.

Definition of top: FOD of *Hemidiscus triangularus*.

Definition of base: FOD of *Fragilariopsis arcula*.

Age: middle Late Miocene, 8.45 - 7.3 Ma.

Paleomagnetic correlation: This zone ranges from the lower part of Subchron C4r up to the Subchron C3Br.2r.

Remark: This zone replaces the lower portion of the *C. intersectus* Zone of Gersonde and Burckle (1990) as well as the lower part of NSOD Zone 12 (*T. torokina* Zone) of Baldauf and Barron (1991). The FO of *A. ingens* var. *ovalis,* a species that occurs only in rare abundances in the southern part of the Southern Ocean is close to the FOD of *F. arcula* (8.45 Ma). At Leg 120 Sites 747, 748 and 751 the stratigraphical range of *F. arcula* is disturbed by disconformities (Harwood and Maruyama, 1992).

Asteromphalus kennettii - Fragilariopsis praecurta Partial Range Zone

Authors: Censarek and Gersonde, herein.

Definition of top: FOD of *Fragilariopsis arcula*.

Definition of base: FOD of *Asteromphalus kennettii*.

Age: Late Miocene, ca.10.15 - 8.45 Ma.

Paleomagnetic correlation: The zone ranges from the middle portion of Subchron C5n.2n up to the lower part of Subchron C4r.

Discussion: This zone is close to the *A. kennettii* Zone of Gersonde and Burckle (1990) that was modified by Harwood and Maruyama (1992) and the northern Southern Ocean *A. kennettii* Zone (this paper). Gersonde and Burckle (1990) defined the top of their *A. kennettii* Zone by the FOD of *Cosmiodiscus intersectus*, a taxon that was included to *Thalassiosira oliverana* var. *sparsa* by

Harwood and Maruyama (1992). Baldauf and Barron (1991) proposed to replace the *A. kennettii* Zone of Gersonde and Burckle (1990) by the NSOD 11 (*Actinocyclus fryxellae)* Zone, arguing, that the nominate species of the *A. kennettii* Zone should not be used as a biostratigraphic marker because its occurrence might be easily biased by selective dissolution. However, Harwood and Maruyama (1992) reestablished the *A. kennettii* Zone of Gersonde and Burckle (1990) while modifying the definition of the top by the FOD of *Thalassiosira torokina*.

Consistently with our results, *A. kennettii* was reported from Leg 119 Holes 744A and 746A having its FO in the middle portion of Chron C5n.2n (Baldauf and Barron, 1991). In the northern area of the Southern Ocean the FOD of *A. kennettii* might occur somewhat earlier (see discussion of *A. kennettii* Zone in NSODZ section). We did not consider *A. fryxellae* and *T. torokina* as taxonomic markers for the SSODZ because of the rare and scattered occurrence of both taxa in the studied holes.

***Fragilariopsis praecurta* Partial Range Zone**

Authors: Gersonde and Burckle (1990), revised herein.

Definition of top: FOD of *Asteromphalus kennettii.*

Definition of base: FOD of *Fragilariopsis praecurta*.

Age: Middle to Late Miocene, 11.4 - ca. 10.15 Ma.

Paleomagnetic correlation: The zone ranges from the Subchron C5r.2r up to the middle portion of Subchron C5n.2n.

Discussion: This zone was originally described as *Nitzschia praecurta* Zone (Gersonde and Burckle, 1990). The transfer of *Nitzschia praecurta* to the genus *Fragilariopsis* by Gersonde and Bárcena (1998) resulting in the new zonal name. Gersonde and Burckle (1990) correlated the base of the zone with the reversed interval between Subchrons C5N-2 and C5N-1. However, in the magnetostratigraphical interpretation of Spieß (1990) the normal polarised interval C5N-2 is documented as C5N-3, which was translated to the nomenclature of Cande and Kent (1992) in C5n.2n. Thus, we place the base of the *Fragilariopsis praecurta* Zone into Subchron C5r.2r (Figs. 2.4, 2.6).

***Denticulopsis dimorpha - Denticulopsis ovata* Partial Range Zone**

Authors: Censarek and Gersonde, herein.

Definition of top: FOD of *Fragilariopsis praecurta.*

Definition of base: LOD of *Nitzschia denticuloides.*

Age: upper Middle Miocene, 11.8 - 11.4 Ma.

Paleomagnetic correlation: The zone ranges from the middle of Subchron C5r.3r up to Subchron C5r.2r.

Discussion: The *D. dimorpha-D. ovata* Zone correlates with the upper portion of *the D. praedimorpha* Zone of Gersonde and Burckle (1990), the middle portion of the NSOD Zone 10 (*D. dimorpha* Zone) of Baldauf and Barron (1991) and the lower portion of the *D. dimorpha* Zone of Harwood and Maruyama (1992). We propose to use the LOD of *N. denticuloides* as a stratigraphical event for redefinition of the zonal base of the *D. dimorpha* Zone, as proposed by Harwood and Maruyama (1992). The age assignment for the *N. denticuloides* LOD placed by Harwood and Maruyama (1992) near or slightly below the base of magnetostratigraphic Subchron C5N-3 (=C5r.2n) relies on an extrapolation because this subchron is present at none of the OPD Leg 120 sites. However, Harwood and Maruyama's estimate is only slightly younger than our absolute age assignment (11.8 Ma) that is based on a linear extrapolation of the sedimentation rate at Site 690 between Subchrons C5n.2n and C5An.1n. Further stratigraphic information on the range of *N. denticuloides* comes from Hole 737B (Baldauf and Barron, 1991), but unfortunately no magnetostratigraphic data are available from this site. At Site 1092 we found the LO of *N. denticuloides* also between C5n.2n and C5An.1n (Fig. 2.10).

***Denticulopsis ovata-Nitzschia denticuloides* Partial Range Zone**

Authors: Censarek and Gersonde, herein.

Definition of top: LOD of *Nitzschia denticuloides.*

Definition of base: FOD of *Denticulopsis ovata.*

Age: Middle Miocene, 12.1 - 11.8 Ma.

Paleomagnetic correlation: The zone ranges from the Subchron C5An.1r up to the middle portion of Subchron C5r.3r.

Discussion: This zone is closely related to the *D. praedimorpha-N. denticuloides* Zone of Harwood and Maruyama (1992) and falls within the lower portion of the NSOD Zone 10 (*D. dimorpha* Zone) of Baldauf and Barron (1991). The base of both, the *D. praedimorpha-N. denticuloides* Zone and the *D. dimorpha* Zone was defined by the FOD of *D. dimorpha* which defines the base of the following *D. dimorpha* Zone in our SSODZ. The occurrence of *D. ovata*, a species originally described by Schrader (1976) as *Denticula hustedtii* var. *ovata* and emended by Yanagisawa and Akiba (1990), allows a zonal refinement in the lower portion of Chron C5. The FO of *D. ovata* is located in Hole 748B (Leg 120) between Subchrons C5n.2n and C5An.1n (Harwood and Maruyama, 1992).

Denticulopsis dimorpha **Partial Range Zone**

Authors: Baldauf and Barron (1991) as NSOD Zone 10 (*D. dimorpha* acme zone), modified herein.

Definition of top: FOD of *Denticulopsis ovata.*

Definition of base: FOD of *Denticulopsis dimorpha.*

Age: Middle Miocene, 12.75 - 12.1 Ma.

Paleomagnetic correlation: The zone ranges from the Subchron C5Ar.2r up to the middle portion of Chron C5r.3r.

Discussion: The original definition of the zonal top (LCO of *D. dimorpha*) was replaced by the FOD of *Denticulopsis ovata.* The species counting revealed that the FOD of *D. dimorpha* is older than previously reported (Gersonde and Burckle, 1990) and is correlated to Subchron C5Ar.2r (Figs. 2.4, 2.6).

Denticulopsis praedimorpha **Partial Range Zone**

Authors: Gersonde and Burckle (1990), modified by Baldauf and Barron (1991) as NSOD Zone 9 (*D. praedimorpha* Partial Range Zone), modified herein.

Definition of top: FOD of *Denticulopsis dimorpha.*

Definition of base: FOD of *Denticulopsis praedimorpha.*

Age: Middle Miocene, 12.85 - 12.75 Ma.

Paleomagnetic correlation: The zone ranges from the upper part of Subchron C5Ar.3r up to the Subchron C5Ar.2r.

Discussion: This zone is equivalent to the lower portion of the *D. praedimorpha* Zone described by Gersonde and Burckle (1990) and modified by Baldauf and

Barron (1991) (Fig. 2.1). In their zonal description, Baldauf and Barron (1991) presented an erroneous magnetostratigraphic age assignment for the base of this zone. The first stratigraphic occurrence of the nominate taxon is not documented at Site 744 due to the occurrence of a hiatus, which however is not indicated in figure 4 of Baldauf and Barron (1991). Also at Leg 120 Sites, the base of this zone is not documented (Harwood and Maruyama, 1992). Based on our species counting we found a slightly earlier FOD of *D. praedimorpha* than presented by Gersonde and Burckle (1990) from Sites 689 and 690 (Figs. 2.4, 2.6).

Nitzschia denticuloides **Partial Range Zone**

Authors: Weaver and Gombos (1981), redefined by Gersonde and Burckle (1990), revised herein.

Definition of top: FOD of *Denticulopsis praedimorpha.*

Definition of base: FOD of *Nitzschia denticuloides.*

Age: Middle Miocene, 13.5 - 12.85 Ma.

Paleomagnetic correlation: The zone ranges from the lower portion of Chron C5ABn up to the upper part of Subchron C5Ar.3r.

Discussion: Gersonde and Burckle (1990) defined the top of the zone by the FOD of *D. praedimorpha* to replace the last abundant appearance datum (LAAD) of *N. denticuloides* as proposed by Weaver and Gombos (1981). The FOD of *N. denticuloides* was correlated to lower portion of Chron C5ABn in Holes 747A and 751A (Harwood and Maruyama, 1992). In their zonal description, Gersonde and Burckle (1990) present a FOD of *N. denticuloides* that falls between Subchrons C5AN-7 (=C5ACn) and C5AN-6 (=C5ABn). This is inconsistent with the data presented in their Hole 689B range charts, where first *N. denticuloides* were reported from an interval that correlates with the upper portion of C5ABn. Our reinvestigation found that the FOD of *N. denticuloides* in Hole 689B coincides with the results from Harwood and Maruyama (1992) and can be correlated with the lower portion of Chron C5ABn (Fig. 2.4).

Our study also shows that a stratigraphic coincidence of the LOD of *N. grossepunctata* with the FOD of *N. denticuloides*, as reported by Weaver and Gombos (1981) and Gersonde and Burckle (1990), must be questioned. We found rare but continuous occurrences of *N. grossepunctata* ranging into the lower portion of the *N. denticuloides* Zone (Fig. 2.3). *N. denticuloides*, *Cruciden-*

ticula nicobarica, Actinocyclus ingens var. *nodus* and *Nitzschia grossepunctata* comprise the typical diatom assemblage of this zone (Figs. 2.4, 2.6).

Denticulopsis simonsenii - Nitzschia grossepunctata Partial Range Zone

Authors: Gersonde and Burckle (1990), renamed herein.

Definition of top: FOD of *Nitzschia denticuloides.*

Definition of base: FOD of *Denticulopsis simonsenii.*

Age: Middle Miocene, 14.2 - 13.5 Ma.

Paleomagnetic correlation: The zone ranges from the top of Chron C5ADn up to the lower portion of Chron C5ABn.

Discussion: Considering revision of the genus *Denticulopsis* (Yanagisawa and Akiba, 1990) the former *D. hustedtii - N. grossepunctata* Zone (Gersonde and Burckle, 1990) was renamed (Fig. 2.1). The stratigraphic ranges of *Denticulopsis* taxa at Holes 689B and 690B confirm that specimen previously related to *D. hustedtii* are conspecific with *D. simonsenii*, a taxon newly described by Yanagishawa and Akiba (1990). Baldauf and Barron (1991) reported at Site 744 a FOD of *D. simonsenii* (as *D. hustedtii*) correlated to Chron C5ADn, which agrees with our results.

Actinocyclus ingens var. _nodus_ Partial Range Zone

Authors: Harwood and Maruyama (1992).

Definition of top: FOD of *Denticulopsis simonsenii.*

Definition of base: FOD of *Actinocyclus ingens* var. *nodus.*

Age: Middle Miocene, ca. 14.35 - 14.2 Ma.

Paleomagnetic correlation: This zone ranges from the middle portion to the top of Chron C5ADn.

Nitzschia grossepunctata Partial Range Zone

Authors: Weaver and Gombos (1981), redefined by Gersonde and Burckle (1990), modified by Harwood and Maruyama (1992).

Definition of top: FOD of *Actinocyclus ingens* var. *nodus.*

Definition of base: FOD of *Nitzschia grossepunctata.*

Age: early Middle Miocene, 15.2 - ca. 14.35 Ma.

Paleomagnetic correlation: The zone ranges from the upper portion of Chron C5Br up to the middle part of Chron C5ADn.

Discussion: Weaver and Gombos (1981) defined the top of the zone with the LOD of *C. lewisianus*. This was redefined by Gersonde and Burckle (1990) by the FOD of *D. hustedtii* (= FOD of *D. simonsenii*). Introducing the *A. ingens* var. *nodus* Zone, Harwood and Maruyama (1992) divided this zone into two zones. Thus, the present *N. grossepunctata* Zone is equivalent to the middle and lower portion of the *N. grossepunctata* Zone of Gersonde and Burckle (1990) (Fig. 2.1). Characteristic assemblages in the lower portion of this zone comprise nominate species, *Cavitatus jouseanus* and *F. maleinterpretaria* (Figs. 2.4, 2.6).

Actinocyclus ingens - Denticulopsis maccollumii Partial Range Zone

Authors: Baldauf and Barron (1991), modified by Harwood and Maruyama (1992).

Definition of top: FOD of *Nitzschia grossepunctata.*

Definition of base: FOD of *Actinocyclus ingens.*

Age: late Early Miocene, ca. 16.2 - 15.2 Ma.

Paleomagnetic correlation: The zone ranges from the middle portion of Chron C5Cn.1n up to upper portion of Chron C5Br.

Discussion: Baldauf and Barron (1991) established the NSOD Zone 6 (*A. ingens - D. maccollumii*) Zone using the FOD of *A. ingens* for the definition of the base. The upper portion of the NSOD Zone 6 is equivalent to the *A. ingens* var. *nodus* and the *Nitzschia grossepunctata* Zone, proposed, respectively revised by Harwood and Maruyama (1992). The lower portion of the NSOD Zone 6 is equivalent to the *A. ingens - D. maccollumii* Zone of Harwood and Maruyama (1992) who define its base by the FCOD (First common occurrence datum) of *A. ingens*. However, this definition is questionable because the base of this zone is not documented from any of the Leg 120 Sites. The evidence Harwood and Maruyama (1992) used for the FCOD is only based on a general statement that „*A. ingens* ... is known to occur ... in the lower lower Miocene". In addition, the sediments drilled during Leg 113 do not document the FOD of *A. ingens* due to the occurrence of disconformities. For definition and age assignment of the base of the *A. ingens-D. maccollumii* Zone we follow Baldauf and Barron (1991) using the FOD of *A. ingens*, which occurs in Hole 744B in the upper portion of

Chron C5n with an age of ca. 16.2 Ma according to the GPTS of Cande and Kent (1995).

Denticulopsis maccollumii **Partial Range Zone**

Authors: McCollum (1975), renamed and modified by Gersonde and Burckle (1990), redefined by Harwood and Maruyama (1992).

Definition of top: FOD of *Actinocyclus ingens.*

Definition of base: FOD of *Denticulopsis maccollumii.*

Age: late Early Miocene, ca. 16.7 - ca. 16.2 Ma.

Paleomagnetic correlation: This zone ranges from the uppermost part of Chron C5Cr up to the middle portion of Chron C5Cn.1n.

Discussion: Gersonde and Burckle (1990) renamed this zone from *Denticula antarctica* to *D. maccollumii* Zone and modified the top of the zone. Later on Harwood and Maruyama (1992) defined the top with the FCOD of *A. ingens*. In Hole 747A, as well as in Hole 751A, the FO of *D. maccollumii* falls with the upper portion of Chron C5Cr (Harwood and Maruyama, 1992). Baldauf and Barron (1991) reported the same for Site 744.

Crucidenticula kanayae **Partial Range Zone**

Authors: Harwood and Maruyama (1992).

Definition of top: FOD of *Denticulopsis maccollumii.*

Definition of base: FOD of *Crucidenticula kanayae.*

Age: late Early Miocene, ca. 17.4 - ca. 16.7 Ma.

Paleomagnetic correlation: This zone ranges from the middle of Chron C5D up to the uppermost part of Chron C5Cr.

Remark: This zone established by Harwood and Maruyama (1992) comprises portions of the *D. maccollumii* and *N. maleinterpretaria* Zone proposed by Gersonde and Burckle (1990). The FO of *C. kanayae* is documented in Hole 744B (Leg 119) and correlated to the lower portion of Chron C5Dn (Baldauf and Barron, 1991). Harwood and Maruyama (1992) report the same from Holes 747A, 748B and 751A.

2.4.2 Definition of northern Southern Ocean diatom biostratigraphic zonation (NSODZ)

***Thalassiosira inura* Partial Range Zone**

Authors: Gersonde and Burckle (1990), revised by Baldauf and Barron (1991) as NSOD Zone 14 (*T. inura* Partial Range Zone), revised herein.

Definition of top: FOD of *Fragilariopsis barronii.*

Definition of base: FOD of *Thalassiosira inura.*

Age: Early Pliocene, ca. 4.9 - ca. 4.5 Ma.

Paleomagnetic correlation: This zone ranges from the uppermost portion of Subchron C3n.3r close to the base of Subchron C3n.3n to interval between the top of C3n.2n and the lowermost portion of Subchron C3n.1r.

Remark: Sediments related to this zone are bounded by disconformities at Site 1092. For this reason we use the zonal definitions and age assignments applied to the southern zonation. Characteristic species within the *T. inura* Zone are *F. praeinterfrigidaria* and *F. lacrima* (Fig. 2.10).

Discussion: Ciesielski (1983) notes that the FOD of *N. angulata* (=*F. barronii*) is diachronous in most of his cores. From Site 704 a FO of the species in Subchron C3n.2n is reported (Ciesielski, 1991; Hailwood and Clement, 1991b). This differs from our results in the southern zonation (lowermost portion of C3n.1r). Due to the occurrence of disconformities in the Lower Pliocene of Leg 177 Sites 1090 and 1092 (Zielinski and Gersonde, 2002) that do not allow a definition of the FOD of *F. barronii*, the exact timing of this event in the northern portion of the Southern Ocean is not possible and awaits for further investigations.

***Hemidiscus triangularus-Fragilariopsis aurica* Partial Range Zone**

Authors: Censarek and Gersonde, herein.

Definition of top: FOD of *Thalassiosira inura.*

Definition of base: FOD of *Hemidiscus triangularus.*

Age: Late Miocene to Early Pliocene, 7.3 - ca. 4.9 Ma.

Paleomagnetic correlation: The zone ranges from the upper part of Subchron C3Br.2r up to the uppermost portion of Subchron C3n.3r close to the base of Subchron C3n.3n.

Remark: This zone is stratigraphically equivalent to the *H. triangularus-F. aurica* Zone proposed for the southern zonation of the Southern Ocean (Fig. 2.1). A disconformity bounds the upper portion of the *H. triangularus* Zone at Site 1092 (Fig. 2.10). For further discussion see zonal description in SSODZ section.

***Fragilariopsis reinholdii* Partial Range Zone**

Authors: Censarek and Gersonde, herein.

Definition of top: FOD of *Hemidiscus triangularus*.

Definition of base: FOD of *Fragilariopsis reinholdii*.

Age: Late Miocene, ca. 7.95 - 7.3 Ma.

Paleomagnetic correlation: The zone ranges from the lower portion of Subchron C4n.2n up to the upper portion of Subchron C3Br.2r.

Remark: Nominate species has been transferred to the genus *Fragilariopsis* (Zielinski and Gersonde, 2002).

Discussion: Our zone is not identical with the *Nitzschia reinholdii* Zone proposed by Harwood and Maruyama (1992) and defined by the FOD of *Thalassiosira miocenica* (base) and the FOD of *T. oestrupii* (top). Reasons for not following the zonation proposed by Harwood and Maruyama (1992) are discussed in the description of the *H. triangularus-F. aurica* Zone presented in the SSODZ section. The *F. reinholdii* Zone is equivalent to the upper portion of the *F. arcula* Zone proposed for the SSODZ (see above), the middle portion of the *Hemidiscus ovalis* Zone of Harwood and Maruyama (1992) and lower parts of the long-ranging *Cosmiodiscus intersectus* and NSOD 12 (*T. torokina* Zone) Zones proposed by Gersonde and Burckle (1990) and Baldauf and Barron (1991) for the Late Miocene, respectively (Fig. 2.1). Together with the following *Actinocyclus ingens* var. *ovalis* Zone the *F. reinholdii* Zone helps to refine the Late Miocene diatom zonation in the northern area of the Southern Ocean. The FO of *F. reinholdii* was placed into the lower portion of Subchron C4n.2n. This is consistent with the data from Ciesielski (1991) who reports the FO of *F. reinholdii* in Hole 704B (Leg 114) from the upper portion of Chron C4An, according to the data of Hailwood and Clement (1991b). However, erroneously a wrong age assignment for this event was presented in table 3 of Hailwood and Clement (1991b). Further indication for the FO age assignment of *F. reinholdii* in southern latitudes comes from Baldauf and Barron (1991). They report the FO of a *Fragilariopsis* *marina/F. reinholdii*-group in Hole 746A to be correlated to the lower portion of an extended normal polarised interval (?C4n.2n) of Chron C4. Thus the FOD of *F. reinholdii* in the northern zone of the Southern Ocean is synchronous or nearly synchronous to its FOD in the Equatorial Pacific, where it was placed into Chron C4 (Barron, 1992a).

***Actinocyclus ingens* var. *ovalis* Partial Range Zone**

Authors: Harwood and Maruyama (1992), modified herein.

Definition of top: FOD of *Fragilariopsis reinholdii.*

Definition of base: FOD of *Actinocyclus ingens* var. *ovalis.*

Age: Late Miocene, 8.7 - ca. 7.95 Ma.

Paleomagnetic correlation: The zone ranges from the base of Subchron C4r.2r up to the lower portion of Subchron C4n.2n.

Discussion: This zone is equivalent to the lower portion of the *Hemidiscus ovalis* Zone of Harwood and Maruyama (1992). Harwood and Maruyama (1992) transferred *Actinocyclus ingens* var. *ovalis* to *Hemidiscus ovalis.* We cannot follow this transfer because of the lack of distinct morphological characteristics that would require a transfer of the original taxon to the genus *Hemidiscus.* In Hole 747A (Leg 120) the FO of the species is in Chron C4An (Harwood and Maruyama, 1992). The FOD of *A. ingens* var. *ovalis* was found in Hole 746A (Leg 119) in the lower portion of a normal polarity interval in Chron C4 (Baldauf and Barron, 1991). In Hole 689B we found the base of the stratigraphical range of *A. ingens* var. *ovalis* in the lowermost part of Chron C4 (Fig. 2.4).

***Asteromphalus kennettii* Partial Range Zone**

Authors: Gersonde and Burckle (1990), modified by Harwood and Maruyama (1992), modified herein.

Definition of top: FOD of *Actinocyclus ingens* var. *ovalis.*

Definition of base: FOD of *Asteromphalus kennettii.*

Age: early Late Miocene, ca. 10.3 - 8.7 Ma.

Paleomagnetic correlation: This zone ranges from Subchron C5n.2n up to the base of Subchron C4r.2r.

Discussion: This zone is close to the *Asteromphalus kennettii-Fragilariopsis praecurta* Zone of our SSODZ (for discussion see SSODZ section). However, the definition of the top of this zone differs. Another difference might concern the basal age of the zone. Linear extrapolation of sedimentation rates at Site 1092 as well as in Hole 704B (see data in Ciesielski, 1991 and Hailwood and Clement, 1991b) indicate a slightly older (0.1-0.2 m.y.) FOD of *A. kennettii* in the northern area of the Southern Ocean (Tab. 2.3).

Denticulopsis ovata **Partial Range Zone**

Authors: Censarek and Gersonde, herein.

Definition of top: FOD of *Asteromphalus kennettii.*

Definition of base: FOD of *Denticulopsis ovata.*

Age: early Late Miocene, 11.1 - ca. 10.3 Ma.

Paleomagnetic correlation: This zone ranges from the upper portion of Subchron C5r.2r up to the middle part of Subchron C5n.2n.

Denticulopsis dimorpha - D. simonsenii **Partial Range Zone**

Authors: Censarek and Gersonde, herein.

Definition of top: FOD of *Denticulopsis ovata.*

Definition of base: FOD of *Denticulopsis dimorpha.*

Age: upper Middle Miocene, 12.1 - 11.1 Ma.

Paleomagnetic correlation: This zone ranges from the upper portion of Subchron C5An.1r up to the upper part of Subchron C5r.2r.

Discussion: This zone is equivalent to the *D. praedimorpha-N. denticuloides* Zone and the lower part of the *D. dimorpha* Zone of Harwood and Maruyama (1992). In the lower portion of this zone the LO of *N. denticuloides* at 11.8 Ma provides a useful stratigraphic datum (Fig. 2.1). The reliability of this datum is discussed in description of the *Denticulopsis dimorpha-Denticulopsis praedimorpha* Partial Range Zone (see SSODZ section).

***Denticulopsis simonsenii* Partial Range Zone**

Authors: Censarek and Gersonde, herein.

Definition of top: FOD of *Denticulopsis dimorpha.*

Definition of base: FOD of *Denticulopsis simonsenii.*

Age: Middle Miocene, 14.2 - 12.1 Ma.

Paleomagnetic correlation: This zone ranges from the top of Chron C5ADn up to the upper part of Subchron C5An.1r.

Remark: For discussion about the FOD of *D. simonsenii* see *Denticulopsis simonsenii-Nitzschia grossepunctata* Partial Range Zone in the SSODZ section.

***Actinocyclus ingens* var. *nodus* Partial Range Zone**

Authors: Harwood and Maruyama (1992).

Definition of top: FOD of *Denticulopsis simonsenii.*

Definition of base: FOD of *Actinocyclus ingens* var. *nodus.*

Age: Middle Miocene, ca.14.35 -14.2 Ma.

Paleomagnetic correlation: This zone ranges from the middle portion to the top of Chron C5ADn.

Remark: This zone is equivalent to the *Actinocyclus ingens* var. *nodus* Partial Range Zone of the SSODZ.

***Actinocyclus ingens* Partial Range Zone**

Authors: Baldauf and Barron (1991), modified by Harwood and Maruyama (1992), modified and renamed herein.

Definition of top: FOD of *Actinocyclus ingens* var. *nodus.*

Definition of base: FOD of *Actinocyclus ingens.*

Age: lower Middle Miocene, ca. 16.2 - ca. 14.35 Ma.

Paleomagnetic correlation: This zone ranges from the upper portion Chron C5Cn up to the middle portion of Chron C5ADn.

Discussion: We propose this zone only preliminarily because of the problematic age assignment and the occurrence of disconformities around the Early/Middle Miocene boundary at Site 1092. For age assignment of the FOD of

A. ingens we follow Baldauf and Barron (1991) who placed the FOD of *A. ingens* in Hole 744B in the upper portion of Chron C5n. For further discussion see *A. ingens-D. maccollumii* Zone in the SSODZ section.

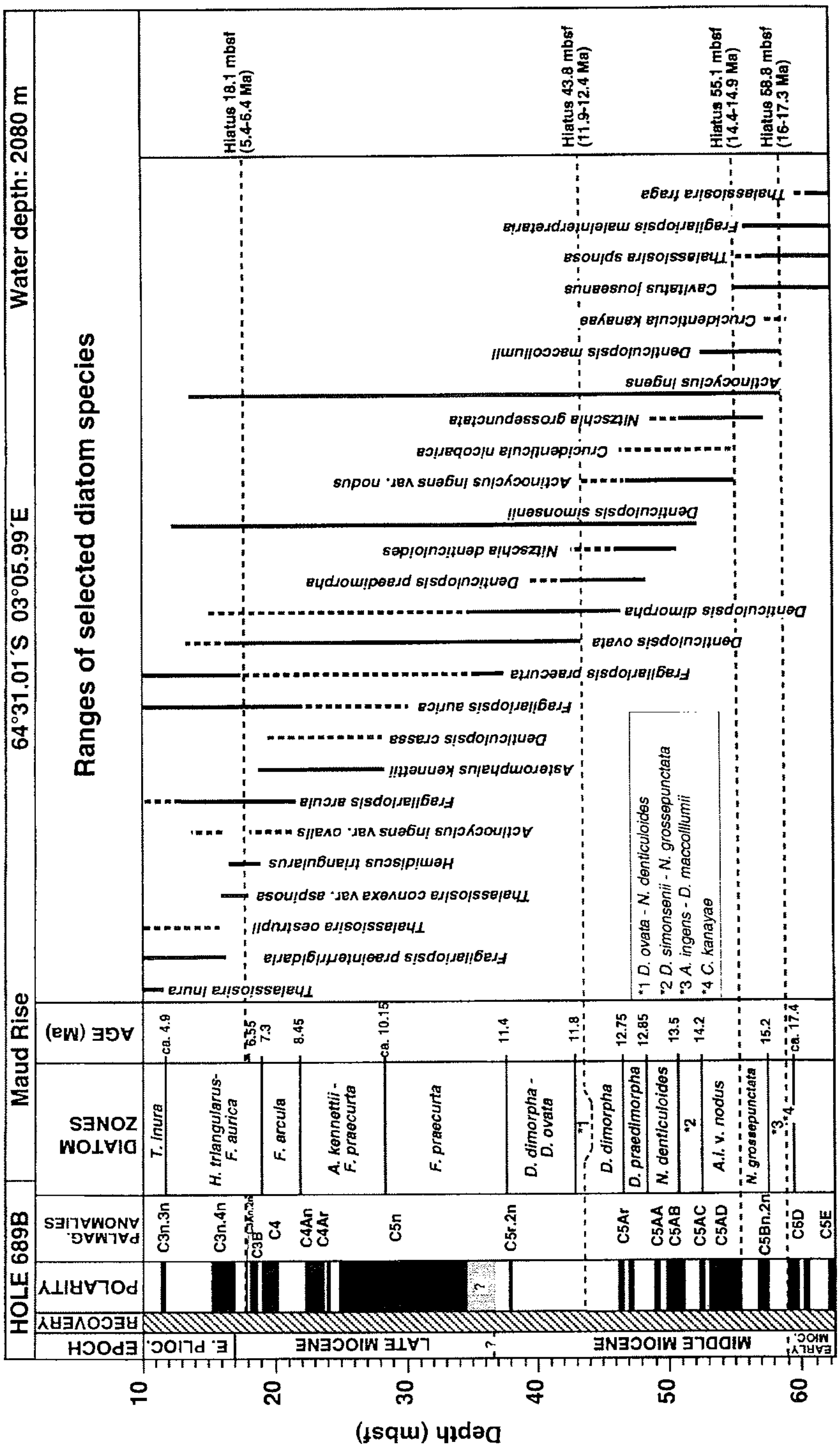
2.5 Description of sites

2.5.1 Site 689

Site 689 (64°31.01'S, 3°5.99'E) is located near the northeastern crest of Maud Rise at a water depth of 2080 m. In this study we reinvestigated a sediment interval between 10 and 62 mbsf from Hole 689B, which represents the most continuously recovered hole out of four drilled at Site 689 (Shipboard Scientific Party, 1988a). The pelagic, mostly biogenic sediments contain common to abundant diatoms with good to moderate preservation. The obtained stratigraphic data are presented on Figures 2.4 and 2.5 and in Table 2.2.

Range charts of the stratigraphic occurrence of selected diatom species are available from a data report (Table 1 in Censarek and Gersonde, subm. a), also accessible under *www-odp.tamu.edu/publications*. The reinvestigation of the Early Miocene to Early Pliocene section identified four disconformities (Fig. 2.5). The lowermost hiatus was placed at 58.8 mbsf, separating the Early Miocene from the Middle Miocene and spanning ca. 16-17.3 Ma. Two disconformities occur in the Middle Miocene and have been located at 55.1 and 43.8 mbsf. In the latest Miocene (18.1 mbsf) we found a hiatus that covers a time interval from ca. 6.4 to 5.4 Ma. The calculated average sedimentation rates range between 1 and 15 m/m.y. and reach highest values in the Late Miocene and Early Pliocene. The occurrence of *T. inura* in the absence of *F. barronii* in Sample 113-689B-2H-5, 27-28 cm, places the interval above Sample 113-689B-2H-5, 55-56 cm (11.71 mbsf) into the *T. inura* Zone. There is no diatom bio- and magnetostratigraphic evidence for the short ranging hiatus at 11.7 mbsf assumed by Gersonde and Burckle (1990). The following zone is the *H. triangularus-F. aurica* Zone, which is interrupted by the uppermost Miocene hiatus at 18.1 mbsf for a time period of extrapolated 5.4 - 6.4 Ma. Gersonde and Burckle (1990) and Spieß (1990) also report this disconformity. Below this hiatus there is the lowermost portion of Subchron C3An.2n. The base of the *H. triangularus-F. aurica* Zone is placed between samples 113-689B-3H-3, 148-150 cm and 113-689B-3H-4, 56-58 cm, marked by the FOD of *H. triangularus*. Another datum point in this zone is the FOD of *T. convexa* var. *aspinosa* (6.55 Ma) at 18.68 mbsf. Other characteristic diatoms besides the nominate species are *Fragilariopsis* *donahuensis*, *F. praecurta* and *F. arcula*. The base of the subsequent *F. arcula* Zone is placed between samples 113-689B-3H-5, 114-115 cm and 113-689B-3H-6, 28-29 cm at 21.94 mbsf. This zone is characterised by the co-occurrence of *F. arcula* and *A. ingens* var. *ovalis*. Between samples 113-689B-4H-3, 114-115 cm and 113-689B-4H-4, 29-30 cm at 28.59 mbsf is the base of the *A. kennettii-F. praecurta* Zone, which is defined by the FOD of *A. kennettii* at 10.15 Ma. This zone spans a time interval of approx. 1.7 m.y. The diatom assemblages of this zone are characterised by high abundance of *A. ingens* (Censarek and Gersonde, subm. a). This taxon is accompanied by rarer occurrences of *F. claviceps*, *F. donahuensis* and *F. praecurta*. The long-ranging *Fragilariopsis praecurta* Zone has its base between samples 113-689B-5H-3, 114-115 cm and 113-689B-5H-3, 145-147 cm at 37.94 mbsf. Characteristic species found in the *F. praecurta* Zone are *Thalassiosira yabei*, *D. dimorpha*, *D. ovata*, *Actinocyclus karstenii* and, in the upper portion of the zone, *F. aurica*. The Middle to Late Miocene boundary is in the lower portion of the *F. praecurta* Zone. The base of the underlying *Denticulopsis dimorpha-Denticulopsis ovata* Zone is placed between samples 113-689B-5H-6, 28-29 cm and 113-689B-5H-6, 114-115 cm at 43.06 mbsf. The base is defined by the LOD of *Nitzschia denticuloides* (11.8 Ma). The occurrence of *D. dimorpha*, *D. praedimorpha* characterise the assemblages of this zone. The following *D. ovata-N. denticuloides* Zone is marked by a disconformity at 43.8 mbsf. This hiatus, which is also reported by Gersonde and Burckle (1990), spans from 11.9 to 12.4 Ma and omits the normal polarised Subchrons C5An.1n and C5An.2n and thus most of the *D. ovata-N. denticuloides* Zone and the upper portion of the underlying *D. dimorpha* Zone. The hiatus is very likely tied to major oceanographic changes associated with the Middle Miocene cooling event (Censarek and Gersonde, subm. a). The base of the *Denticulopsis dimorpha* Zone between samples 113-689B-6H-3, 28-29 cm and 113-689B-6H-3, 114-115 cm, is defined by the FOD of the nominate species. The FO of Denticulopsis praedimorpha between samples 113-689B-6H-4, 28-29 cm and 113-689B-6H-4, 114-115 cm at 48.51 mbsf places the interval above into the D. praedimorpha Zone.

Figure 2.4 (right): Stratigraphic ranges of selected diatom species in the reinvestigated Miocene section of Hole 689B and diatom zonal assignment tied to the geomagnetic data of Spieß (1990). The chron nomenclature is according to Cande and Kent (1992). Dotted lines indicate scattered and trace occurrences of diatom taxa


HOLE 689B
Maud Rise
64°31.01'S 03°05.99'E
Water depth: 2080 m
Ranges of selected diatom species
EPOCH
RECOVERY
POLARITY
PALMAG. ANOMALIES
DIATOM ZONES
AGE (Ma)
Depth (mbsf)
E. PLIOC.
LATE MIOCENE
MIDDLE MIOCENE
EARLY MIOC.
Hiatus 18.1 mbsf (5.4-6.4 Ma)
Hiatus 43.8 mbsf (11.9-12.4 Ma)
Hiatus 55.1 mbsf (14.4-14.9 Ma)
Hiatus 58.8 mbsf (16-17.3 Ma)
*1 D. ovata - N. denticuloides
*2 D. simonsenii - N. grossepunctata
*3 A. ingens - D. maccollumii
*4 C. kanayae
Thalassiosira inura
Fragilariopsis praeinterfrigidaria
Thalassiosira oestrupii
Thalassiosira convexa var. aspinosa
Hemidiscus triangularus
Actinocyclus ingens var. ovalis
Fragilariopsis arcula
Asteromphalus kennettii
Denticulopsis crassa
Fragilariopsis aurica
Fragilariopsis praecurta
Denticulopsis ovata
Denticulopsis dimorpha
Denticulopsis praedimorpha
Nitzschia denticuloides
Denticulopsis simonsenii
Actinocyclus ingens var. nodus
Crucidenticula nicobarica
Nitzschia grossepunctata
Actinocyclus ingens
Denticulopsis maccollumii
Crucidenticula kanayae
Cavitatus jouseanus
Thalassiosira spinosa
Fragilariopsis maleinterpretaria
Thalassiosira fraga

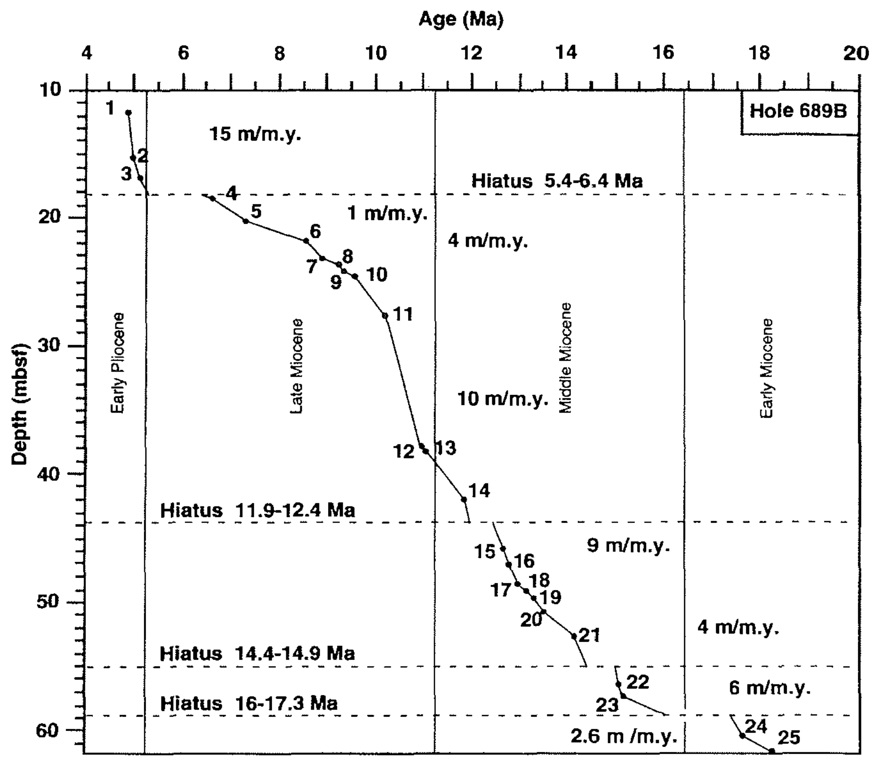


Figure 2.5: Age-depth diagram for the Miocene of Hole 689B and calculated average sedimentation rates. For definition of stratigraphic datum points compare Table 2.2.

In this zone few occurrences of D. praedimorpha, Actinocyclus ingens var. nodus, Denticulopsis simonsenii and N. denticuloides are noted. The next biostratigraphic unit is the N. denticuloides Zone found between samples 113-689B-6H-5, 114-115 cm and 113-689B-6H-6, 28-29 cm at 50.76 mbsf. Typical species within this zone are Crucidenticula nicobarica, Nitzschia grossepunctata, A. ingens var. nodus and D. simonsenii. The FO of D. simonsenii between samples 113-689B-6H-7, 28-29 cm and 113-689B-7H-1, 28-29 cm places the interval above into the D. simonsenii-N. grossepunctata Zone. Below this interval the quality of diatom preservation decreases. The lower portion of the following A. ingens var. nodus Zone is omitted by a hiatus found at 55.1 mbsf ranging from ca. 14.4 to 14.9 Ma.

Table 2.2: Definition of stratigraphic datum points in the Miocene section of Hole 689B used to construct the age-depth diagram in Figure 2.5.

Datum points	Depth (mbsf)	Age (Ma)	Definition
1	11.72	4.89	Base C3n.3n
2	15.17	4.98	Top C4n.3n
3	16.92	5.23	Base C4n.3n
Hiatus	18.1	5.4-6.4	
4	18.67	6.567	Base 3An.2n
5	20.05	7.3	FOD *H. triangularus*
6	22.15	8.699	Top C4An
7	23.65	9.025	Base C4An
8	23.81	9.230	Top C4Ar.1n
9	24.17	9.308	Base C4Ar.1n
10	24.67	9.58	Top C4Ar.2n
11	27.72	10.15	FOD *A. kennettii*
12	37.93	10.949	Base C5n
13	38.26	11.4	FOD *F. praecurta*
14	42.01	11.8	LOD *N. denticuloides*
Hiatus	43.8	11.9-12.4	
15	45.93	12.678	Top C5Ar.1n
16	47.18	12.819	Base C5Ar.2n
17	48.68	12.991	Top C5AA
18	49.18	13.139	Base C5AA
19	49.68	13.302	Top C5AB
20	50.91	13.51	Base C5AB
21	52.8	14.2	FOD *D. simonsenii*
Hiatus	55.1	14.4-14.9	
22	56.53	15.034	Top C5Bn.2n
23	57.4	15.155	Base C5Bn.2n
Hiatus	58.8	16-17.3	
24	60.4	17.615	Base C5Dn
25	61.76	18.281	Top C5En

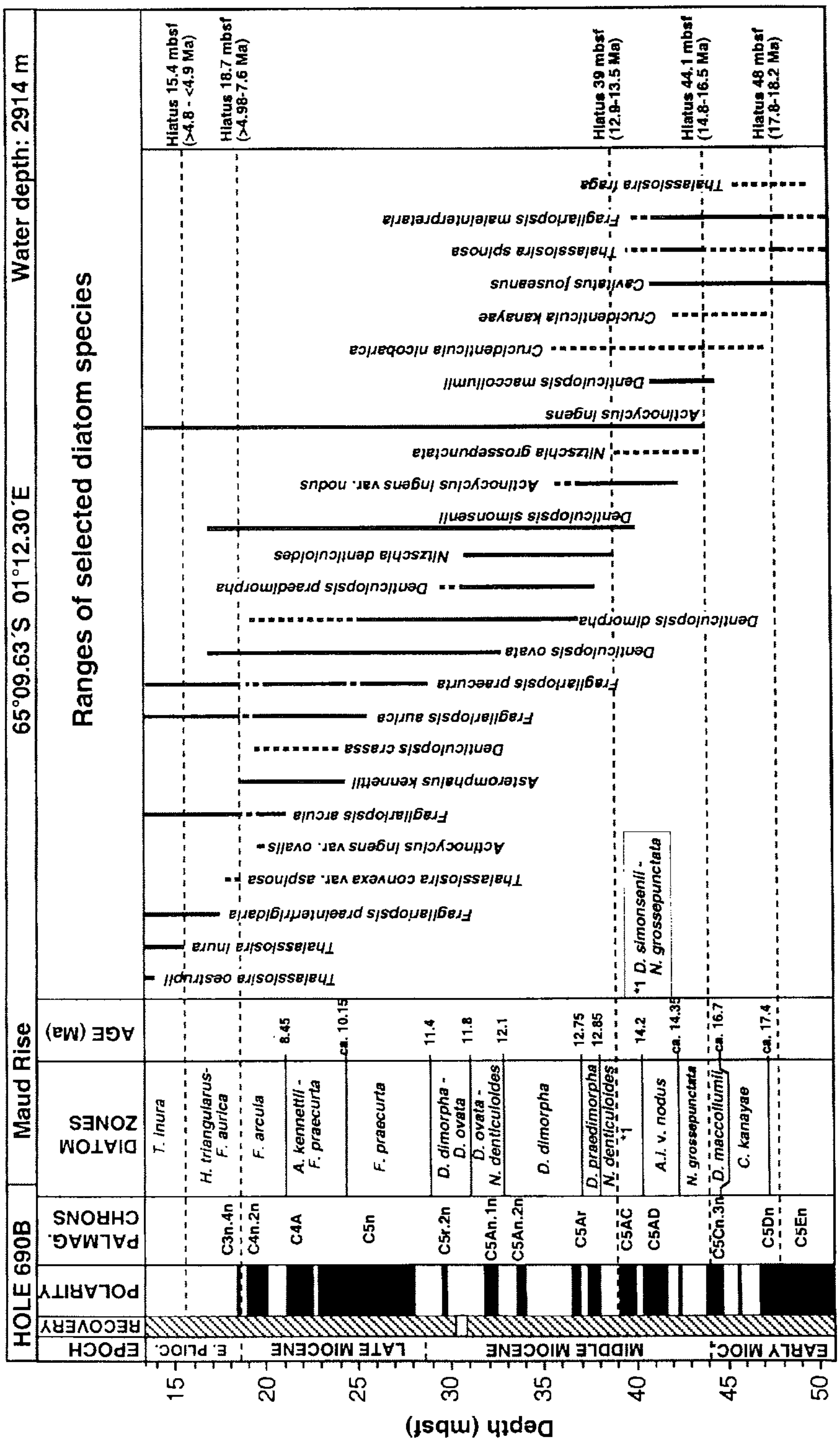
This disconformity, also reported by Gersonde and Burckle (1990) and Spieß (1990), is indicated by the joint FOs of *A. ingens* var. *nodus*, *C. nicobarica* and the LOD of *Cavitatus jouseanus*. Besides the nominate species the assemblage of the *A. ingens* var. *nodus* Zone is characterised by *Denticulopsis maccollumii*, *C. nicobarica* and *N. grossepunctata*. Below the hiatus the *N. grossepunctata* Zone was recognised with its base between samples 113-689B-7H-3, 145-147 cm and 113-689B-7H-4, 28-29 cm at 57.51 mbsf. The sediments at the base of the zone correspond to the lower portion of Subchron C5Bn.2n. Typical species within this zone are *C. jouseanus*, *Thalassiosira spinosa* and *Fragilariopsis maleinterpretaria*. The sediments of the lower *A. ingens-D. maccollumii* Zone and of the *D. maccollumii* Zone are not present due to a hiatus located at 58.8 mbsf. This conspicuous hiatus separates the Early from the Middle Miocene and spans from approx. 16 to 17.3 Ma. Similar hiatuses at the Early to Middle Miocene boundary can also be observed at Sites 690 and 1092. Occurrences of

A. ingens, *C. kanayae*, *C. jouseanus* and *F. maleinterpretaria* characterise the *A. ingens-D. maccollumii* Zone. The lowermost zone in the studied interval is the *Crucidenticula kanayae* Zone, whose base was found between samples 113-689B-7H-5, 28-29 cm and 113-689B-7H-5, 55-57 cm at 59.62 mbsf. The assemblage consists of only few diatom species, dominated by *F. maleinterpretaria*, *C. jouseanus* and *Coscinodiscus lewisianus*. Below this zone the assemblage is characterised by occurrences of *C. jouseanus*, *T. spinosa*, *F. maleinterpretaria* and *Thalassiosira fraga*.

2.5.2 Site 690

Site 690 (65°09.63'S, 01°12.30'E) is located on the western flank of Maud Rise in 2914 m water depth. Hole 690B contains a total sediment section of 213.4 m, providing the most continuous recovery of three drilled holes (Shipboard Scientific Party, 1988b). The lower Miocene to lowermost Pliocene sediments (51 to 13 mbsf) were restudied. A recovery gap, spanning at least a period of 0.1 m.y. disturbs the sediment below the Middle/Late Miocene boundary. The stratigraphic data are presented on Figures 2.6 and 2.7 and on Table 2.3. Range charts of the stratigraphic occurrence of selected diatom species from the studied interval are available from a data report (Table 2 in Censarek and Gersonde, subm. a), also accessible under *www-odp.tamu.edu/publications*.The study of the Lower Miocene to Lower Pliocene section identified five disconformities. The lowermost hiatus was placed at 48 mbsf and spans from ca. 18.2 to 17.8 Ma. As it was observed at Site 689, the Lower Miocene is separated from the Middle Miocene by a hiatus, located at 44.1 mbsf. The third disconformity, at 39 mbsf, has a range of about 0.6 m.y. in the lower portion of the Middle Miocene. At 18.7 mbsf the Miocene is separated from the Pliocene by a hiatus that ranges from ca. 7.6 Ma into the lowermost Pliocene. The uppermost disconformity identified in the studied section is at around 15.4 mbsf. The calculated average sedimentation rates range between 2 and 10 m/m.y. (Fig. 2.7) and display a similar pattern to the sedimentation rate at Site 689 (Fig. 2.5).

Figure 2.6 (right): Stratigraphic ranges of selected diatom species in the reinvestigated Miocene section of Hole 690B and diatom zonal assignment tied to the geomagnetic data of Spieß (1990). The chron nomenclature is according to Cande and Kent (1992). Dotted lines indicate scattered and trace occurrences of diatom taxa.


HOLE 690B
Maud Rise
65°09.63'S 01°12.30'E
Water depth: 2914 m
Ranges of selected diatom species
EPOCH
RECOVERY
POLARITY
PALMAG. CHRONS
DIATOM ZONES
AGE (Ma)
Depth (mbsf)
E. PLIOC.
LATE MIOCENE
MIDDLE MIOCENE
EARLY MIOC.
Hiatus 15.4 mbsf (>4.8 - <4.9 Ma)
Hiatus 18.7 mbsf (>4.98-7.6 Ma)
Hiatus 39 mbsf (12.8-13.5 Ma)
Hiatus 44.1 mbsf (14.8-16.5 Ma)
Hiatus 48 mbsf (17.8-18.2 Ma)
Thalassiosira oestrupii
Thalassiosira inura
Fragilariopsis praeinterfrigidaria
Thalassiosira convexa var. aspinosa
Actinocyclus ingens var. ovalis
Fragilariopsis arcula
Asteromphalus kennettii
Denticulopsis crassa
Fragilariopsis aurica
Fragilariopsis praecurta
Denticulopsis ovata
Denticulopsis dimorpha
Denticulopsis praedimorpha
Nitzschia denticuloides
Denticulopsis simonsenii
Actinocyclus ingens var. nodus
Nitzschia grossepunctata
Actinocyclus ingens
Denticulopsis maccollumii
Crucidenticula nicobarica
Crucidenticula kanayae
Cavitatus jouseanus
Thalassiosira spinosa
Fragilariopsis maleinterpretaria
Thalassiosira fraga
*1 D. simonsenii - N. grossepunctata
T. inura
H. triangularus-F. aurica
F. arcula
A. kennettii - F. praecurta
F. praecurta
D. dimorpha - D. ovata
D. ovata - N. denticuloides
D. dimorpha
D. praedimorpha
N. denticuloides
*1
A.I. v. nodus
N. grossepunctata
D. maccollumii
C. kanayae
C3n.4n
C4n.2n
C4A
C5n
C5r.2n
C5An.1n
C5An.2n
C5Ar
C5AC
C5AD
C5Cn.3n
C5Dn
C5En
8.45
ca. 10.15
11.4
11.8
12.1
12.75
12.85
14.2
ca. 14.35
ca. 16.7
ca. 17.4
15
20
25
30
35
40
45
50

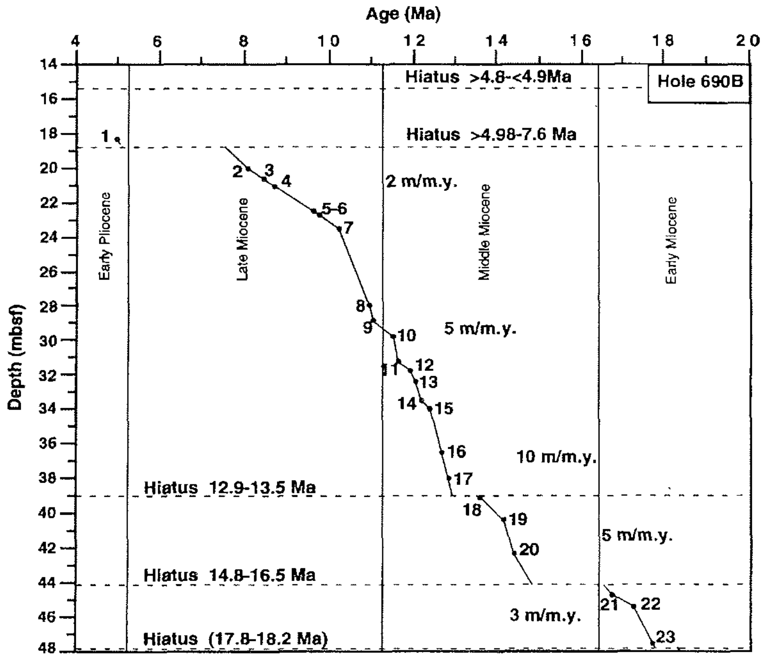


Figure 2.7: Age-depth diagram for the Miocene of Hole 690B and calculated average sedimentation rates. For definition of stratigraphic datum points compare Table 2.3.

The lack of Subchron C3n.3n (Spieß, 1990) and the report of a disconformity between 15.0 and 16.5 mbsf in the silicoflagellate biostratigraphy (McCartney and Wise, 1990) let us assume a short range hiatus (>4.8-<4.9 Ma) between samples 113-690B-3H-3, 27-28 cm and 113-690B-3H-3, 73-75 cm at 15.41 mbsf. The absence of *F. barronii* and the occurrence of *Thalassiosira inura* places the sediment interval above the hiatus into the *T. inura* Zone. It is underlain by the *H. triangularus-F. aurica* Zone that is disturbed by a hiatus at 18.7 mbsf, ranging from ca. 4.98 to 7.6 Ma. *F. praeinterfrigidaria* dominates the assemblage in the upper portion of the zone; accompanying species are *Eucampia antarctica* and *Fragilariopsis clementia*. The base of the following *F. arcula* Zone is recognised between samples 113-690B-3H-7, 27-28 cm and 113-690B-4H-1, 26-27 cm at 21.31 mbsf. *A. ingens* var. *ovalis* was rarely found in this zone. Other characteristic species are *Denticulopsis crassa* and *Actinocyclus karstenii*, both species having ther LO in the middle portion of the *F. arcula* Zone. The following *Asteromphalus kennettii-Fragilariopsis praecurta* Zone has its base between samples 113-690B-4H-2, 115-116 cm and 113-690B-4H-3, 26-27 cm, indicated by the FOD of *A. kennettii*. This interval is characterised by the continuous occurrence of *F. claviceps* and *F. donahuensis*. The base of the underlying *F. praecurta* Zone is located between samples 113-690B-4H-5, 115-116 cm and 113-690B-4H-6, 27-28 cm at 28.86 mbsf. The FO of *F. aurica* occurs in the upper middle portion of this zone, but has rare occurrences in this interval. The following *Denticulopsis dimorpha-Denticulopsis ovata* Zone is disturbed by a recovery gap, which is between 30.15 and 31.36 mbsf (Spieß, 1990). A hiatus proposed by Gersonde and Burckle (1990) to occur at 31.2 mbsf could not be confirmed.

The base of this zone is located at 31.82 mbsf between samples 113-690B-5H-1, 28-29 cm and 113-690B-5H-1, 116-117 cm. The LO of *D. praedimorpha* is identified in the upper portion of the *D. dimorpha- D. ovata* Zone near Subchron C5r.2n. The next biostratigraphical unit is the *D. ovata-N. denticuloides* Zone, which is defined by the FOD of *D. ovata* at 33.1 mbsf, between samples 113-690B-5H-2, 28-29 cm and 113-690B-5H-2, 115-116 cm. The base of the subsequent *D. dimorpha* Zone is defined by the FOD of the nominate species (36.95 mbsf), between samples 113-690B-5H-3, 115-116 cm and 113-690B-5H-4, 28-29 cm. The diatom assemblage within this zone consist mostly of the nominate species, *D. praedimorpha*, *N. denticuloides*, *A. ingens* and *D. simonsenii*. In the lower portion of the zone, the LO of *A. ingens* var. *nodus* is recognised. The base of the underlying *D. praedimorpha* Zone is located between samples 113-690B-5H-5, 28-29 cm and 113-690B-5H-5, 115-116 cm at 37.82 mbsf. High abundances of the nominate species characterise this short ranging zone. The subsequent *N. denticuloides* Zone is marked by a hiatus at 39 mbsf, which spans from about 12.9 to 13.5 Ma and includes a time interval that corresponds to Chrons C5AA and C5AB. Gersonde and Burckle (1990) also report this Middle Miocene hiatus. The base of the *Denticulopsis simonsenii-Nitzschia grossepunctata* Zone is recognised between samples 113-690B-5H-7, 28-29 cm and 113-690B-6H-1, 27-28 cm at 40.74 mbsf, which correlates to the upper portion of magnetostratigraphical Chron C5AD. Typical for this interval are high abundances of *A. ingens* and *Actinocyclus ingens* var. *nodus*. The lower boundary of the following *A. ingens* var. *nodus* Zone at 42.26 mbsf is between samples 113-690B-6H-1, 114-115 cm and 113-690B-6H-2, 27-28 cm. This base is defined by the FOD of the nominate species. Characteristic is the co-occurrence of *A. ingens* var. *nodus* with *D. maccollumii*. Due to a hiatus at 44.1 mbsf only the upper portion of the subsequent *Nitzschia grossepunctata* Zone is present. This hiatus spans a time interval of 14.8 to 16.5 Ma and is indicated by co-occurring FOs *of N. grossepunctata* and *A. ingens*. The hiatus includes a time interval that ranges from Chron C5B to the upper portion of Chron C5C, including the sediments of the lower *N. grossepunctata* and of the *A. ingens-D. maccollumii* zone. Below this hiatus the sediments of the lower *D. maccollumii* Zone are present, which has its base between samples 113-690B-6H-3, 27-28 cm and 113-690B-6H-3, 49-51 cm at 44.51 mbsf. The base of the following *Crucidenticula kanayae* Zone was encountered between samples 113-690B-6H-5, 114-115 cm and 113-690B-6H-5, 27-28 cm at 47.51 mbsf. The zone is characterised by the occurrences of species such as *Cavitatus jouseanus, Thalassiosira spinosa* and *Fragilariopsis maleinterpretaria,* as well as *Thalassiosira fraga* occurring trace abundances. A hiatus was identified below this zone at 48 mbsf, based on combined diatom, radiolarian (Abelmann, 1990) and magnetostratigraphic (Spieß, 1990) results.

Table 2.3: Definition of stratigraphic datum points in the Miocene section of Hole 690B used to construct the age-depth diagram in Figure 2.7.

Datum points	Depth (mbsf)	Age (Ma)	Definition
Hiatus	15.41	>4.8-<4.9	
1	18.32	4.98	Top C4n.3n
Hiatus	18.7	>4.98-7.6	
2	20.07	8.072	Base C4n.2n
3	20.66	8.45	FOD *F. arcula*
4	21.07	8.699	Top C4An
5	22.53	9.642	Base C4Ar.2n
6	22.76	9.74	Top C5n
7	23.62	10.15	FOD *A. kennettii*
8	28.03	10.949	Base C5n.2n
9	28.86	11.4	FOD *F. praecurta*
10	29.78	11.531	Base C5r.2n
11	31.28	11.8	FOD *N. denticuloides*
12	31.72	11.935	Top C5An.1n
13	32.45	12.078	Base C5An.1n
14	33.47	12.184	Top C5An.2n
15	33.95	12.401	Base C5An.2n
16	36.35	12.678	Top C5Ar.1n
17	37.97	12.819	Base C5Ar.2n
Hiatus	38.97	12.9-13.5	
18	39	13.703	Top C5AC
19	40.4	14.2	FOD *D. simonsenii*
20	42.26	14.35	FOD *A. ingens* var. *nodus*
Hiatus	44.1	14.8-16.5	
21	44.68	16.726	Base C5Cn.3n
22	45.41	17.277	Top C5Dn
23	47.51	17.4	FOD *C. kanayae*
Hiatus	48	17.8-18.2	

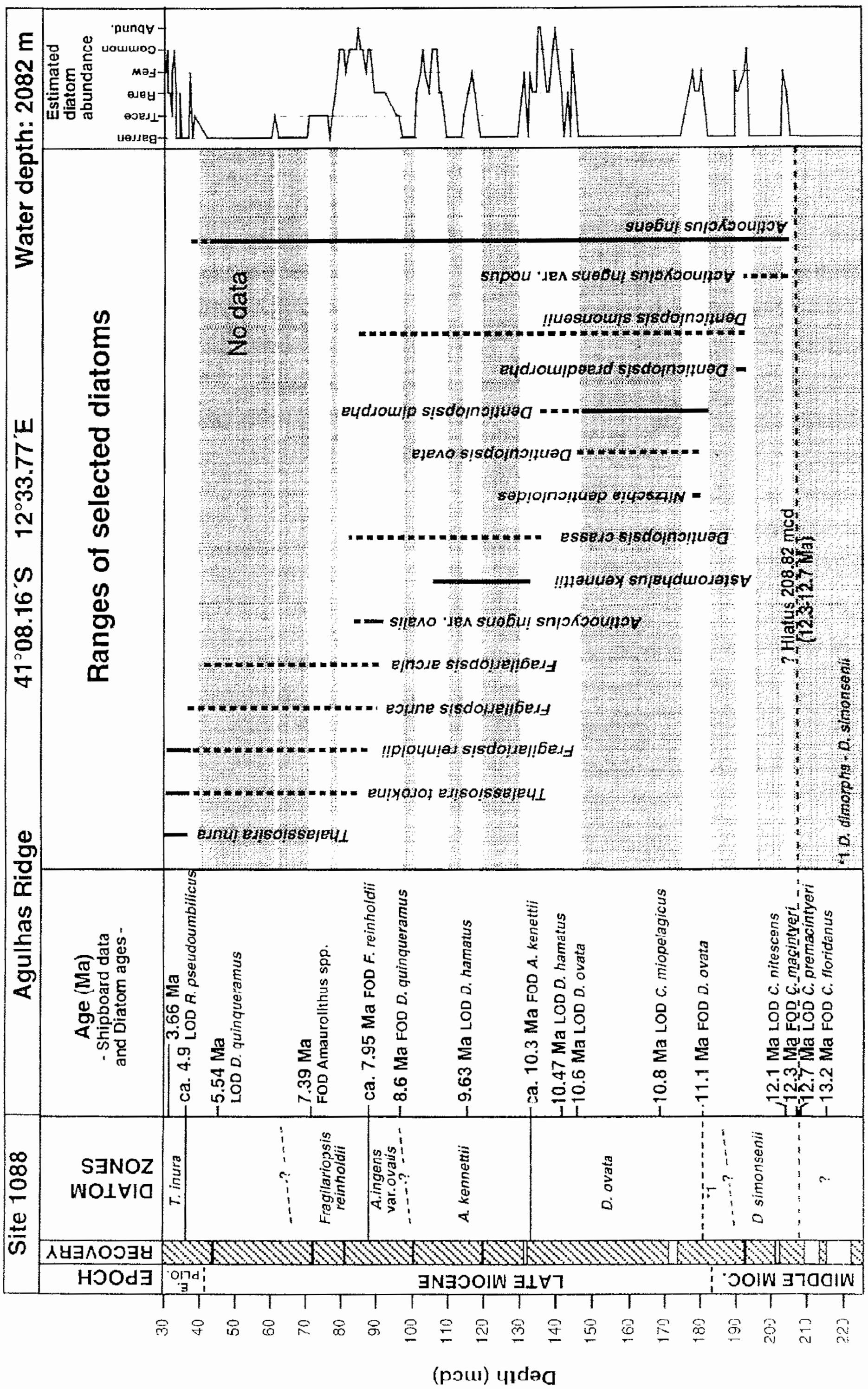
Another disconformity documented by Gersonde and Burckle (1990) at the top of Chron C5Dn could not be validated. The diatom preservation in the early Middle Miocene portion is poor to moderate, as reported for Hole 689B.

2.5.3 Site 1088

Site 1088 (41°08.16'S, 13°33.77'E) is located on the Agulhas Ridge in 2082 m water depth. This bathymetric setting places the site near the interface between North Atlantic Deep Water (NADW) and Circumpolar Deep Water (CDW). The drilling of three holes recovered predominantly calcareous ooze, Holocene to Middle Miocene in age. Diatoms are intermittent, mainly as a trace component, although some diatom-bearing nannofossil ooze is present. Our study is about sediment sequences recovered from Holes B and C. Stratigraphic data are presented in Figures 2.8 and 2.9 and in Table 2.4. Sediment barren of diatoms is marked grey in Figure 2.8. Range charts of the stratigraphic occurrence of selected diatom species from the studied interval are available from a data report (Table 3 in Censarek and Gersonde, subm. a), also accessible under *www-odp.tamu.edu/publications.*

No magnetostratigraphic data could be obtained at this site (Shipboard Scientific Party, 1999a). To support the scattered diatom biostratigraphic data for the Miocene section we include shipboard data based on the calcareous nannofossil record (Shipboard Scientific Party, 1999a). Calculated sedimentation rates are 14 m/m.y. in the middle Late Miocene, increasing up to 31 m/m.y. in the early Late Miocene and 11 m/m.y. during the Middle Miocene (Fig. 2.9). A probable Middle Miocene hiatus at 208.82 mcd was identified by shipboard calcareous nannofossil investigations (Shipboard Scientific Party, 1999a).

The uppermost zone is the *Thalassiosira inura* Zone. Its base was placed between samples 177-1088B-5H-3, 25-26 cm and 177-1088B-5H-2, 137-138 cm. *Neobrunia mirabilis* and *Fragilariopsis fossilis* dominate this zone, besides the nominate species and *Thalassiosira torokina*. An interval barren of diatoms is located from approx. 38 to 70 mcd. Within this interval the LOD of calcareous nannofossil *D. quinqueramus* at 46 mcd indicates an age of around 5.5 Ma (Shipboard Scientific Party, 1999a). Below this interval the *Fragilariopsis reinholdii* Zone has its base at 89.45 mcd between samples 177-1088B-10H-6, 0-1 cm and 177-1088B-10H-6, 90-91 cm.


Site 1088
Agulhas Ridge
41°08.16'S 12°33.77'E
Water depth: 2082 m
Ranges of selected diatoms
Estimated diatom abundance
Barren
Trace
Rare
Few
Common
Abund.
Age (Ma) - Shipboard data and Diatom ages -
DIATOM ZONES
RECOVERY
EPOCH
PLIO. E.
LATE MIOCENE
MIDDLE MIOC.
T. inura
Fragilariopsis reinholdii
A.ingens var.ovalis
A. kennettii
D. ovata
D simonsenii
ca. 4.9
3.66 Ma LOD R. pseudoumbilicus
5.54 Ma LOD D. quinqueramus
7.39 Ma FOD Amaurolithus spp.
ca. 7.95 Ma FOD F. reinholdii
8.6 Ma FOD D. quinqueramus
9.63 Ma LOD D. hamatus
ca. 10.3 Ma FOD A. kenettii
10.47 Ma LOD D. hamatus
10.6 Ma LOD D. ovata
10.8 Ma LOD C. miopelagicus
11.1 Ma FOD D. ovata
12.1 Ma LOD C. nitescens
12.3 Ma FOD C. macintyeri
12.7 Ma LOD C. premacintyeri
13.2 Ma FOD C. floridanus
No data
Thalassiosira inura
Thalassiosira torokina
Fragilariopsis reinholdii
Fragilariopsis aurica
Fragilariopsis arcula
Actinocyclus ingens var. ovalis
Asteromphalus kennettii
Denticulopsis crassa
Nitzschia denticuloides
Denticulopsis ovata
Denticulopsis dimorpha
Denticulopsis praedimorpha
Denticulopsis simonsenii
Actinocyclus ingens var. nodus
Actinocyclus ingens
? Hiatus 208.82 mcd (12.3-12.7 Ma)
↑ D. dimorpha - D. simonsenii
Depth (mcd)

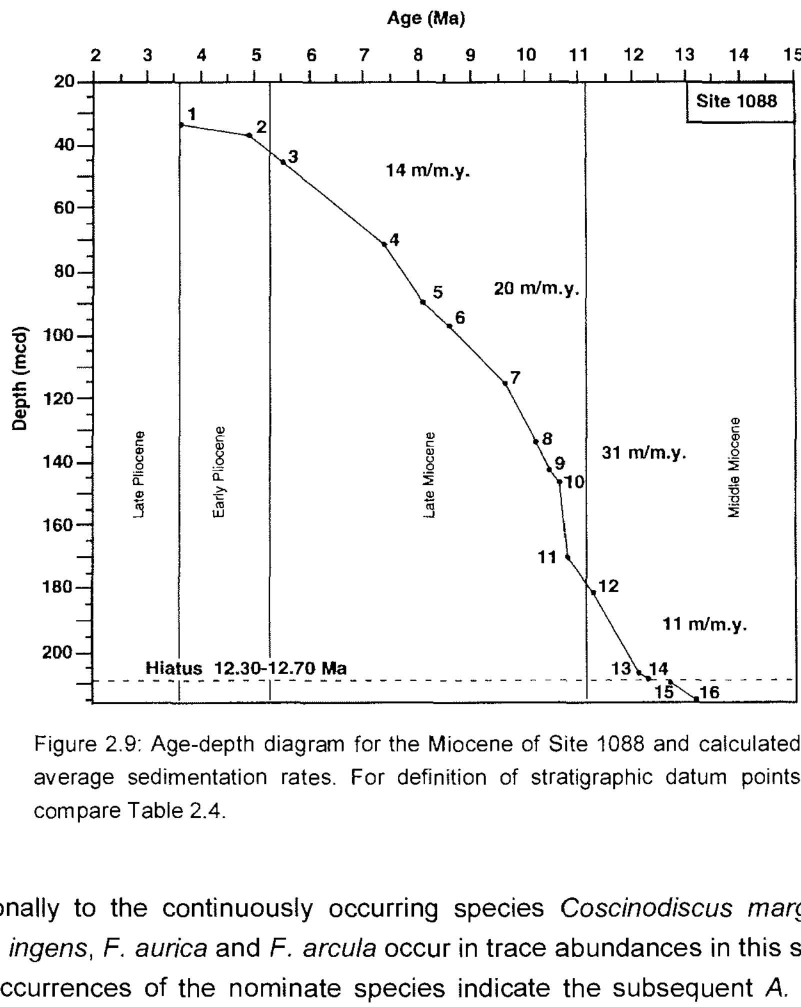


Figure 2.9: Age-depth diagram for the Miocene of Site 1088 and calculated average sedimentation rates. For definition of stratigraphic datum points compare Table 2.4.

Additionally to the continuously occurring species *Coscinodiscus marginatus* and *A. ingens*, *F. aurica* and *F. arcula* occur in trace abundances in this section. Few occurrences of the nominate species indicate the subsequent *A. ingens* var. *ovalis* Zone. The base of the zone could not be determined. Below a section barren of diatoms, from approx. 119 mcd to 130 mcd, we encountered the base of the *Asteromphalus kennettii* Zone between samples 177-1088C-2H-3, 20-21 cm and 177-1088C-3H-3, 20-21 cm. *Denticulopsis crassa* occurs sporadically in this interval. The sediment section is barren of diatoms between approx. 146 mcd and 179 mcd.

Figure 2.8 (left): Stratigraphical ranges of selected diatom species in the Miocene section of Site 1088 and diatom zonal assignment supported by nannofossil shipboard data (Shipboard Scientific Party, 1999a). Estimations of diatom abundances are also indicated. Dotted lines indicate scattered and trace occurrences.

The base of the subsequent *Denticulopsis ovata* Zone (11.1 Ma) is located above sample 177-1088C-9X-5, 95-96 cm at 181.42 mcd. This boundary is supported by the LOD of the calcareous nannofossil *C. miopelagicus*, which indicates an age of 10.8 Ma (Shipboard Scientific Party, 1999a). Below this, falls the *D. dimorpha - D. simonsenii*- and *D. simonsenii* Zone, recognised by the occurrence of assemblages which contain *N. denticuloides*, *D. praedimorpha* and *A. ingens* var. *nodus* and the nominate species. The disconformity at 208.82 mcd, spanning from 12.3 to 12.7 Ma could be estimated by nannofossil ages (Shipboard Scientific Party, 1999a). Below this hiatus diatoms are absent.

Table 2.4: Definition of stratigraphic datum points in the Miocene section of Site 1088 used to construct the age-depth diagram in Figure 2.9.

Datum points	Depth (mcd)	Age (Ma)	Definition
1	33.65	3.66	LOD *R. pseudoumilicus*
2	37.06	4.9	FOD *T. inura*
3	46.05	5.54	LOD *D. quinqueramus*
4	71.29	7.39	FOD *Amaurolithus* spp.
5	89.45	7.95	FOD *F. reinholdii*
6	97.3	8.6	FOD *D. quinqueramus*
7	115.2	9.63	LOD *D. hamatus*
8	134.02	10.3	FOD *A. kennettii*
9	142.49	10.47	FOD *D. hamatus*
10	146.14	10.6	LOD *D. ovata*
11	169.84	10.8	LOD *C. miopelagicus*
12	181.56	11.1	FOD *D. ovata*
13	206.15	12.1	LOD *C. nitescens*
14	208.27	12.3	FOD *C. macintyeri*
Hiatus	208.82	12.30-12.70	
15	209.37	12.7	LOD *C. premacintyeri*
16	214.84	13.2	LOD *C. floirdanus*

2.5.4 Site 1092

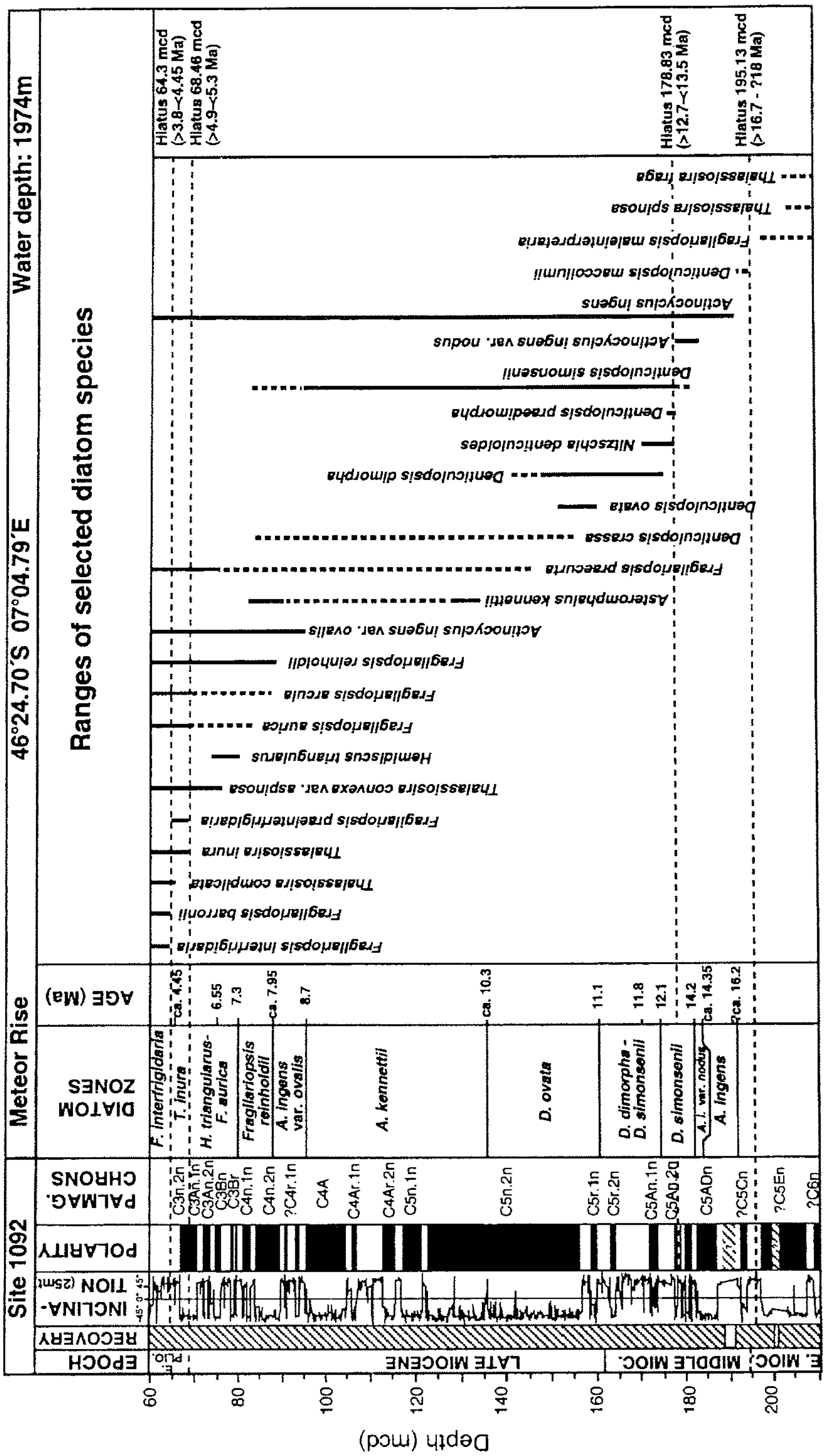
Site 1092 (46°24.70'S, 07°04.79'E) is located in 1974 m water depth on the northern Meteor Rise, one of the dominant topographic features in the south-east Atlantic that defines the westward limit of the Agulhas Basin. This site is located in the Polar Front Zone (PFZ). It is located above the regional carbonate lysocline and carbonate compensation depth (CCD) and within a mixing zone between NADW and the CDW water masses. Three holes were drilled by the APC at a high recovery rate. A composite section was constructed up to 210.54 mcd including a 150 m interval assigned to the Middle and the Late Miocene

(Shipboard Scientific Party, 1999b). The stratigraphic data are presented on Figures 2.10 and 2.11 and on Table 2.5. Range charts of the stratigraphic occurrence of selected diatom species from the studied interval are available from a data report (Table 4 in Censarek and Gersonde, subm. a), also accessible under *www-odp.tamu.edu/publications*. The pattern of sedimentation rates is similar to those obtained from the Maud Rise sites. Lower values are encountered during the Early Pliocene and Late Miocene (6-15 m/m.y.). Highest average sedimentation rates (32m/m.y.) were obtained around the Middle to Late Miocene boundary (Fig. 2.11). The preliminary magnetostratigraphic interpretation based on shipboard inclination data obtained from Shipboard Scientific Party (1999b) allows a correlation of diatom ranges with the magnetostratigraphic record.

The lower Lower Pliocene section is characterised by two disconformities at 64.3 mcd and 68.46 mcd. According to Zielinski and Gersonde (2002) the Lower Pliocene hiatus is located between samples 177-1092A-6H-6, 79-80 cm and 177-1092A-7H-1, 79-80 cm. The co-occurrence of *Fragilariopsis barronii* and *Fragilariopsis interfrigidaria* above this hiatus indicates that at least the *F. barronii* Zone (3.8-4.45 Ma) is absent. Findings of *Thalassiosira inura* (FOD of 4.9 Ma) and *F. praeinterfrigidaria* (3.8-?5.3 Ma) in the absence of *F. barronii* indicate that the section below the Lower Pliocene hiatus can be placed into the *T. inura* Zone. The lower part of this zone is removed by a hiatus, located between Samples 177-1092A-7H-3, 112-113 cm and 177-1092A-7H-3, 142-143. The FOD of *Fragilariopsis praeinterfrigidaria* was not recognised. This suggests that the hiatus at the Miocene/Pliocene boundary spans from 4.9 to 5.3 Ma. The normal polarised interval between the Upper Miocene-Lower Pliocene boundary hiatus and the Lower Pliocene hiatus is interpreted as Subchron C3n.2n, based upon the occurrence of the FOD of *Thalassiosira complicata* (ca. 4.45 Ma) at 67.23 mcd. The sediment below the Miocene/Pliocene disconformity can be correlated to the *Hemidiscus triangularus-Fragilariopsis aurica* Zone, revealing its base at 80.36 mcd, between samples 177-1092C-9H-3, 6-7 cm and 177-1092C-9H-2, 126-127 cm. The FOD of *H. triangularus* was interpreted to be at around 7.3 Ma. We encountered within the *H. triangularus-F. aurica* Zone the FO of *T. convexa* var. *aspinosa* between samples 177-1092A-8H-1, 79-80 cm and 177-1092B-8H-4, 66-67 cm at 6.55 Ma. Few to common occurrences of *Fragilariopsis reinholdii*, *Fragilariopsis praecurta* and *Fragilariopsis fossilis* have been encountered in this zone. Sediments below this interval represent the *F. reinholdii* Zone, which has its base at 87.67

mcd, between samples 177-1092A-9H-3, 79-80 cm and 177-1092A-9H-3, 88-89 cm. Based on the diatom record we interpret the geomagnetic record between 69 and 90 mcd to represent Subchrons C3An.1n to C4n.2n. Two short-ranging normal polarised events between 90.5 to 93 mcd could not be identified. The following *A. ingens* var. *ovalis* Zone has its base between samples 177-1092A-10H-2, 79-80 cm and 177-1092B-10H-4, 90-91 cm at 96.20 mcd. The base is defined by the FOD of the nominate species, showing only rare abundances in the lower portion of the zone. The FO of *A. kennettii* was encountered between samples 177-1092A-13H-6, 79-80 cm and 177-1092C-14H-2, 91-92 cm at 135.11 mcd. Also present are the nominate species, *Denticulopsis simonsenii*, *A. ingens,* and less abundances of *F. praecurta* and *D. crassa*. The underlying zone is the *Denticulopsis ovata* Zone, its base defined by the FO of *D. ovata* (160.39 mcd) between samples 177-1092B-16H-3, 117-118 cm and 177-1092B-16H-4, 67-68 cm. Characteristic species occurring in the *D. ovata* Zone are *Denticulopsis dimorpha,* which dominates in the lower portion; and *D. crassa*, with a FO in the lower part of this zone. The base of the subsequent *D. dimorpha-D. simonsenii* Zone is recognised between samples 177-1092A-17H-4, 79-80 cm and 177-1092A-17H-4, 79-80 cm. This zone is defined by the FO of *D. dimorpha* at 174.22 mcd. Within this zone the LO of *Nitzschia denticuloides* is found at a depth of 170.95 mcd and with an age of 11.8 Ma. The following *D. simonsenii* Zone is marked by a hiatus at 178.83 mcd, which spans from ca. 12.7 to 13.5 Ma. This is indicated by the joint FO of *D. praedimorpha* and *N. denticuloides* and the LO of *A. ingens* var. *nodus*. *Denticulopsis praedimorpha* occurs in only a few samples above this hiatus. The base of the *D. simonsenii* Zone (FO of the nominate species) is between samples 177-1092B-18H-3, 48-49 cm and 177-1092A-18H-2, 148-149 cm at 183.08 mcd. The FO of *A. ingens* between samples 177-1092A-19H-1, 79-80 cm and 177-1092A-19H-1, 104-105 cm (192.76 mcd) defines the *A. ingens* Zone. Considering the FODs of *D. simonsenii* and *Actinocyclus ingens* var. *nodus* at 183.08 mcd and 184.58 mcd, respectively, we propose to interpret the normal polarity interval between 187.52 and 182.48 mcd as Chron C5ADn. Between 188 and 192 mcd no shipboard geomagnetic polarity data are available. Based on the FOD of *A. ingens* at 192.76 mcd we tentatively assign the normal polarity interval around this depth to represent Chron C5Cn.

Figure 2.10 (right): Ranges of selected diatom species in the Miocene section of Site 1092. The geomagnetic polarity record is based on the shipboard inclination record (Shipboard Scientific Party, 1999b. The chron nomenclature is according to Cande and Kent (1992). Dotted lines indicate scattered and trace occurrences.


Site 1092
Meteor Rise
46°24.70'S 07°04.79'E
Water depth: 1974m
EPOCH
RECOVERY
INCLINATION (2sm)
POLARITY
PALMAG. CHRONS
DIATOM ZONES
AGE (Ma)
Ranges of selected diatom species
Fragilariopsis interfrigidaria
Fragilariopsis barronii
Thalassiosira complicata
Thalassiosira inura
Fragilariopsis praeinterfrigidaria
Thalassiosira convexa var. aspinosa
Hemidiscus triangularus
Fragilariopsis aurica
Fragilariopsis arcula
Fragilariopsis reinholdii
Actinocyclus ingens var. ovalis
Asteromphalus kennettii
Fragilariopsis praecurta
Denticulopsis crassa
Denticulopsis ovata
Denticulopsis dimorpha
Nitzschia denticuloides
Denticulopsis praedimorpha
Denticulopsis simonsenii
Actinocyclus ingens var. nodus
Actinocyclus ingens
Denticulopsis maccollumii
Fragilariopsis maleinterpretaria
Thalassiosira spinosa
Thalassiosira fraga
Hiatus 64.3 mcd (>3.8-<4.45 Ma)
Hiatus 68.46 mcd (>4.9-<5.3 Ma)
Hiatus 178.83 mcd (>12.7-<13.5 Ma)
Hiatus 195.13 mcd (>16.7 - ?18 Ma)
PLIO.
LATE MIOCENE
MIDDLE MIOC.
E. MIOC.
F. interfrigidaria
T. inura
H. triangularus-F. aurica
Fragilariopsis reinholdii
A. ingens var. ovalis
A. kennettii
D. ovata
D. dimorpha - D. simonsenii
D. simonsenii
A. i. var. nodus
A. ingens
ca. 4.45
6.55
7.3
ca. 7.95
8.7
ca. 10.3
11.1
11.8
12.1
14.2
ca. 14.35
ca. 16.2
C3n.2n
C3An.1n
C3An.2n
C3Bn
C3Br
C4n.1n
C4n.2n
?C4r.1n
C4A
C4Ar.1n
C4Ar.2n
C5n.1n
C5n.2n
C5r.1n
C5r.2n
C5An.1n
C5AD.2n
C5ADn
?C5Cn
?C5En
?C6n
-45° 0° 45°
60
80
100
120
140
160
180
200
Depth (mcd)

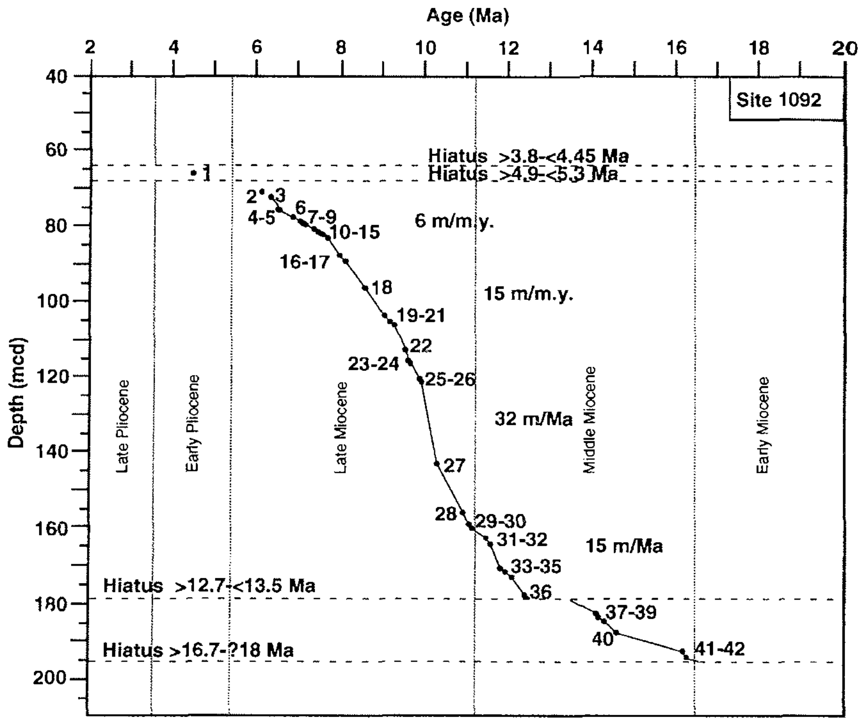


Figure 2.11: Age-depth diagram for the Miocene of Site 1092 and calculated average sedimentation rates. For definition of stratigraphic datum points compare Table 2.5.

For age assignment of the FOD of *A. ingens* we follow Baldauf and Barron (1991) who placed this FOD in the upper portion of Chron C5n (Hole 744 B). As a consequence of this interpretation, Chrons C5Bn and C5Br that span a time interval of more than 1 m.y. fall either in the magnetostratigraphic record gap and/or a hiatus should occur in this interval. Another explanation might be that the FOD of *A. ingens* in Southern Ocean sediments is diachronous and occurs in the northern zone of the Southern Ocean at a younger age compared to the southern zone. The incomplete stratigraphical range of *Denticuloides maccollumii* let us suggest a disconformity occurring at 195.13 mcd. The stratigraphic range of the missing sediments can be estimated considering the FO of *D. maccollumii* (ca. 16.7 Ma) and the age assignment of the assemblage recovered below 195 mcd consisting of *Fragilariopsis maleinterpretaria*, *Thalassiosira fraga* and *Thalassiosira spinosa*. An age of the lowermost portion of Site 1092 is suggested to be around 18-19 Ma, according to Baldauf and Barron (1991).

Table 2.5: Definition of stratigraphic datum points in the Miocene section of Site 1092 used used to construct the age-depth diagram in Figure 2.11. * - magnetostratigraphic datum points differs from the shipboard interpretation; ** - magnetostratigraphic datum point coincide with the shipbord interpretation (Shipboard Scientific Party, 1999b).

Datum points	Depth (mcd)	Age (Ma)	Definition
Hiatus	64.30	>3.8-<4.45	
1	66.12	4.480	Top C3n.2n
Hiatus	68.46	>4.9-<5.3	
2	71.58	6.137	Base C3An.1n
3	73.97	6.269	Top C3An.2n
4	75.38	6.55	FOD *T. convexa* var. *aspinosa*
5	75.45	6.567	Base C3An.2n
6	77.88	6.935	Top C3Bn
7	78.48	7.091	Base C3Bn
8	78.95	7.135	Top C3Br.1n
9	79.33	7.170	Base C3Br.1n
10	80.36	7.3	FOD *H. triangularus*
11	80.56	7.341	Top C3Br.2n
12	81.13	7.375	Base C3Br.2n
13	81.43	7.432	Top C4n.1n
14	82.68	7.562	Base C4n.1n
15	83.45	7.65	Top C4n.2n *
16	87.67	7.95	FOD *F. reinholdii*
17	89.16	8.072	Base C4n.2n
18	95.28	8.699	Top C4An *
19	104.31	9.025	Base C4An
20	105.32	9.230	Top C4Ar.1n
21	106.87	9.308	Base C4Ar.1n
22	112.73	9.580	Top C4Ar.2n
23	115.63	9.642	Base C4Ar.2n *
24	116.73	9.740	Top C5n.1n
25	121.58	9.880	Base C5n.1n
26	121.88	9.920	Top C5n.2n
27	143.82	10.3	FOD *A. kennettii*
28	156.69	10.949	Base C5n.2n **
29	159.90	11.052	Top C5r.1n
30	160.22	11.099	Base C5r.1n
31	163.00	11.476	Top C5r.2n
32	164.56	11.531	Base C5r.2n
33	170.95	11.8	LOD *N. denticuloides*
34	172.18	11.935	Top C5An.1n
35	173.03	12.078	Base C5An.1n
36	177.44	12.401	Top C5An.2n
Hiatus	178.83	>12.7-<13.5	
37	182.48	14.178	TopC5ADn
38	183.08	14.2	FOD *D. simonsenii*
39	184.58	14.35	FOD *A. ingens* v. *nodus*
40	187.52	14.612	Base C5ADn
41	192.76	16.2	FOD *A. ingens*
42	194.07	16.293	Base C5Cn.1n
Hiatus	195.13	>16.7-?18.0	

2.6 Discussion

The study of Miocene sections recovered at different latitudes in the Southern Ocean reveals apparent latitudinal differentiations of occurrence and stratigraphic range of biostratigraphic marker diatoms. Considering this pattern, we propose the use of two diatom zonations, applicable to the northern and southern area of the Southern Ocean, respectively. Further refinement comes from the application of new taxonomic concepts, proposed for the genus *Denticulopsis* by Yanagisawa and Akiba (1990).

The reinvestigation of Sites 689 and 690 results in a refinement of the diatom biostratigraphic zonation proposed by Gersonde and Burckle (1990), Baldauf and Barron (1991) and Harwood and Maruyama (1992) for Miocene marine deposits in southern-high latitudes. Based on these data we propose a southern Southern Ocean diatom biostratigraphic zonation (SSODZ). New or revised zones and stratigraphic ranges of diatom taxa can be defined for the middle Late Miocene (*F. arcula*- and *H. triangularus-F. aurica* Zone), the late Middle Miocene (*D. praedimorpha*-, *D. dimorpha*-, *D. ovata-N. denticuloides*- and *F. praecurta* Zone) and the late Early Miocene (*C. kanayae* Zone). However, the lack of stratigraphically useful first or last occurrences and the occurrence of disconformities in most Southern Ocean records prevents a further stratigraphic refinement of the latest Miocene in southern-high latitudes. The acquisition of species distribution data by counting instead of estimation of species abundance, as done by Gersonde and Burckle (1990), results in the revision of stratigraphic ranges of some taxa. The FODs of *D. dimorpha* and *D. praedimorpha* were found to be ca. 0.6 m.y. and ca. 0.1 m.y. older than reported by Gersonde and Burckle (1990). Revised diatom and geomagnetic polarity age assignments allows a recalculation of the stratigraphic range of disconformities at sites 689 and 690. The presence of the short ranging disconformities of Gersonde and Burckle (1990); in the middle Lower Pliocene of Hole 689B (11.7 mbsf), in the Upper Miocene of Hole 690B (21 mbsf) as well as the Middle Miocene of Hole 690B (31.2 mbsf) could not be confirmed. All other disconformities identified by Gersonde and Burckle (1990) from the Lower Miocene to Lower Pliocene sediment record at sites 689 and 690 could be verified and the age determinations were updated according to the GPTS of Berggren et al. (1995).

The study of Site 1092 reveals latitudinal differences in the occurrence and stratigraphic ranges of diatom species between the southern and northern zone of the Southern Ocean. The data obtained from this site were used for the establishment of a northern Southern Ocean diatom zonation (NSODZ), also considering paleomagnetic information and diatom distribution records from ODP Leg 114 sites (Hailwood and Clement, 1991a, b; Ciesielski, 1991). However, in the absence of shore-based stratigraphic refinement of the geomagnetic polarity record obtained from Site 1092 we needed to tie the diatom ranges to a magnetostratigraphic record that is based on the interpretation of shipboard inclination data (Shipboard Scientific Party, 1999b). Thus, further shore-based magnetostratigraphic investigations might lead to revisions of age assignments of our stratigraphic interpretation.

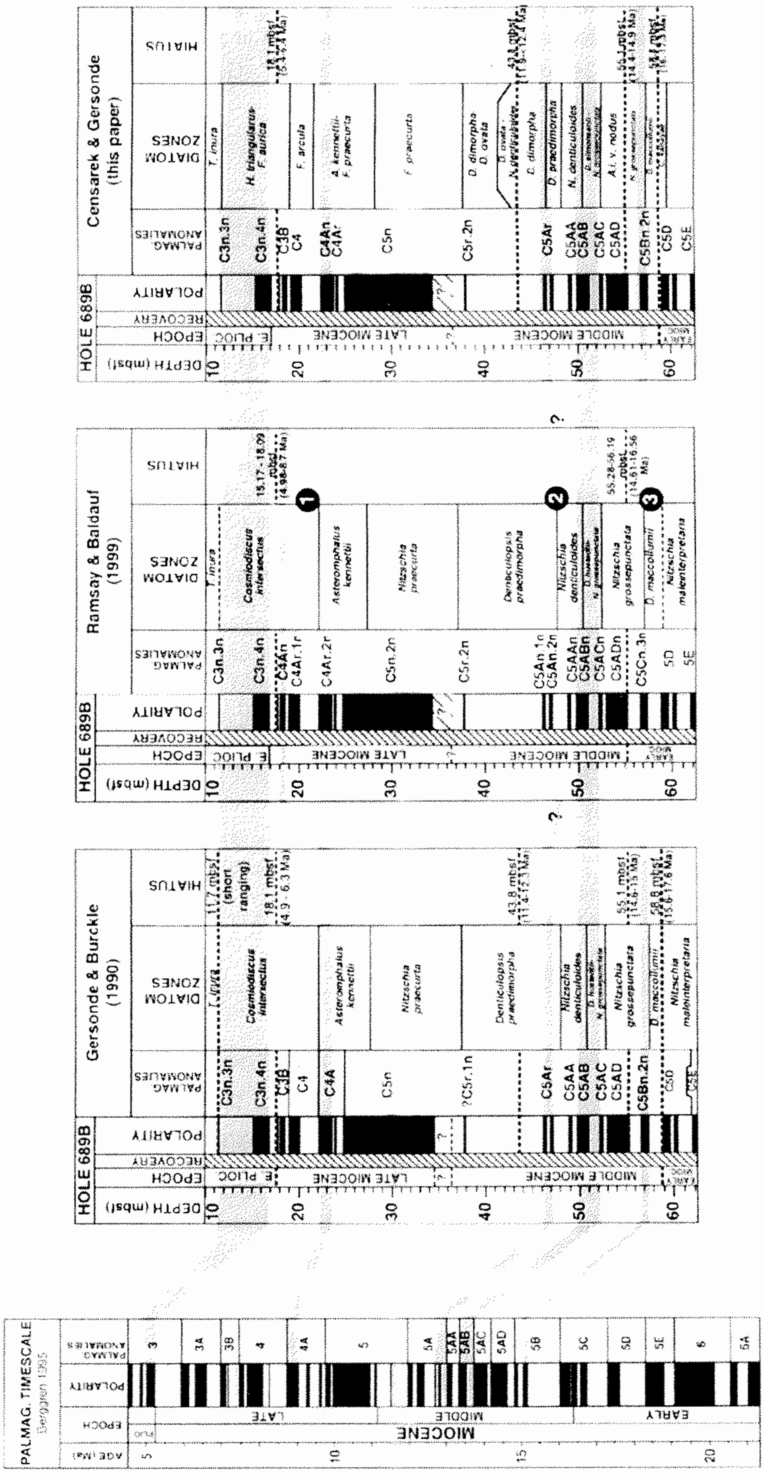
Latitudinal differentiations of the occurrence ranges of *D. dimorpha* and *D. ovata* are observed in the late Middle to early Late Miocene (Fig. 2.3). At the Maud Rise sites 689 and 690 both taxa display FOs occurring ca. 0.6 m.y. respectively 1 m.y. earlier than observed at 1092. While the ranges of both taxa are restricted to a period around the Middle/Late Miocene boundary at the northern site (1092), they reach into the latest Late Miocene at the sites close to the Antarctic continent (689, 690). These changes can be interpreted to mirror latitudinal differentiations of surface water in relation to the Antarctic cryosphere development. As a consequence of the major increase of the East Antarctic Ice Sheet (EAIS) and subsequent Antarctic cooling between 15 and 13 Ma, meridional temperature gradients increased (Flower and Kennett, 1993). A distinct sea level fall excursion between 10 and 11 Ma (Abreu and Anderson, 1998) might indicate a cooling event with a strong EAIS increase. This time interval has a close temporal relation to the occurrence pattern of *D. dimorpha* and *D. ovata* at Site 1092. It can be speculated that the occurrence of both taxa is indicative for a cold water excursion into the present central portion of the ACC related to a southern high latitude cooling event close to the Middle/Late Miocene boundary. Diachronous FODs were also observed in the Late Miocene, affecting the temporal and spatial distribution of species such as *F. arcula* and *F. aurica,* both occurring distinctly earlier at the Maud Rise sites. This might indicate latitudinal expansion of colder waters during the Late Miocene. A more detailed study reconstructing Southern Ocean surface water development based on Miocene diatom species ranges and abundance pattern is currently in progress (Censarek and Gersonde, subm. b).

The quantitative diatom reinvestigation at sites 689 and 690 allows a comparison with the stratigraphic interpretation of both sites recently proposed by Ramsay and Baldauf (1999). This is done exemplarily for Hole 689B, also considering the results obtained from the second site (690) drilled on Maud Rise (Fig. 2.12). Ramsay and Baldauf (1999) recalculated diatom occurrence datums and reassessed magnetostratigraphic interpretations obtained from 17 DSDP and ODP sites located in the Southern Ocean. This was accomplished by an iterative integrated process with the assumption that the sedimentary sequences were continuous. Due to this assumption some disconformities identified by Gersonde and Burckle (1990) and Gersonde et al. (1990) at sites 689 and 690 were not taken into account. The age model proposed by Ramsay and Baldauf (1999) for Hole 689B coincides with our results in the Early Pliocene, in the Late Middle to early Late Miocene and in the Early Miocene. Intervals bearing disagreements between the interpretation of Ramsay and Baldauf (1999), Gersonde and Burckle (1990) and this study are labelled 1 to 3 in Figure 2.12. Ramsay and Baldauf (1999) interpreted in Hole 689B the three normal polarised intervals between ca. 18 to 24 mbsf to represent chrons C4Ar to C4An (Fig. 2.12, Point 1). We interpreted this to represent C4An to C3An.2n. Our interpretation is based on the occurrence of the FOD of *T. convexa* at 18.58 mbsf, which has an age of 6.55 Ma and correlates to the lower portion of Subchron C3An.2n (see Hole 746A in Baldauf and Barron, 1991). Further we refer to the FOD of *Fragilariopsis arcula* to support our interpretation. This FOD is located in Hole 689 at 21.51 mbsf, in Hole 690B at 21.31 mbsf and correlates in both holes to the lower portion of Chron C4r (Figs. 2.4, 2.6). According to the interpretation of Ramsay and Baldauf (1999) the FOD of *F. arcula* would be diachronous between the two Maud Rise sites, occurring in the lower portion of C4Ar.2r, respectively in C4Ar.3r. Another reliable hint to support our interpretation comes from the FOD of *A. ingens* var. *ovalis*. Baldauf and Barron (1991) locate the FOD in Hole 746A close to the base of Subchron C4n.2n, an age assignment that was approved by Ramsay and Baldauf (1999). Applying the age model of Ramsay and Baldauf (1999) at Hole 689B, the FOD of *A. ingens* var. *ovalis* should fall into a hiatus at 18 mbsf. However, we found the FOD of *A. ingens* var. *ovalis* at 22.26 mbsf and interpreted this to correlate with the reversed portion of Chron C4r, thus close to the age assignment reported by Baldauf and Barron (1991). A similar age interpretation of the FOD of *A. ingens* var. *ovalis* results from the study of Hole 690B. The second discrepancy concerns the FOD of *Denticulopsis praedimorpha*, located at 47.77 mbsf in Hole 689B (Fig. 2.12, Point 2). Applying Ramsay and Baldauf's (1999) stratigraphic interpretation the FOD of *D. praedimorpha* would be diachronous between holes 689B and 690B, having an age of 12.51-12.76 Ma and 13.09-13.35 Ma, respectively.

Table 2.6: List of selected Miocene diatom events, ages from previous studies and new interpolated ages from the age-depth plots. Ages interpolated by linear relationship. Italic style: low reliability. References: 1 - Gersonde and Barcena (1998), 2 - Gersonde et al. (1998), 3 - Barron and Baldauf (1995), 4 - Barron (1992a).

Datum	**Estimated diatom ages (Ma)**				**Age (Ma)**	**Publis-hed age**	**Ref.**
	SSODZ		NSODZ		SSODZ/NSODZ		
	689B	690B	1988	1092	rounded	(Ma)	
FOD *T. complicata*	-	-	-	-	? / ?	4.45	2
FOD *T. inura*	4.89	-	*4.17*	-	4.98 / *4.17*	4.92	1
FOD *F. praeinterfigidaria*	5.09	-	-	-	5.09 / n.p.	5.30	2
LOD *H. triangularus*	5.13	-	-	6.43	5.13 / 6.43		
FOD *Thal. convexa* var. *aspinosa*	6.58	-	-	6.54	6.58 / 6.54	6.70	4
FOD *H. triangularus*	7.3	-	-	7.3	7.3 / 7.3		
LOD *D. crassa*	*7.39*	*7.76*	-	7.51	*7.58* / 7.51		
FOD *F. reinholdii*	-	-	*8.23*	7.96	n.p. / 7.96	8.10	4
FOD *F. arcula*	8.49	8.41	-	*7.4*	8.45 / *7.4*	8.60	2
FOD *A.ingens* var. *ovalis*	*8.49*	-	-	8.7	*8.49* / 8.7	8.68	3
FOD *A. kennettii*	10.21	10.12	*10.3*	10.31	10.17 / 10.31	10.23	2
LOD *D. ovata*	*4.93*	-	*10.5*	10.6	*4.93* / 10.6		
FOD *F. aurica*	*9.5*	*10.3*	-	*6.94*	*9.9* / *6.94*		
FOD *D. crassa*	*10.12*	*9.7*	-	*10.95*	*9.91* / *10.95*		
FOD *F. praecurta*	11.43	11.40	-	*10.59*	11.42 / *10.59*	11.05	2
LOD *N. denticuloides*	*11.82*	11.78	-	11.86	11.78 / 11.86	11.70	2
FOD *D. ovata*	-	12.11	*11.1*	11.1	12.11 / 11.1		
FOD *D. dimorpha*	12.74	12.73	-	12.12	12.74 / 12.12	12.20	3
LOD *D. praedimorpha*	-	-	-	12.25	n.p. / 12.25		
FOD *D. praedimorpha*	12.92	12.81	-	-	12.87 / n.p.	12.84	3
FOD *N. denticuloides*	13.48	-	-	-	13.48 / n.p.	13.51	2
FOD *D. simonsenii*	14.18	14.3	-	*14.22*	14.24 / *14.22*	14.17	2
FOD *A. ingens* var. *nodus*	-	14.178-14.8	-	*14.35*	ca. 14.5 / *14.35*	14.38	2
FOD *N. grossepunctata*	15.2	-	-	-	15.2 / n.p.	15.38	2
FOD *A. ingens*	16-17.3	14.8-16.5	*16.2*	*12.3-12.7*	ca. 16.2 / *16.2*	16.20	2
FOD *D. maccollumii*	-	*16.7*	-	-	*16.7* / n.p.	16.75	2
FOD *C. kanayae*	17.28-17.61	17.27-17.61	-	-	ca. 16.7 / n.p.	17.72	3

Such a discrepancy between two sites that have been drilled nearby each other is rather unlikely. Harwood and Maruyama (1992) place the FOD of *D. praedimorpha* below C5Ar.2n (Hole 751A, Leg 120), an age assignment that was followed by Ramsay and Baldauf (1999). We considered the age assignment of Harwood and Maruyama (1992) and interpreted the normal polarity intervals at ca. 46 and 47 mbsf to represent C5Ar (Hole 689B). This age assignment is consistent with the stratigraphic interpretation in Hole 690B and shows that the age determination of Ramsay and Baldauf (1999) must be revised. The third disagreement occurs in the lower Middle Miocene (Fig. 2.12, Point 3). Ramsay and Baldauf (1999) proposed the normal polarity interval at ca. 57 mbsf to represent C5Cn.3n.


HOLE 689B
Censarek & Gersonde (this paper)
Ramsay & Baldauf (1999)
Gersonde & Burckle (1990)
DEPTH (mbsf)
EPOCH
RECOVERY
POLARITY
PALMAG ANOMALIES
DIATOM ZONES
HIATUS
PALMAG. TIMESCALE
MIOCENE

This is close to the FOD of *Nitzschia grossepunctata* at 57.99 mbsf. Applying the age interpretation of Ramsay and Baldauf (1999) the FOD of *N. grossepunctata* would be diachronous between holes 689B and 690B. The FO in Hole 689B having an age between 16.85 and 17.09 Ma (uppermost portion of Subchron C5Cr), whereas in Hole 690B the FO (43.77 mbsf) of this species would fall between 17.19 and 17.42 Ma (upper portion of Chron C5D). Harwood and Maruyama (1992) placed the FOD of *N. grossepunctata* into the uppermost portion of Chron C5Br (Hole 747A, Leg 120) an age assignment accepted by Ramsay and Baldauf (1999). This is consistent with our interpretation that the normal polarised chron at ca. 57 mbsf in Hole 689B represents C5Bn.2n. In Hole 690B the FO of *N. grossepunctata* is located at a hiatus (ca. 44 mbsf, 14.8-16.5 Ma) that omits C5Bn.2n. The hiatus is indicated by a sharp facies boundary between calcareous nannofossil-bearing sediments below and diatom ooze above. Thus the comparison of our stratigraphic interpretation of Miocene strata recovered at Maud Rise with the age model proposed by Ramsay and Baldauf (1999) shows that the method used by Ramsay and Baldauf (1999) for the establishment of stratigraphic age models may lead to misinterpretations of the geomagnetic record and to a diachronous occurrence pattern of species between the two Maud Rise holes. This can partly be ascribed to the fact that they did not examine additional new material and based their studies only on available data.

2.7 Summary

In this paper the reinvestigation of the Leg 113 Sites 689 and 690 and the study of Leg 177 Sites 1088 and 1092 leads to an improved dating of the stratigraphic species ranges considering the progress in diatom taxonomy and magneto-stratigraphic age assignment as well as previous diatom biostratigraphic results of ODP Legs 113, 114, 119 and 120. Due to latitudinal changes in species composition and abundance pattern that can be related to latitudinal differentiations of surface water masses, two Miocene diatom zonations, a southern and a northern one, are established.

Figure 2.12 (left): Comparison of Hole 689B (Leg 113) age models with diatom zonations and magnetostratigraphical interpretations: Gersonde and Burckle (1990) based on the magneto-stratigraphic interpretation of Spieß (1990), Ramsay and Baldauf (1999) and Censarek and Gersonde (this paper). All geomagentic polarity designations are in accordance to the nomenclature proposed by Cande and Kent (1992). Black marked numbers (1-3) mark stratigraphic discrepancies discussed in the text.

Despite the increased knowledge on the stratigraphic occurrence of southern high latitude Neogene diatoms, the biostratigraphic zonation of some time intervals is still not well elaborated. This is true especially for the late Late Miocene and the Miocene/Pliocene transition, as well as portions of the middle Miocene marked by the occurrence of disconformities at most sites drilled in the Southern Ocean. Also the delineation of the stratigraphic ranges of taxa such as *Thalassiosira inura*, *Asteromphalus kennettii*, *Fragilariopsis praeinterfrigidaria* and *F. aurica* needs further improvement.

2.8 Taxonomic notes and floral references

The first citation in the following list is the original description of the species, the other one are more recent references, where those with good illustrations were used. Plate and figure numbers given in parenthesis refer to illustrations of taxa in this paper.

2.8.1 New combinations

Considering the comments and descriptions of Round et al. (1990), Medlin and Sims (1993), Hasle et al. (1995) and Gersonde and Bárcena (1998) about the transfer of taxa belonging to the genus *Nitzschia* to the genus *Fragilariopsis* we follow the strategy proposed by Round et al. (1990) and transfer the following Miocene diatom taxa:

Fragilariopsis claviceps (Schrader) Censarek et Gersonde, comb. nov.

Basionym: Nitzschia claviceps Schrader, 1976, p. 633, pl. 2, figs. 2, 4.

Fragilariopsis cylindrica (Burckle) Censarek et Gersonde, comb. nov., (Plate 3, Fig. 24).

Basionym: *Nitzschia cylindrica* Burckle, 1972, p. 239, pl. 2, figs. 1-6.

Fragilariopsis donahuensis (Schrader) Censarek et Gersonde, comb. nov., (Plate 3, Figs. 13-14).

Basionym: *Nitzschia donahuensis* Schrader, 1976, p.633, pl. 2, fig. 30.

Fragilariopsis efferans (Schrader) Censarek et Gersonde, comb. nov.

Basionym: *Nitzschia efferans* Schrader, 1976, p. 633, pl. 2, figs. 1, 3, 5-7; Gersonde and Burckle, 1990, pl. 2, fig. 9.

Fragilariopsis miocenica (Burckle) Censarek et Gersonde, comb. nov.

Basionym: *Nitzschia miocenica* Burckle, 1972; Akiba and Yanagisawa, 1986, p. 469, pl. 39, figs. 7-15, pl. 41, figs. 1-2.

Fragilariopsis maleinterpretaria (Schrader) Censarek et Gersonde, comb. nov., (Plate 3, Fig. 26).

Basionym: *Nitzschia maleinterpretaria* Schrader, 1976, p.634, pl.2, figs. 9, 11-19, 21, 24; Gersonde and Burckle, 1990, pl. 2, figs. 13-16; Harwood and Maruyama, 1992, pl. 6, fig. 17-19.

Fragilariopsis pusilla (Schrader) Censarek et Gersonde, comb. nov. (Plate 3, Fig. 25).

Basionym: *Nitzschia pusilla* Schrader, 1976, p. 643, pl. 2, fig. 20; Gersonde and Bruckle, 1990, pl. 2, figs. 17-19.

2.8.2 Floral list

Actinocyclus curvatulus Janisch in Schmidt et al., 1878, pl. 57, fig. 31; Akiba, 1982, pp. 41-42, pl. 5, figs. 5a-6.

Actinocyclus fasciculatus Maruyama in Harwood and Maruyama, 1992, pl. 13, figs. 14-15.

Remarks: Harwood and Maruyama (1992) described *A. fasciculatus* from middle Pliocene sediments. We found it also in late Miocene sections. (Plate 1, Fig. 5).

Actinocyclus ingens Rattray, 1890, p.149, pl. 11, fig. 7; Whiting and Schrader, 1985; Gersonde 1990, pp. 791-792, pl. 1, fig 1, 3-5, pl. 4, fig. 1. Harwood and Maruyama, 1992, pl. 8, fig. 10, pl. 11, figs. 4 and 6, pl. 12, fig. 8. (Plate 1, Fig. 1).

Actinocyclus ingens var. *nodus* Baldauf, in Baldauf and Barron, 1980, p. 104, pl. 1, figs. 5-9; Gersonde 1990, p. 792, pl. 1, fig. 6, pl. 3. figs. 4-7. (Plate 1, Fig. 4.)

Actinocyclus ingens var. *ovalis* Gersonde, 1980, p. 792, pl. 1, fig. 7, pl. 3, figs. 1-3, pl. 5. figs. 4, 7, pl. 6, figs. 1, 4-5; Gersonde and Burckle, 1990, pl. 5, figs. 4-5; (Plate 1, Figs. 6, 8).

Actinocyclus karstenii Van Heurck, 1909, p. 44, pl. 12, fig. 158; Harwood and Maruyama, 1992, p. 700, pl. 13, figs. 1, 2, 6-8, 10, 11, 13.

Synonym: *Actinocyclus fryxellae* Barron, in Baldauf and Barron, 1991, pl. 1, figs. 1-2, 4.

Actinoptychus senarius Ehrenberg (Ehrenberg); Hendey, 1964, p. 95, pl. 23, figs. 1-2; Synonym: *A. undulatus* (Bailey) Ralfs in Pritchard, 1861; Hustedt, 1930, pp. 475-478, fig. 264. (Plate 5, Fig. 11).

Asteromphalus inaequabilis Gersonde, 1990, p. 792, pl. 2, fig. 4, and pl. 6, fig. 3.

Asteromphalus kennettii Gersonde, 1990, p. 793, pl. 2, fig. 1 and pl. 6, fig. 2. (Plate 1, Fig. 2.)

Azpeitia tabularis (Grunow) Fryxell and Sims, in Fryxell et al., 1986, p. 16 figs. XIV, XV, XXX-I. (Plate 1, Fig. 7).

Cavitatus jouseanus (Sheshukova-Poretzkaya), Williams, 1989, p. 260; Akiba et al., 1993, p. 20-22, figs. 6-20. Synonym:*Synedra jouseana* Schrader, 1973, p. 710, pl. 23, figs. 21-23, 25, 38. (Plate 5, Fig. 12).

Cavitatus miocenicus (Schrader) Akiba and Yanagishawa in Akiba et al., 1993, p. 28, figs.9-1 to 9-11. Synonym: *Synedra miocenica* Schrader, 1976, p. 636, pl. 1, figs. 1, 1a, 1b.

Chaetoceros spp. resting spores, not taxonomic differentiation made.

Corethron criophilum Castracane, 1886, p. 85, pl. 21, figs. 14, 15; Hargraves, 1968, p. 38, figs. 54-60; Harwood and Maruyama, 1992, pl. 19, figs. 12-15.

Coscinodiscus lewisianus Greville, 1866, p. 78, pl. 8, figs. 8-10; Schrader, 1973, pl. 8. figs. 1-6, 10, 15.

Coscinodiscus marginatus Ehrenberg. Hustedt, 1930, pp. 416-418, fig. 223.

Coscinodiscus rhombicus Castracane, 1886, p. 164, pl. 22, fig. 11; Schrader and Fenner, 1976, pl. 21, figs. 1-3, 5; Harwood and Maruyama, 1992, pl. 3, figs. 16-17, pl. 8, figs. 12-13, pl. 11, fig. 1. (Plate 1, Fig. 3).

Crucidenticula kanayae var. kanayae Akiba et Yanagisawa, 1986, p. 486, pl. 1, figs. 3-8; pl. 3, figs. 1-6, 9-10; Yanagisawa and Akiba, 1990, p. 229, pl. 1, figs. 33-35, 39, pl. 8, figs. 14-17. (Plate 2, Figs. 35-36).

Crucidenticula nicobarica (Grunow) Akiba and Yanagisawa, 1986, p. 486, pl. 1, fig. 9; pl. 2, fig. 1-7; pl. 5, figs. 1-9; Yanagisawa and Akiba, 1990, p. 232, pl. 1, figs. 23-29. (Plate 2, Figs. 25-26).

Denticulopsis crassa Yanagisawa et Akiba in Yanagisawa and Akiba, 1990, pp. 248-249, pl. 3, figs. 21-27, pl. 12, figs. 1-8. (Plate 2, Fig. 12).

Denticulopsis dimorpha (Schrader) Simonsen, 1979, p. 64; Yanagisawa and Akiba, 1990, p. 254, pl. 4, figs. 42-49, pl. 7, figs. 14-16. (Plate 2, Figs. 8-11).

Denticulopsis hustedtii (Simonsen et Kanaya) Simonsen emend., 1979; Yanagisawa and Akiba, 1990, pl. 3, figs. 14-19, pl. 11, figs. 11-13.

Denticulopsis maccollumii Simonsen, 1979, p.65; Gersonde, 1990, pl. 5, figs. 7-9; Schrader, 1976, p.631, pl.4, figs. 3, 22, 23, 25. (Plate 2, Figs. 32-34).

Denticulopsis ovata (Schrader) Yanagisawa and Akiba, 1990, pl. 6, figs. 6-14, 24-32.

Synonyms: *Denticula lauta* var. *ovata* Schrader, 1976, p. 632, pl. 4, fig. 7; *Denticula hustedtii* var. *ovata* Schrader, 1976, p. 632, pl.4, figs. 5, 6, 12, 14 and 15; *D. meridionalis* Maruyama in Harwood and Maruyama, 1992, p. 702, pl. 6, figs. 1-4; pl. 7, figs. 1-4, 6-9, 11-13; pl. 9, figs 1-4, 10-14; pl. 10, fig. 7 (Plate 2, Figs. 13-20).

Denticulopsis praedimorpha Barron ex Akiba 1982, pp. 46-48, pl. 11, figs. 9a-16, 18-27a; Yanagisawa and Akiba, 1990, p. 251, pl. 4, figs. 3-5, 10, 12-17, 39; pl. 5, figs. 4-12. (Plate 2, Figs. 1-6).

Denticulopsis simonsenii Yanagisawa and Akiba, 1990, pl. 3, figs. 1-3, pl. 11, figs. 1, 5. (Plate 2, Figs. 21-24).

Diploneis bombus Ehrenberg; Hustedt, 1933, Kieselalg., II, p. 704, figs. 1086a-c; Akiba, 1986, pl. 30, fig. 13. (Plate 5, Fig. 3).

Eucampia antarctica (Castracane) Mangin, 1914, p. 480, figs. 7-8; Mangin, 1915, pp. 58-66, figs. 41-44, pl. 1, fig. 1; Syvertsen and Hasle, 1983, pp. 181-187; Basionym: *Eucampia balaustium* Castracane, 1886, pp. 97-99, pl. 18, figs. 5-6.

Fragilariopsis arcula (Gersonde) Gersonde et Bárcena, 1998; Gersonde, 1991, pp. 143-144, pl. 2, fig. 4; pl. 4, fig. 4; pl. 5, figs. 1-6; Gersonde and Burckle, 1990, pl. 2, figs. 25-26. (Plate 3, Figs. 15-18).

Basionym: *Nitzschia arcula* Gersonde, 1991.

Fragilariopsis aurica (Gersonde) Gersonde et Bárcena, 1998; Gersonde, 1991, p. 144; pl. 1, figs. 18-25; pl. 3, figs. 5, 6; pl. 7, fig. 6; Gersonde and Burckle, 1990, pl. 1, figs. 11-13; Harwood and Maruyama, 1992, pl. 17, fig. 18. (Plate 3, Figs. 9-12).

Basionym: *Nitzschia aurica* Gersonde 1991.

Fragilariopsis barronii (Gersonde) Gersonde and Bárcena, 1998; Gersonde, 1991, p.146; pl. 3, fig. 6; pl. 4, figs. 1-3; pl. 5, figs. 7-17; Gersonde and Burckle, 1990, pl.1, figs. 11-13.

Basionym: *Nitzschia barronii* Gersonde, 1991.

Fragilariopsis claviceps (Schrader) Censarek and Gersonde, comb. nov.

Fragilariopsis clementia (Gombos) Zielinski et Gersonde, 2002;

Basionym: *Nitzschia clementia* Gombos 1977, p. 595, pl. 8, figs. 18-19; Gersonde and Burckle, 1990, pl. 2, figs. 22-23, Harwood and Maruyama, 1992, pl. 17, fig. 18. (Plate 3, Figs. 7-8).

Fragilariopsis cylindrica Censarek and Gersonde, comb. nov. (Plate 3, Fig. 24).

Fragilariopsis donahuensis (Schrader) Censarek et Gersonde, comb. nov. (Plate 3, Figs. 13-14).

Fragilariopsis efferans (Schrader) Censarek et Gersonde, comb. nov.

Fragilariopsis fossilis (Frenguelli) Medlin and Sims, 1993, pp. 332-333.

Basionym: *Pseudonitzschia fossilis* Frenguelli 1949

Synonym: *Nitzschia fossilis* (Frenguelli) Kanaya, in Kanaya and Koizumi, 1970; Schrader 1973, p. 707, pl. 4, figs. 9-11, 24, 25; Gersonde and Burckle, 1990, pl. 1 figs. 19-20. (Plate 3, Figs. 3-4).

Fragilariopsis lacrima (Gersonde) Gersonde and Bárcena, 1998; Gersonde, 1991, p. 148, pl. 1, figs. 1-6, 26, pl. 2. figs. 1-3; Gersonde and Burckle, 1990, pl.1, figs. 14-15. (Plate 3, Figs. 5-6).

Basionym: *Nitzschia lacrima* Gersonde, 1991.

Fragilariopsis maleinterpretaria (Schrader) Censarek and Gersonde, comb. nov. (Plate 3, Fig. 26).

Fragilariopsis miocenica (Burckle) Censarek and Gersonde, comb. nov.

Fragilariopsis praecurta (Gersonde) Gersonde and Bárcena, 1998; Gersonde, 1991, p. 148-149; pl. 1, fig. 7-17; pl. 2, figs. 5, 6; pl. 3, figs. 3, 4; pl. 10, fig. 7; Harwood and Maruyama, 1992, pl. 17, figs. 25-26. (Plate 3, Figs. 19-21).

Basionym: *Nitzschia praecurta* Gersonde, 1991.

Fragilariopsis praeinterfrigidaria (McCollum) Gersonde and Bárcena, 1998; McCollum, 1975, p. 535; pl. 10, fig. 1; Gersonde and Burckle, 1990, pl. 1, figs. 4-10. (Plate 3, Figs. 22-23).

Basionym: *Nitzschia praeinterfrigidaria* McCollum, 1975.

Fragilariopsis pusilla (Schrader) Censarek and Gersonde, comb. nov. (Plate 3, Fig. 25).

Fragilariopsis reinholdii (Kanaya ex Schrader) Zielinski et Gersonde, 2002; Akiba and Yanagisawa, 1986, p. 469, pl. 40, figs. 8-9; pl. 41, figs. 3-4. Gersonde and Burckle, 1990, pl. 1, fig. 1.

Basionym: *Nitzschia reinholdii* Kanaya et Koizumi, 1970 in Schrader 1973, pl. 4. figs. 12-16, pl. 5, figs. 1-9; (Plate 3, Figs.1-2).

Hemidiscus cuneiformis Wallich. Hustedt, 1930, pp. 904-907, fig. 542; Simonsen, 1972, pp. 267-272, figs. 7-11. (Plate 4, Fig. 5).

Hemidiscus karstenii Jousé in Jousé et al., 1963, pl. 1, Fig. 2. ; Jousé, 1965, pl. 1, figs. 6,7. Fenner, 1991, p. 98, pl. 1, fig. 2. (Plate 3, Fig. 27).

Hemidiscus triangularus (Jousé) Harwood and Maruyama, 1992

Basionym:*Cosmoidiscus insignis* f. *triangula*, Jousé, 1977, pl. 79, fig. 2; Ciesielski, 1983, p. 656, pl. 5, figs. 1-10; Ciesielski, 1986, pl. 4, figs. 5-6. (Plate 4, Figs. 1-4).

Katahiraia aspera Komara, 1976, p. 385, fig. 5; Gersonde, 1990, pl. 4, fig. 8.

Mediaria splendidia Sheshukova-Poretzkaya, Schrader, 1973, p. 706, pl. 3, figs. 14-15. Gersonde and Burckle, 1990, pl. 4, fig. 14. (Plate 5, Fig. 5).

Neobrunia mirabilis (Brun in Brun and Tempére) Kuntze, Hendey, 1981, p. 11, pl. 1, figs. 1-3, pl. 2, figs. 4-7, and pl. 3., figs. 10-13.

Nitzschia denticuloides Schrader, 1976, p. 633, pl. 3, figs. 7-8, 10, 12, 18-24; Gersonde and Burckle, 1990, pl. 2, figs, 7-8; Harwood and Maruyama, 1992, pl. 8, figs. 5-8, 17, pl. 9, figs. 24-26, pl. 10, fig. 1. (Plate 2, Figs. 27-31).

Nitzschia grossepunctata Schrader, 1976, p. 633, pl. 3, figs. 1-4; Gersonde and Burckle, 1990, pl. 2, figs. 3-6.(Plate 2, Figs. 37-38).

Nitzschia pseudokerguelensis Schrader, 1976, p. 634, pl.15, figs. 13-15; Gersonde and Burckle, 1990, pl. 2, fig. 2. (Plate 2, Fig. 39).

Paralia sulcata (Ehrenberg) Cleve. Hustedt, 1930, pp. 276-278, figs. 118-120.

Pleurosigma spp., only fragments of valves were found.

Proboscia barboi (Brun) Jordan and Priddle, 1991, p. 56, figs. 1-2; Fenner, 1991, pl. 3, figs. 1, 3.

Synonym: *Rhizosolenia barboi* (Brun) Temére and Peragallo.

Raphidodiscus marylandicus Christian. Schrader, 1976, p. 635, pl. 5, fig. 19; pl. 15, fig. 16.

Rhizosolenia antennata f. *semispina* Sundström, 1986, pp. 44-46, pl. 4, fig. 20, pl. 17, figs. 114, 116; Zielinski, 1993, p. 111, pl. 7, fig.1.

Rhizosolenia hebetata f. *semispina* (Hensen) Gran, 1904, p. 524, pl. 17, fig. 11; Hustedt, 1930, p. 590.

Rouxia antarctica (Heiden) Hanna 1930. Schrader, 1976, pl. 5, figs. 1-8.

Rouxia heteropolara Gombos, 1974, p. 275, fig. 1; Gersonde and Burckle, 1990, pl. 5, fig. 2.

Rouxia isopolica Schrader, 1976, pp. 635-336, pl. 5. figs. 9, 14, 15, 20.

Rouxia peragalli Brun and Heribaud in Heribaud. Abbott, 1974, p.318, pl. 9, figs. A-C; Hanna, 1930, p. 180-184, pl. 14, figs. 1, 5. McCollum, 1975, pl. 12, figs. 1, 2.

Rouxia naviculoides Schrader, 1973, p. 710, pl. 3, figs. 27-32.

Rouxia sp. 1 Gersonde in Gersonde and Burckle, 1990, pl. 4, fig. 15. (Plate 5, Fig. 8).

Rouxia sp. 2 Gersonde in Gersonde and Burckle, 1990, pl. 5, fig. 3.

Rouxia sp. 3 Gersonde in Gersonde and Burckle, 1990, pl. 5, fig. 1.

Stellarima microtrias (Ehrenberg) Hasle and Sims. Hustedt, 1958, pp. 113-114, pl. 3, figs. 18-19, pl. 5, fig. 39; Hasle et al., 1988, pp. 196-198, figs. 1-25.

Stephanopyxis turris (Greville and Arnott) Ralfs, in Pritchard, 1861; Hustedt, 1930, pp. 304-307, figs. 140-144.

Thalassionema nitzschioides Grunow. Hustedt, 1930, p. 244, fig. 725.

Thalassionema nitzschioides var. *capitulatum* (Castracane) Moreno-Ruiz and Licea, 1995, pp. 397-398, figs. 6-7, 42-43; Heiden and Kolbe, 1928, p. 565, pl. 5, fig. 119.

Thalassionema nitzschioides var. *inflatum* Heiden in Heiden and Kolbe 1928; Moreno-Ruiz and Licea, 1995, pp. 400-401, figs. 14-15, 20-22, 47-49.

Thalassionema nitzschioides var. *parvum* (Heiden) Moreno-Ruiz and Licea, 1995, p. 402, figs. 25-27, 57-58; Zielinski, 1993, pl. 6, figs. 7-8; Fenner et al., 1976, pl. 14, fig. 10; Gersonde, 1980, pp. 283-284, pl. 9, figs. 12-13.

Thalassiosira complicata Gersonde, 1991, pp. 150-151, pl. 3, figs. 1-2, pl. 5, figs. 18-20, pl. 6, figs. 1-6, pl. 7, figs. 1-5.

Thalassiosira convexa var. *aspinosa* Schrader, 1974, p. 916, pl. 2, figs. 8, 9, 13-21; Gersonde, 1990, pl. 3, figs. 2, 3. (Plate 4, Figs. 8-9).

Thalassiosira fraga Schrader in Schrader and Fenner, 1976; Akiba and Yanagisawa, 1986, p. 498, pl. 51, figs. 5-10; pl. 53, figs. 1-8. Gersonde, 1980, pl. 3, figs. 9, 10. (Plate 4, Fig. 6).

Thalassiosira inura Gersonde, 1991, p. 151, pl. 6, figs. 7-14; pl. 8, figs. 1-6; Harwood and Maruyama, 1992, pl. 14, figs. 12-16; pl. 5, fig. 14. (Plate 4, Figs. 11-12).

Thalassiosira leptopus (Grunow) Hasle and Fryxell, 1977, pp. 20-22, figs. 1-14; Hallegraeff, 1984, figs. 20a-b.

Thalassiosira miocenica Schrader, 1974, p. 916, pl. 22, figs. 1-5, 11-13; Barron, 1985a, pl. 11, fig. 11.

Thalassiosira oestrupii (Ostenfeld) Proschkina-Lavrenko. Schrader, 1973, p. 712, pl. 11, figs. 16-22, 26-33, 36, 39-45. (Plate 5, Figs. 9-10).

Thalassiosira oliverana (O´Meara) Makarova and Nikolaev. Fenner et al., 1976, p. 779, pl. 14, figs. 1-5.

*Thalassiosira oliverana*var. *sparsa* Harwood in Harwood and Maruyama, 1992, p. 708, pl.16, fig. 13. (Plate 5, Figs. 1-2).

Thalassiosira praelineata Jousé. Harwood and Maruyama, 1992, pl. 5, figs. 6-9. (Plate 5, Figs. 6-7). Synonym: *Coscinodiscus praelineatus* Jousé as synonyms of *Thalassiosira leptopus* (Grun.) Hasle and Fryx in Hasle and Syversten, 1982, pl. 1, fig. 6.

Thalassiosira sancettae Akiba, 1986, p. 441, pl. 7, figs. 1-3. (Plate 5, Figs. 13-14).

Thalassiosira spinosa Schrader, 1976, p. 636, pl. 6, figs. 5-7; Gersonde and Burckle, 1990, pl. 4, figs. 3-4. (Plate 4, Fig. 7).

Thalassiosira spumellaroides Schrader, 1976, p. 636, pl. 6, figs. 1-2. (Plate 4, Fig. 10).

Thalassiosira torokina Brady, 1977, pp.122-123; Brady, 1979, pl. 4, figs. 1-5; Harwood, 1986, pl. 15, figs. 11, 13, 14; pl. 19, figs. 10, 11; pl. 25, figs. 1-3.

Thalassiothrix longissima Cleve and Grunow. Hustedt, 1958, p. 247, fig. 726.

Thalassiothrix miocenica Schrader, 1973, p. 713, pl. 23, figs. 2-5. (Plate 5, Fig. 15).

Triceratium cinnamonium Greville. Schrader, 1974, pl. 20, figs. 10-11; Van Heurck, 1880, pl. 126, fig. 1.

2.9 Plates

Plate 1

Scale bar equals 10 µm

1. *Actinocyclus ingens,* Sample 689B-6H-3, 114-115 cm.
2. *Asteromphalus kennettii*, Sample 1092A-10H-4, 79-80 cm.
3. *Coscinodiscus rhombicus*, Sample 1092A-20H-3, 20-21 cm.
4. *Actinocyclus ingens* var. *nodus* (Specimen at different focus), Sample 1092B-18H-2, 102-103 cm.
5. *Actinocyclus karstenii*, Sample 1092A-8H-3, 127-128 cm.
6. *Actinocyclus ingens* var. *ovalis*, Sample 689B-3H-5, 47-48 cm.
7. *Azpeitia tabularis*, Sample 690B-3H-7, 28-29 cm.
8. *Actinocyclus ingens* var. *ovalis*, Sample 689B-3H-5, 28-29 cm.

Plate 1

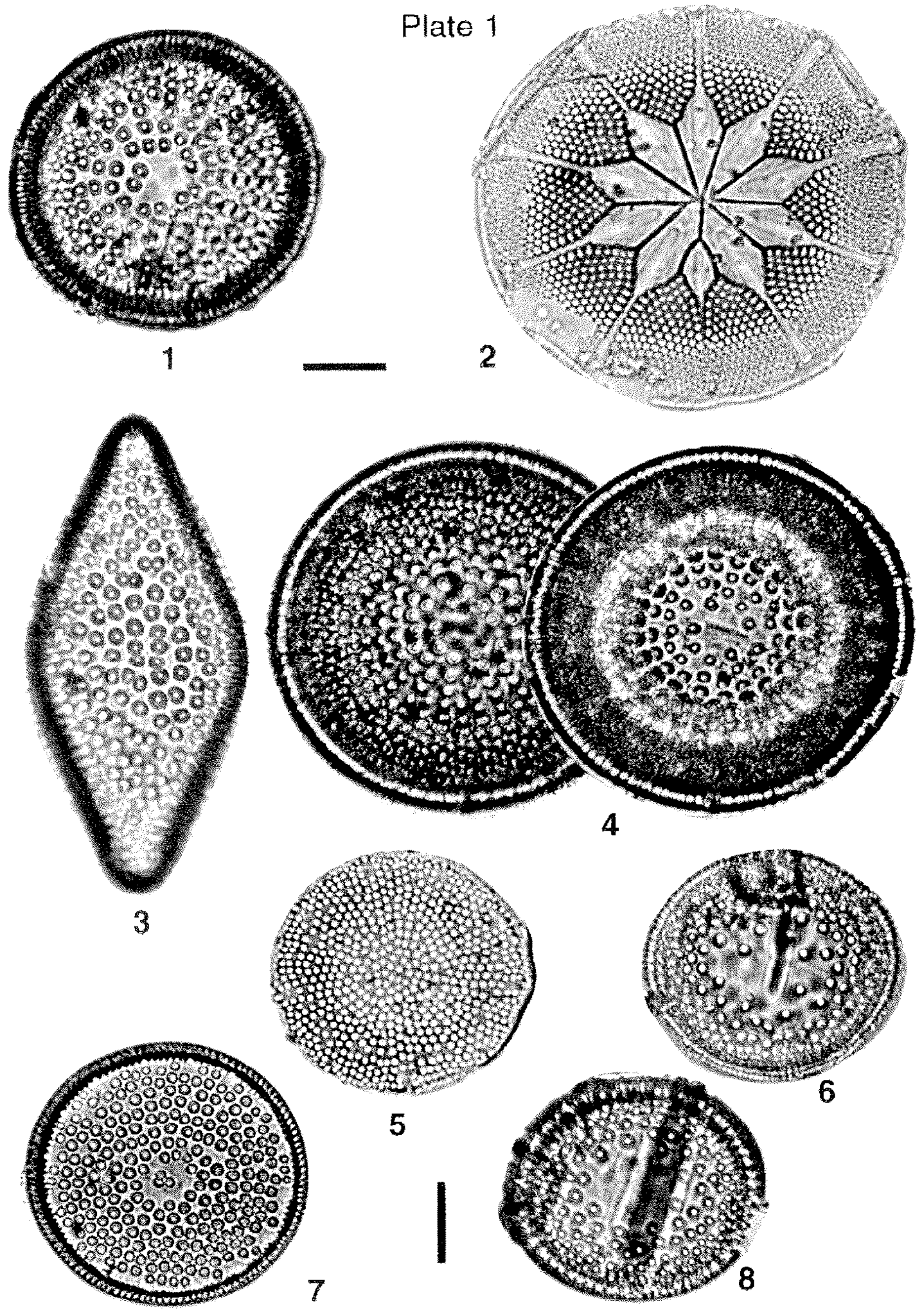


Plate 2

Scale bar equals 10 µm

1-6. *Denticulopsis praedimorpha*, Sample 689B-6H-1, 114-115 cm.

7. *Denticulopsis praedimorpha*, Sample 689B-6H-1, 28-29 cm.

8-11. *Denticulopsis dimorpha*, Sample 1092A-15H-6, 79-80 cm.

12. *Denticulopsis crassa*, Sample 689B-3H-3, 56-57 cm.

13. *Denticulopsis ovata*, Sample 689B-3H-5, 28-29 cm.

14. *Denticulopsis ovata*, Sample 689B-4H-5, 28-29 cm.

15. *Denticulopsis ovata*, Sample 689B-3H-3, 56-57 cm.

16,17. *Denticulopsis ovata*, Sample 689B-4H-5, 28-29 cm.

18. *Denticulopsis ovata*, Sample 1092A-15H-5, 15-16 cm.

19, 20. *Denticulopsis ovata*, Sample 689B-4H-5, 28-29 cm

21-24. *Denticulopsis simonsenii*, Sample 689B-4H-5, 28-29 cm.

25, 26. *Crucidenticula nicobarica*, Sample 1092A-20H-2, 20-21 cm.

27, 28. *Nitzschia denticuloides*, Sample 689B-6H-1, 115-116 cm.

29. *Nitzschia denticuloides*, Sample 689B-6H-4, 29-30 cm.

30, 31. *Nitzschia denticuloides*, Sample 689B-6H-31, 114-115 cm.

32. *Denticulopsis maccollumii*, Sample 689B-7H-2, 115-116 cm.

33, 34. *Denticulopsis maccollumii* (both specimen at different focus), Sample 689B-7H-4, 115-116 cm.

35, 36. *Crucidenticula kanayae* var. *kanayae*, Sample 689B-7H-4, 115-116 cm.

37, 38. *Nitzschia grossepunctata*, Sample 689B-6H-5, 54-55 cm.

39. *Nitzschia pseudokerguelensis*, Sample 689B-6H-5, 54-55 cm.

Plate 2

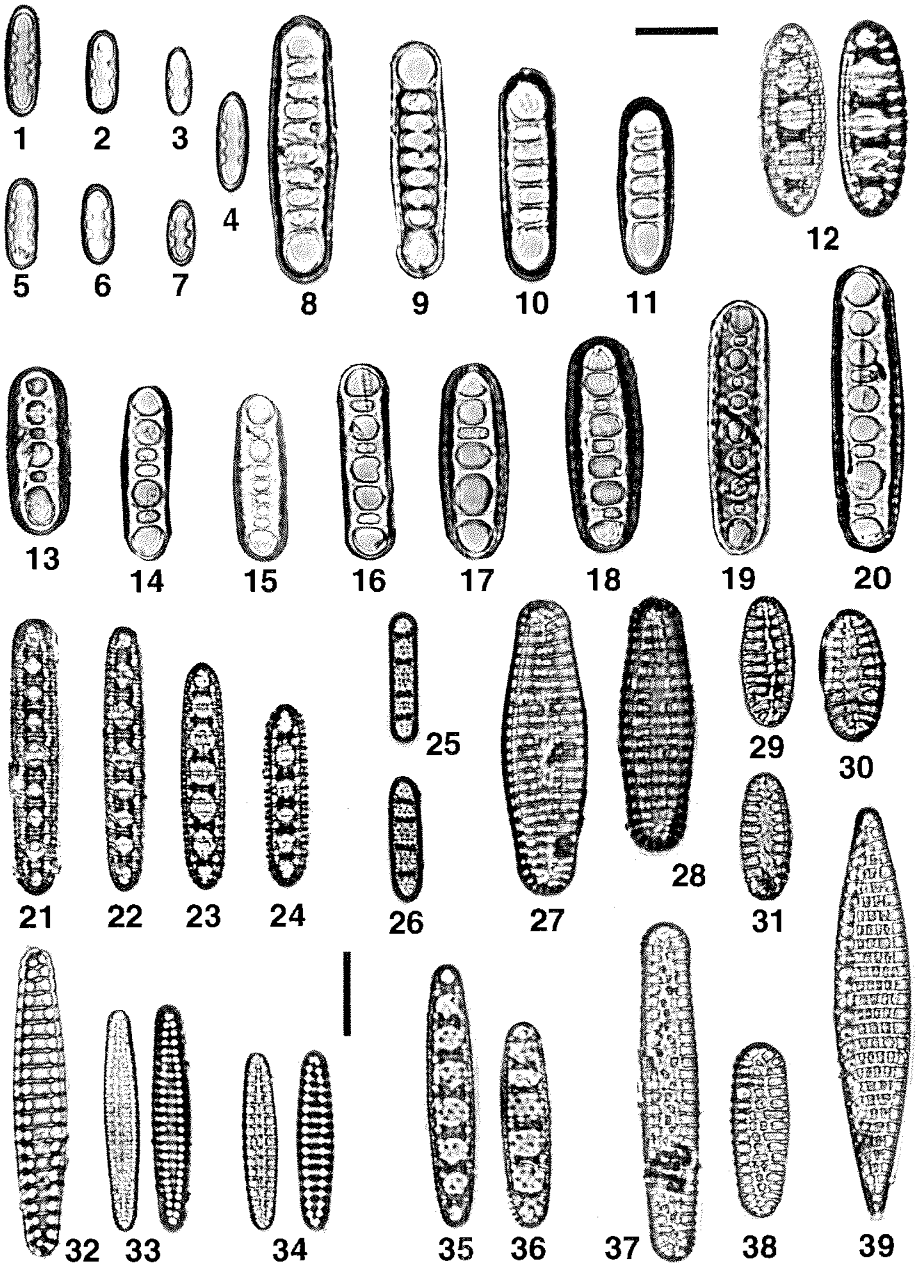

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Plate 3

Scale bar equals 10 μm

1. *Fragilariopsis reinholdii*, Sample 1092A-7H-2, 79-80 cm.
2. *Fragilariopsis reinholdii*, Sample 1092A-7H-5, 79-80 cm.
3. *Fragilariopsis fossilis*, Sample 1092B-8H-2, 96-97 cm.
4. *Fragilariopsis fossilis*, Sample 1092A-7H-5, 79-80 cm.

5, 6. *Fragilariopsis lacrima*, Sample 1092A-6H-6, 79-80 cm.

7, 8. *Fragilariopsis clementia*, Sample 1092A-7H-3, 79-80 cm.

9. *Fragilariopsis aurica*, Sample 689B-3H-2, 114-115 cm.

10, 12. *Fragilariopsis aurica*, Sample 1092A-7H-5, 79-80 cm.

11. *Fragilariopsis aurica*, Sample 1092A-7H-2, 79-80 cm.
13. *Fragilariopsis donahuensis*, Sample 689B-6H-1, 114-115 cm.
14. *Fragilariopsis donahuensis*, Sample 689B-4H-5, 28-29 cm.
15. *Fragilariopsis arcula*, Sample 689B-3H-2, 79-80 cm.

16, 17. *Fragilariopsis arcula*, Sample 1092A-7H-3, 79-80 cm.

18. *Fragilariopsis arcula*, Sample 689B-3H-3, 50-52 cm.
19. *Fragilariopsis praecurta*, Sample 689B-3H-3, 56-57 cm.
20. *Fragilariopsis praecurta*, Sample 1092A-7H-3, 79-80 cm.
21. *Fragilariopsis praecurta*, Sample 1092D-3H-6, 20-21 cm.

22, 23. *Fragilariopsis praeinterfrigidaria*, Sample 1092A-6H-6, 79-80 cm.

24. *Fragilariopsis cylindrica*, Sample 1092A-8H-2, 76-77 cm.
25. *Fragilariopsis pusilla*, Sample 1092A-20H-2, 20-21 cm.
26. *Fragilariopsis maleinterpretaria*, Sample 689B-7H-6, 28-29 cm.
27. *Hemidiscus kastenii*, Sample 1092A-7H-7, 29-30 cm.

Plate 3

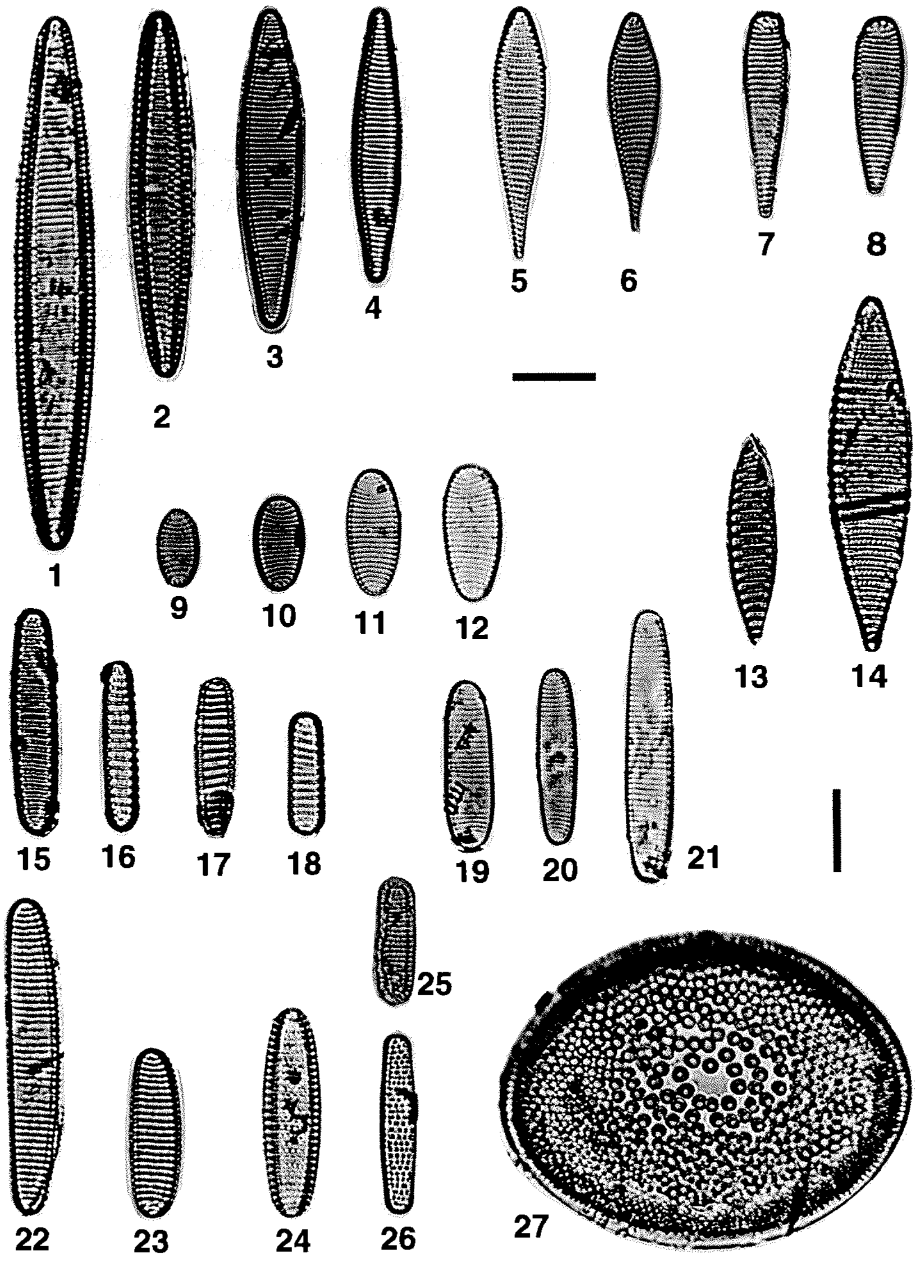

Plate 4

Scale bar equals 10 µm

1, 3, 4. *Hemidiscus triangularus*, Sample 1092A-8H-2, 79-80 cm.

2. *Hemidiscus triangularus*, Sample 1092A-8H-3, 127-128 cm.

5. *Hemidiscus cuneiformis*, Sample 1092A-6H-6, 79-80 cm.

6. *Thalassiosira fraga* (Specimen at different focus), Sample 690B-6H-5, 114-115 cm.

7. *Thalassiosira spinosa* (Specimen at different focus), Sample 689B-7H-7, 28-29 cm.

8. *Thalassiosira convexa* var. *aspinosa*, Sample 689B-3H-2, 114-115 cm

9. *Thalassiosira convexa* var. *aspinosa*, Sample 689B-3H-3, 56-57 cm

10. *Thalassiosira spumellaroides* (Specimen at different focus), Sample 690B-6H-7, 25-26 cm.

11. *Thalassiosira inura*, Sample 1092A-6H-6, 79-80 cm.

12. *Thalassiosira inura*, Sample 1092A-7H-2, 79-80 cm.

Plate 4

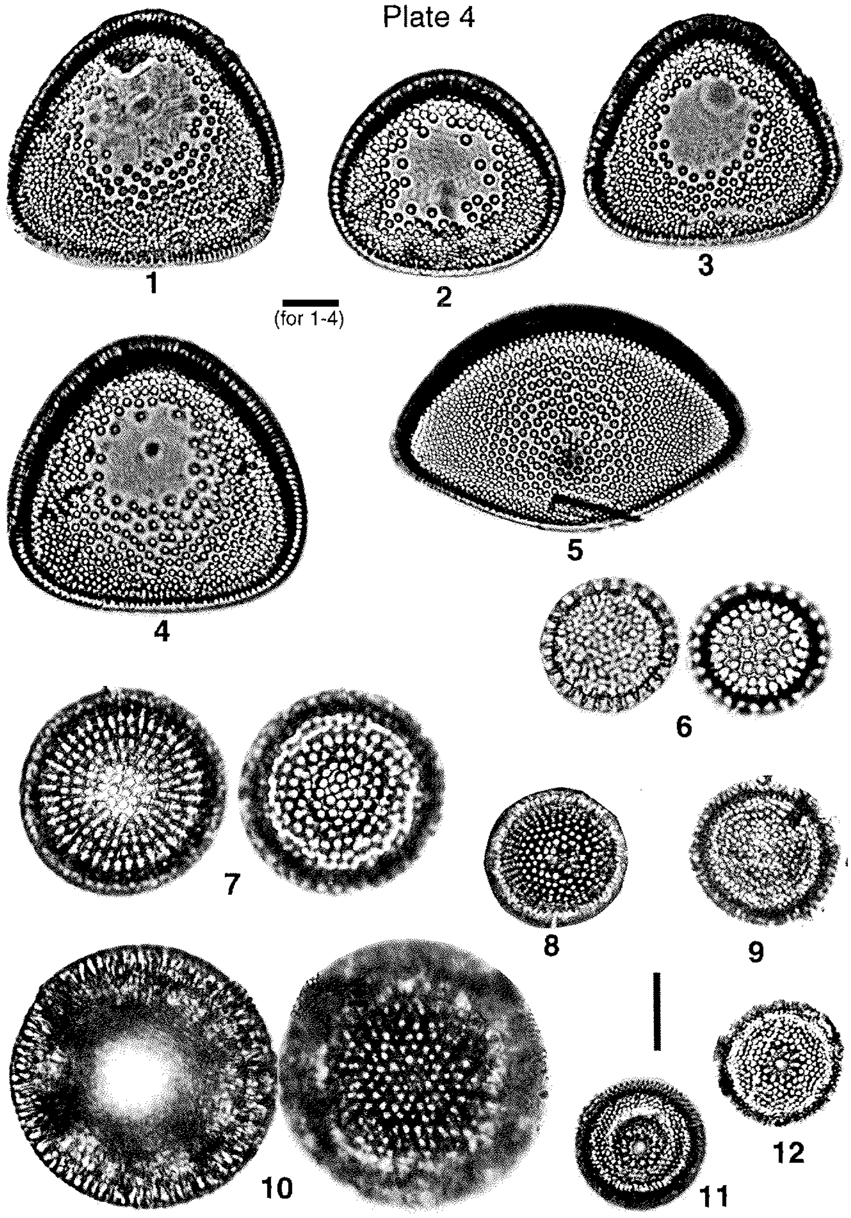

Plate 5

Scale bar equals 10 µm

1. *Thalassiosira oliverana* var. *sparsa*, Sample 689B-3H-3, 56-57 cm.
2. *Thalassiosira oliverana* var. *sparsa*, Sample 1092A-8H-3,127-128 cm.
3. *Diploneis bombus*, Sample 1088B-12H-4, 80-81 cm.
6. *Rouxia peragalli*, Sample 1092A-7H-5, 79-80 cm.
5. *Mediaria splendida*, Sample 1092A-7H-5, 79-80 cm.
6. *Thalassiosira praelineata*, Sample 1092A-7H-6, 52-53 cm.
7. *Thalassiosira praelineata*, Sample 1092A-7H-7, 29-30 cm.
8. *Rouxia* sp.1 Gersonde, Sample 689B-6H-5, 54-55 cm.

9, 10. *Thalassiosira oestrupii*, Sample 1092A-7H-2, 79-80 cm.

11. *Actinoptychus senarius*, Sample 689B-7H-6, 28-29 cm.
12. *Cavitatus jouseanus*, Sample 690B-6H-5, 114-115 cm.

13, 14. *Thalassiosira sancettae*, Sample 1088B-12H-4, 80-81 cm.

15. *Thalassiotrix miocenica*, Sample 1092A-7H-2, 79-80 cm.

Plate 5