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7. Climate Variability of the Holocene, Site 1098, Palmer Deep, Antarctica[1]

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ABSTRACT

Detailed study of four Holocene sediment intervals from Ocean Drilling Program Site 1098 (Palmer Deep, Antarctic Peninsula) reveals that in situ dissolution of calcareous foraminifers in the core repository has significantly altered and in some cases eliminated calcareous foraminifers. Despite dissolution, the foraminifer and supporting diatom data show that the most open-ocean and reduced sea-ice conditions occurred in the early Holocene. The influence of Circumpolar Deep Water was greatest during the early Holocene but continued to be important throughout the Holocene. An increase in sea-ice proximal diatoms at 3500 cal. BP documents an expansion in the amount of persistent sea ice. The inferred increase in sea ice corresponds with an overall increase in magnetic susceptibility values.

Benthic foraminifers are present in all samples from the Palmer Deep, including the middle Holocene pervasively laminated sediments with low magnetic susceptibility values. The consistent presence of mobile epifaunal benthic foraminifers in the laminated sediments demonstrates that the laminations do not represent anoxic conditions. The uniform composition of the agglutinated foraminifer fauna throughout the late Holocene suggests that the Palmer Deep did not experience bottom-water-mass changes associated with the alternating deposition of bioturbated or laminated sediments.

[1] Osterman, L.E., Poore, R.Z., and Barron, J., 2001. Climate variability of the Holocene, Site 1098, Palmer Deep, Antarctica. *In* Barker, P.F., Camerlenghi, A., Acton, G.D., and Ramsay, A.T.S. (Eds.), *Proc. ODP, Sci. Results,* 178, 1–45 [Online]. Available from World Wide Web: <http://www-odp.tamu.edu/publications/178_SR/VOLUME/CHAPTERS/SR178_07.PDF>. [Cited YYYY-MM-DD]
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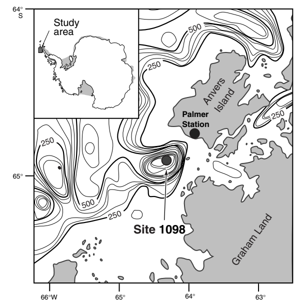
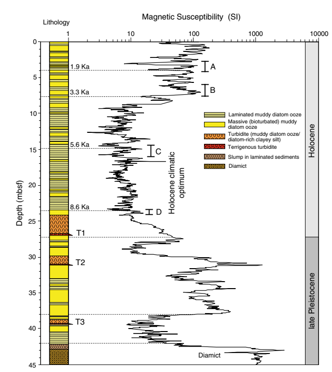
INTRODUCTION

This paper reports on our investigation of Ocean Drilling Program (ODP) Site 1098 (64°51.7′S, 64°12.4′W), collected in 1011 meters water depth (mwd) in the Palmer Deep (Barker, Camerlenghi, Acton, et al., 1999). The Palmer Deep (Fig. F1) is a small basin located 30 km offshore from the U.S. Palmer Station on the Antarctic Peninsula (AP). The outer edge of the AP continental shelf lies at ~500 mwd, but the shelf has considerable relief because of numerous basins, trenches, and plateaus. One basin, the Palmer Deep, includes subbasins in excess of 1000 mwd that were formed by a combination of glacial deepening and tectonic subsidence (Rebecso et al., 1998). Palmer Deep Subbasin I contains >40 m of sediment deposited since the last glacial maximum (Fig. F2) (Shipboard Scientific Party, 1999). The Holocene sediments are an alternating sequence of laminated and bioturbated diatom-rich sediments. In general, the pervasive laminated interval (24–9 meters below seafloor [mbsf]) corresponds to low magnetic susceptibility (MS) values and the alternating bioturbated and laminated interval (9–1 mbsf) corresponds to relatively high MS values (Shipboard Scientific Party, 1999). Rhythmic high-frequency cycles in MS are superimposed on the entire record (Fig F2). Previous studies of piston cores from the upper part of the sedimentary record of the Palmer Deep (Leventer et al., 1996) suggested the large- and small-scale variation in laminations and MS were related to changes in productivity that were driven by climate variability. In this study, our objective is to better understand the Holocene climate record from the Palmer Deep sequence by conducting multiproxy studies of representative parts of the sequence. Toward that end, we selected four intervals of the Holocene for detailed comparison of MS, foraminifer assemblages, diatom assemblages, and stable isotope values of benthic foraminifers. Intervals A, B, C, and D (Fig. F2) were selected to sample several high-frequency cycles of both the relatively high- and relatively low-susceptibility intervals.

F1. Location map of Site 1098, p. 23.



F2. Magnetic susceptibility record and simplified core lithology, Hole 1098C, p. 24.



Oceanography

Several water masses occupy this region of the AP including Antarctic Surface Water (AASW) and various forms of Circumpolar Deep Water (CDW). The most variable water mass, AASW, is found above a permanent pycnocline at 150 mwd on the continental shelf. The temperature (0° to –1.8°C) and salinity (33.9‰ to 34.0‰) of AASW are driven by seasonal changes associated with the melting and freezing of sea ice (Hofmann and Klink, 1998). Present observations do not record the formation of any dense saline waters that penetrate through the pycnocline.

Below 150 mwd, the continental shelf is composed of various modified forms of CDW formed as CDW mixes with local shelf and surface waters. Oceanic CDW, with temperatures >2°C, travels clockwise around Antarctica within the Antarctic Circumpolar Current (ACC). Meandering of the ACC is believed to cause episodic intrusion of oceanic CDW onto the continental shelf. As the CDW moves onto the shelf of the AP, it cools and freshens along its upper boundary as it mixes with the colder and less saline AASW (Hofmann and Klink, 1998). This modified Upper Circumpolar Deep Water (UCDW) comprises most of the shelf water below 150 mwd (Hofmann and Klink, 1998).

Previous Work on the Antarctic Peninsula

Several studies have reported on the sedimentology of various regions of the AP in relation to biological, glaciological, and oceanographic settings. Sediments along the AP can vary from diatomaceous muds to gravels depending upon the amount of primary productivity, ocean currents, and terrestrial sediment input from sea-ice melting and glacial ice rafting (Domack and Ishman, 1993).

Ishman and Domack (1994) reported on the benthic foraminiferal distribution in modern sediments of the AP. Samples collected in Marguerite Bay, under the influence of CDW, are represented by the calcareous species *Bulimina aculeata* cluster, which comprises 0%–3% of the dominantly agglutinated assemblage (average = 77%). Other benthic foraminifer species within the *B. aculeata* cluster include *Bolivinella pseudopunctata, Textularia wiesneri, Milliamina* spp., and *Portatrochammina eltaninae.*

Samples elsewhere along the AP continental shelf in areas under the influence of Weddell Sea Water (WSW) are characterized by a lower diversity calcareous assemblage (74%) dominated by *Fursenkoina* spp., along with *Trochammina intermedia* (= *Deuterammina glabra* in this study).

Leventer et al. (1996) summarize diatom, sedimentologic, MS, and foraminiferal evidence from a 9-m-long piston core collected from Palmer Deep (core PD92-30). Radiocarbon dates indicate that the sedimentation rate in the piston core is 260 cm/k.y. The 9-m-long record of MS in core PD92-30 (Leventer et al., 1996) is almost identical to the upper 10 m of Site 1098, seen in Figure F2 (Shipboard Scientific Party, 1999). Both records contain an upper zone of alternating high and low susceptibility values and a lower zone of reduced susceptibility.

Explanations for the susceptibility fluctuations in core PD92-30 include biogenic, geochemical, and microbiological causes. However, Leventer et al. (1996) report that changes in productivity and the influx of biogenic material, which dilute the magnetite concentration of the sediments, exert the strongest control on the variations in MS (Brachfeld, 1999). Leventer et al. (1996) found that low MS values occur in the strongly laminated sediments, and high MS values occur in the more bioturbated massive intervals.

Leventer et al. (1996) interpreted the laminated sediments with relatively low MS values to indicate stratified ocean conditions. Stable stratified water allows the diatoms to utilize nutrients, resulting in diatom blooms. The diatom blooms form rapidly settling mats of well-preserved diatoms that dilute the MS signal of the laminated sediments. Therefore, the laminated intervals are believed to indicate sea-ice melting, stratified stable water conditions, and resulting high primary productivity. The occurrence of the benthic foraminifer *B. aculeata* in the laminated intervals was believed to indicate that CDW was periodically injected onto the shelf during the times of high diatom productivity (Ishman and Domack, 1994).

Leventer et al. (1996) interpreted the bioturbated massive sediments with relatively high MS values to indicate conditions with a well-mixed ocean and stronger winds. Reduced water-column stratification would result in lower primary productivity and fewer diatom blooms. Slower settling of diatoms results in poor diatom preservation, but a greater accumulation of magnetic minerals results in higher MS values. The presence of a benthic foraminifer assemblage characterized by *B. pseudopunctata* in the high-MS intervals was interpreted to indicate an absence of CDW in the well-mixed ocean. However, this conclusion is contrary to Ishman and Domack (1994), who recognize *B. pseudopunctata* along with *B. aculeata* as an indicator of CDW.

Spectral analysis of the susceptibility record of core PD92-30 indicates a periodicity of 230 yr during the late Holocene (Leventer et al., 1996). A similar 300-yr cyclicity was also recognized in the amount of preserved organic carbon and biogenic silica in Andvord Bay, close to the Palmer Deep on the Antarctic Peninsula (Domack et al., 1993). Leventer et al. (1996) suggest that solar variability is the cause of the observed productivity cycles in the Palmer Deep.

MATERIALS AND METHODS

Hole 1098C (Fig. F1) was advanced hydraulic piston cored during ODP Leg 178. The shipboard party measured whole-core MS at Site 1098 at 2-cm intervals (averaged over 2 s) (Fig. F2) (Shipboard Scientific Party, 1999). The late Holocene (0–9 mbsf) contains high-amplitude fluctuations that have an average value of ~50×10^{-5} SI. From 9 to 25 mbsf the magnitude of MS values drops, but high-frequency cycles are still present.

Based on the variability of the shipboard MS record (Shipboard Scientific Party, 1999), we selected four intervals for the detailed high-resolution analysis of this study. The uppermost interval A (2.82–4.26 mbsf) contains two cycles of high- to low-amplitude MS variations that are characteristic of the late Holocene portion of the Palmer Deep sediment record (Fig. F2). Interval B (6.0–7.75 mbsf) records the transition from the relatively low MS values that characterize the middle section of Hole 1098C into the interval of higher values and high-amplitude cycles that characterize the upper record (Fig. F2). Intervals C (14.42–15.81 mbsf) and D (23.47–24.12 mbsf) are from the strongly laminated sediments with low MS values and low-amplitude fluctuations that characterize the early and middle Holocene record.

Radiometric Dating

The chronology of Hole 1098C is based on accelerator mass spectrometry (AMS) ^{14}C dating of bulk sediments and foraminifers from three sediment columns (Hole 1098C, core PD92-30, and core LMG98-02-KC1) (Domack et al., 2001). The AMS dates were corrected for a reservoir effect of 1260 yr and calibrated using INTCAL98 (Stuiver et al., 1998). The composite depth scale for the three cores was determined using the SPLICER program (Acton et al., Chap. 5, this volume). Based on 54 ^{14}C dates, the age model proposed for the upper 25 mbsf uses a third-order polynomial to regress the age. The resulting polynomial is a better fit than a simple linear trend (Domack et al., 2001). Applying the Domack et al. (2001) equation, the sedimentation rate in Hole 1098C varies between 170 and 340 cm/k.y., with the highest sedimentation rates occurring in the middle Holocene. Most certainly, the sedimentation rate was variable within each of the four intervals studied for this paper, especially between the laminated and homogenous intervals with each cycle, but such small-scale variability is beyond the limits of radiocarbon dating.

Significant differences in the ages of identifiable MS events (i.e., the large transition in interval B between Hole 1098C and the published record of core PD92-30 (Leventer et al., 1996) is probably due to the fact that the chronology for the earlier core PD92-30 research was based on noncalibrated ages. The most recent chronology (Domack et al., 2001) uses corrected and calibrated ages and is supported by more dates than the previously published version.

Sampling

All cores from Site 1098 were split and described on board the *JOIDES Resolution* in March 1998. Restricted shipboard sampling prevented the examination of core-catcher samples. The 130 samples from Hole 1098C for our study were obtained from the ODP Bremen Core Repository in August 1998, ~6 mo postcruise.

The 3- or 5-cm sampling interval for paleontological and isotope analysis was designed to retain the details of the MS cycles. Each sample consists of 13 cm^3 of sediment spanning ~1 cm of core depth and are spaced between 7 and 20 yr, based on the sedimentation rate (Table **T1**) (Domack et al., 2001). Approximately 1 cm^3 of material was reserved for diatom analysis. Based on the foraminiferal results from 130 samples, 38 samples were identified for diatom analysis.

T1. Benthic foraminifers, Hole 1098C, p. 32.

Foraminifers

Samples for foraminifer and isotope analyses were oven dried at <60°C and weighed (Table **T1**). Samples were soaked in 200 mL of distilled water to which 5 mL of 10% hydrogen peroxide solution was added. The samples were placed on a shaker plate for 1 hr then wet-sieved at 63 µm. The sieved fraction was oven dried at <60°C and examined. Because of the large amounts of diatom frustules and the high total organic carbon (>1 wt%) (Shipboard Scientific Party, 1999), the samples were very difficult to disaggregate. Usually the wet-sieving process was repeated up to four times before a final weighing. The sample was examined microscopically after each washing to assure that no foraminifers were lost. Benthic foraminifers in the >63-µm fraction were studied. The entire sample was examined or split to contain ~300 foraminifers (Table **T1**).

In order to describe the most pronounced changes in the benthic foraminifer assemblage, a cluster analysis was performed. A total of 125 samples and 24 species were clustered using the Pearson correlation coefficient and complete linkage with Systat version 5.2. Only samples collected in August 1998 were included in the cluster analysis, and five samples (marked with an asterisk in Table **T1**) were not included because of low foraminiferal numbers.

Stable Isotopes

Oxygen and carbon isotopic analyses were done at the Woods Hole Oceanographic Institution using a Finnigan MAT 252 mass spectrometer with a Kiel automated carbonate preparation device. The occurrence of calcareous foraminifers was sporadic throughout Hole 1098C, and *B. aculeata* was the only calcareous species that occurred in sufficient numbers to be analyzed. In general, ~8 specimens of *B. aculeata* were analyzed in 75 samples. Isotopic values are reported relative to the Peedee belemnite (PDB) standard in delta (δ) notation and expressed in per mil (‰).

Diatoms

Thirty-eight samples representing various MS values from Hole 1098C were selected for diatom analysis based on the preliminary foraminifer results. Slides were prepared according to a settling method described by Scherer (1995), in which a known mass of sediment (average = 10 mg) is settled onto coverslips of a known area (22 mm^2) placed in beakers. Accordingly, quantitative abundance data can be acquired if diatom counts are completed for known areas of the coverslip.

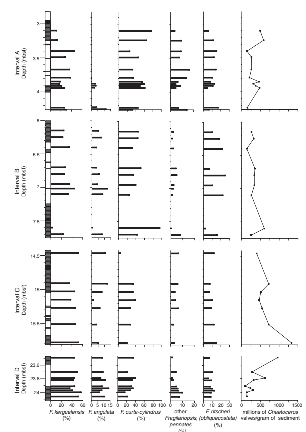
RESULTS

Diatoms

Diatom data from 38 samples are shown on Table T2 and Figure F3. Diatoms are well preserved and abundant in most samples from Hole 1098C. Preservation of diatoms is excellent in the laminated sediments, suggesting burial by rapid deposition and little postdepositional destruction. Diatom preservation is diminished in the bioturbated intervals of Hole 1098C. Abundance of diatoms, expressed as millions of valves per gram of sediment, is high throughout the hole but is consistently high in interval C (Table T2). Highest diatom abundance is also observed in a comparable depth interval in Hole 1098B (Sjunneskog and Taylor, in press; Taylor and Sjunneskog, in press).

T2. Percentage, actual number, and abundance of diatom species, p. 35.

F3. Percentage of most common *Fragilariopsis* diatom species, Hole 1098C, p. 25.



Four diatom taxa (*Chaetoceros* resting spores, *Fragilariopsis kerguelensis*, *Thalassiosira antarctica,* and the *Fragilariopsis curta/Fragilariopsis cylindrus* group) comprise the majority of the species in this study. Most of the other taxa make up a minor component of the assemblages, although in laminated sediments, nearly monospecific assemblages of *Corethron criophilum, Rhizosolenia* spp., *Proboscia* spp., and *Thalassiothrix* sp. are commonly observed. An exception is that the *Fragilariopsis ritscheri/Fragilariopsis obliquecostata* group is more abundant in interval B and *Fragilariopsis angulata* is more common in interval D (Fig. F3).

The relatively small number of samples examined for this study make the recognition of patterns and associations between the diatom assemblages and changes in other proxies within individual intervals difficult. Another problem is the species-specific composition of many of the samples that may represent a single diatom bloom event (e.g., Sample 178-1098C-1H-6, 10–12 cm). However, several changes between the intervals are evident. For example, in intervals A and B, *F. kerguelensis* is consistently less abundant than the *F. curta/F. cylindrus* group, but in intervals C and D, *F. kerguelensis* is more abundant than the *F. curta/F. cylindrus* group.

An interesting characteristic of interval D is the increased abundance of the asymmetric form of *Eucampia antarctica*. This trend has also been recognized from comparable depths in Hole 1098B (16.79–29.58 mbsf) (Sjunneskog and Taylor, in press). The symmetric forms of *E. antarctica* are believed to be a more "polar" form, whereas the asymmetric form is identified as a "more northerly" form (Fryxell, 1989; Kaczmarska et al., 1993). Table T3 shows the high ratio of symmetric/asymmetric forms of the species *E. antarctica* in two samples from interval D (average = 0.645). This ratio can be compared with the modern sediments of the Palmer Deep (core LGM-98-02 KC1, 1–71 cm), where this ratio has an average value of 3 (J. Murray, pers. comm., 2000).

T3. Symmetric/assymetric ratios, interval D, p. 36.

Foraminifers

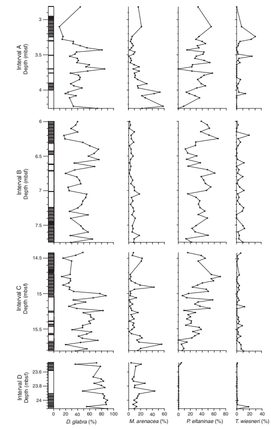
Introduction

As can be seen in Table T1, benthic foraminifers occur in all samples from Hole 1098C. Preservation of the agglutinated foraminifers ranges from excellent to poor. The robust *Milliamina arenacea* and the abundant watch glass–shaped *Deuterammina glabra* are present in every sample (Fig. F4), whereas the organically cemented *Portotrochammina eltaninae* and poorly cemented *Textularia* spp. occur more sporadically and are often very fragile. Percentage values for 24 of the most commonly occurring species are presented in Tables T4, T5, T6, and T7. Rarely occurring benthic species are combined as "other agglutinated" or "other calcareous" species (see "Appendix A," p. 19, for species names). Calcareous foraminifers are poorly preserved in Hole 1098C and are often frosted, pitted, and partially dissolved. *B. aculeata* is the most common calcareous species, followed by *Bolivinella pseudopunctata* (Tables T4, T5, T6, T7). The planktonic foraminifer *Neogloboquadrina pachyderma* sinstral occurs rarely in Hole 1098C (Table T8).

Whereas calcareous foraminifers vary from common to absent in Hole 1098C, their interpretation is greatly complicated by post–core recovery dissolution. In May 1999, ~14 mo postcruise, several levels of Hole 1098C were resampled to obtain additional calcareous foraminifers for ^{14}C dating. We found horizons that yielded common calcareous foraminifers in the original August 1998 samples were essentially barren of calcareous foraminifers in May 1999. Table T9 shows comparison of resampled horizons. For the remainder of the discussion, we must assume that the record of calcareous foraminifers from Hole 1098C has been degraded by an unknown but substantial amount of carbonate dissolution. Downcore changes in the abundance and composition of calcareous foraminifer species may reflect either original variations in the total assemblage, the influence of post-recovery dissolution, or any possible combination of these factors. In addition, we also recognize that there may have been postdepositional dissolution at this site that cannot be documented. Our results can only document an almost total dissolution of the calcareous fauna between August 1998 and May 1999. The timing of dissolution that occurred prior to August 1998 is unknown.

A characteristic feature of Palmer Deep benthic foraminifers that was recognized early in our study is the small size of the agglutinated fauna (Table T10). In most samples, the majority of the calcareous species are found in the larger sand fraction (>100 µm), whereas the majority of the agglutinated species are small and occur most abundantly in the smaller sand fraction (63–100 µm). We suspect the size distribution of calcareous foraminifers is due to the selective dissolution of the smaller calcareous specimens prior to the August 1998 sampling. Summary statistics and averages of agglutinated and calcareous foraminifers in Hole 1098C are located in Table T1. Because of the unknown amount of calcareous faunal dissolution, agglutinated benthic (ABF) and calcareous (CF) foraminifers per gram were calculated separately. In addition, the benthic foraminifer accumulation rate (BFAR) (Herguera and Berger, 1991) was calculated with calcareous foraminifers only, as is usual, and was also calculated as the agglutinated benthic foraminifer accumulation rate (ABFAR) (Table T1). There is no evidence for the selective destruction of agglutinated tests within Hole 1098C. In fact, the large

F4. Percentage of major agglutinated benthic foraminifer species, Hole 1098C, p. 27.



T4. Agglutinated and calcareous benthic foraminiferal species (%), interval A, p. 37.

T5. Agglutinated and calcareous benthic foraminiferal species (%), interval B, p. 38.

T6. Agglutinated and calcareous benthic foraminiferal species (%), interval C, p. 39.

T7. Agglutinated and calcareous benthic foraminiferal species (%), interval D, p. 40.

T8. *N. pachyderma* (s) occurrence, Hole 1098C, p. 41.

T9. Dissolution loss of calcareous foraminifers in the core repository, p. 42.

T10. Size and number of calcareous and agglutinated foraminifers, p. 43.

numbers of very poorly cemented agglutinated foraminifers indicate that lab processing is not an explanation for foraminiferal loss.

Results of Foraminifer Analysis

The abundance and diversity of foraminifers fluctuate in Hole 1098C (Tables T1, T4, T5, T6, T7). Interval B contains the highest numbers of calcareous foraminifers and benthic foraminiferal species. Interval D contains the second largest numbers of calcareous species (Table T1) and also the highest number of planktonic foraminifers, which occur in approximately half of the samples (Table T8). Interval D is also different from the other intervals studied in that both the calcareous benthic foraminifer *B. pseudopunctata* and the agglutinated *P. eltaninae* are rare to absent (Table T7). As a result, *D. glabra* reaches its maximum abundance in interval D (Fig. F4; Table T7). Interval D also contains the largest percentages of rarely occurring calcareous species (defined as the total of all calcareous species except *B. aculeata* and *B. pseudopunctata*) (Table T7). Interval C contains the highest percentage of agglutinated foraminifers and the highest accumulation rate of agglutinated foraminifers (ABFAR on Table T1). Samples from interval C contain the fewest average number of calcareous foraminifers (Table T1), but isolated samples contain common calcareous foraminifers (up to 75% of the total foraminiferal fauna in one sample) (Table T6).

The R-mode cluster analysis of the 24 benthic agglutinated and calcareous foraminifer species resulted in three clusters that described the two end-member associations (laminated vs. bioturbated). Cluster 1 contains *D. glabra* and *M. arenacea,* cluster 2 contains *P. eltaninae* and *Textularia weisneri,* and cluster 3 consists of all the calcareous species with one rare agglutinated species (Fig. F5).

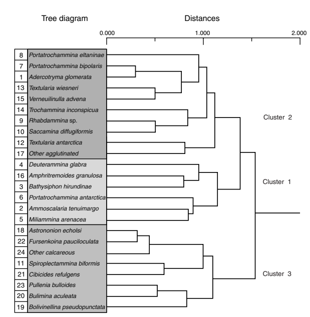
A Q-mode cluster analysis of the 125 samples identified core intervals that were dominated by the *D. glabra* and *M. arenacea* assemblage (cluster 1), the *P. eltaninae* and *T. weisneri* assemblage (cluster 2), and a calcareous assemblage (cluster 3). Samples characterized by cluster 3 included all samples where calcareous foraminifers were abundant (>30% of the total fauna) (Fig. F6). Samples characterized by clusters 1 and 2 (agglutinated species) are samples with low numbers of calcareous foraminifers and lower MS. In addition, interval D does not contain any samples of cluster 2 (*P. eltaninae*).

In each of the four intervals studied, there is a correspondence between laminations, MS, and the type of benthic foraminifers present (Fig. F6). Generally, laminated sediments with relatively low MS are dominated by agglutinated species (clusters 1 and 2) and massive sediments with fluctuating but relatively high MS are characterized by the same agglutinated species along with calcareous foraminifers (cluster 3) (Figs. F4, F6). We suggest that this pattern reflects syndepositional conditions that may have been modified by postdepositional dissolution. This pattern is most pronounced in intervals A, B, and D and is weak but present in the strongly laminated interval C.

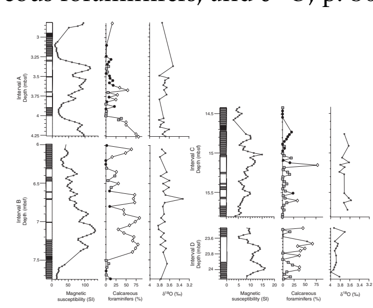
Comparison to Core PD92-30

In an effort to quantify the amount of calcareous foraminiferal dissolution in Hole 1098C, a comparison was done with the original Palmer Deep piston core PD92-30. Core PD92-30 was shipped whole to the Antarctic Research Facility at Florida State University, where it was split and sampled ~6 mo after collection. Because there was no time between

F5. R-mode cluster analysis of the most commonly occurring benthic foraminifers, p. 29.



F6. Magnetic susceptibility, calcareous foraminifers, and $\delta^{18}O$, p. 30.



the splitting and sampling of core PD92-30, a comparison between the faunal counts of core PD92-30 and Hole 1098C could help estimate the carbonate loss that occurred during the 6 mo between the splitting and sampling of Hole 1098C.

Using the MS records, we could easily identify intervals of core PD92-30 that were comparable to intervals A and B in Hole 1098C. Table T11 compares the number of calcareous and agglutinated benthic foraminifers in each sample and per gram in the comparable intervals of core PD92-30 and Hole 1098C. It can be seen that the numbers of calcareous foraminifers in each sample and per gram are quite similar in both Hole 1098C and core PD92-30. The slightly higher values for the number of calcareous foraminifers in Hole 1098C probably result from the unequal number of samples used in the comparison. The significant differences in the number of agglutinated foraminifers probably results from their very small size (Table T10), which may have caused them to be uncounted in the previous study (Leventer et al., 1996).

T11. Benthic foraminiferal statistical comparison between core PD92-30 and Hole 1098C, p. 44.

The comparable numbers of calcareous foraminifers in both core PD92-30 and Hole 1098C suggest that both cores were probably affected by calcareous dissolution prior to sampling. However, the reduced time between splitting and sampling of core PD92-30 suggests that dissolution was not exacerbated during the expanded time interval between splitting (March 1998) and sampling (August 1998) of the Hole 1098C samples. All of this points to dissolution being both a syndepositional and postdepositional process in the Palmer Deep Basin and possibly other high-latitude sedimentary basins.

The calcium carbonate compensation depth (CCD) was approximated at 900 mwd along the AP (Ishman and Domack, 1994), which may help to explain carbonate loss in the Palmer Deep. Nevertheless, calcareous dissolution has continued during storage of Hole 1098C core. Likewise, samples from core PD92-30 collected in August 1999 have confirmed that dissolution of calcareous foraminifers has also occurred in the core repository (Table T12).

T12. Comparison of core PD92-30 samples over time, p. 45.

Agglutinated Foraminifers

Because of the dissolution of calcareous foraminifers in Hole 1098C, any valid paleoceanographic interpretation must be made using the abundant agglutinated assemblage. Unfortunately, agglutinated foraminifers are understudied. Because of their rarity (0%–16% of an assemblage) and poor downcore preservation, agglutinated foraminifers are usually ignored in paleoceanographic studies in favor of the more abundant calcareous species (i.e., Mead and Kennett, 1987; Ishman and Domack, 1994; Ohkushi et al., 2000). Today, agglutinated assemblages are extremely rare and restricted to the deep ocean below the CCD (Gooday, 1990; Evans and Kaminski, 1998; Osterman et al., 1999) or tidal marshes (Goldstein and Watkins, 1990; Scott et al., 1990). To test the value of agglutinated species in paleoceanographic studies, Murray and Alve (1994) subjected calcareous assemblages from the North Atlantic shelf, slope, and abyss to dissolution by acetic acid. The acid-treated samples resulted in a high diversity agglutinated assemblage that showed distribution patterns that correlated with recognized North Atlantic water masses. Murray and Alve (1994) concluded that high diversity agglutinated assemblages of the fossil record were the result of partial or total loss of the calcareous element through either syn- or postdepositional dissolution. Furthermore, the resulting agglutinated assemblages were as useful and perhaps even more useful than calcareous foraminifers for paleoceanographic analysis (Alve and Murray, 1995; Murray and Alve, 1999).

Support for the use of agglutinated foraminifers in Antarctic paleoceanographic studies can be found in several studies. The CDW-influenced diatom oozes of Marguerite Bay contain a diverse assemblage composed of 77% agglutinated foraminifers, and three agglutinated species comprise 14%–50% of the total assemblage in the eight CDW samples but rarely occur elsewhere along the AP shelf (Ishman and Domack, 1994). Harloff and Mackensen (1997) also identify an agglutinated assemblage that characterizes the CDW and the most organic carbon-rich sediments of the Scotia Sea above the CCD. Whereas this fragile agglutinated assemblage would not likely be preserved and would be represented in the geological record of the Scotia Sea as barren intervals (Harloff and Mackensen, 1997), the preservation of agglutinated species is not a major problem in the geologically young and rapidly deposited Palmer Deep sediments. Therefore, several studies have reported a dominantly agglutinated assemblage in association with diatom oozes of the CDW.

Discussion of Foraminiferal Results

In general, the foraminifer accumulation rates (ABFAR and BFAR) can be used as a measure of surface-water productivity (Herguera and Berger, 1991; Herguera, 2000). The high BFAR and ABFAR in Hole 1098C (Table **T1**) attest to the high biogenic productivity of the Palmer Deep (Table **T2**). However, the decay of organic matter in highly productive basins often results in bottom waters reduced both in oxygen and pH. Syndepositional carbonate dissolution caused by lowered pH is one explanation for dominantly agglutinated benthic foraminiferal assemblages found in Hole 1098C. This process may also explain the dominantly agglutinated foraminiferal assemblage from the surface diatom ooze at ODP Site 741, Prydz Bay, Antarctica (561 mbsf) (Schröder-Adams, 1990), and the CDW-influenced Marguerite Bay (Ishman and Domack, 1994) and the Scotia Sea (Harloff and Mackensen, 1997).

Rapidly-accumulating, laminated, organic-rich sediments are also associated with anoxic basins, but the benthic foraminifers of Hole 1098C do not support this conclusion. Agglutinated benthic foraminifer morphologies have been shown to be useful in the identification of bottom-water oxygen levels (Kaminski et al., 1995; Nagy et al., 1995). The two most common agglutinated species of the Palmer Deep, the watch glass–shaped *D. glabra* and troccaminid *P. eltaninae,* are both classified as mobile epifaunal species that are not tolerant of dysoxic conditions (Kaminski et al., 1995). Low-oxygen but not dysoxic conditions are also suggested by the patchy distribution of benthic foraminifer species (Tables **T4, T5, T6, T7**) (Douglas, 1987) and the high numbers of foraminifers (Table **T1**) that often result from the absence of macrobenthos competition (Bernhard and Reimers, 1991).

Isotopes

Carbon and oxygen isotopic values were measured in 75 samples (see **"Appendix B,"** p. 22). The sample data are restricted primarily to the massive high-susceptibility sediments where calcium carbonate is preserved. Only the shallow infaunal species *B. aculeata* was available for isotopic analyses in our samples. This taxon is not generally used in isotopic studies, but there was no alternative species available. Results of

$\delta^{18}O$ are shown on Figure **F6.** The sporadic occurrence of calcareous foraminifers, the infaunal nature of *B. aculeata,* and the unknown effect of carbonate dissolution hamper interpretation of isotope data from our samples. We prefer to not overinterpret the data.

In general, we see little variation in the isotopic data (see **"Appendix B,"** p. 22). There is some evidence that suggests that *B. aculeata* may calcify different chambers at depth within the sediment. This habit would result in each test providing an average isotope value over various sediment slices (Mackensen et al., 2000). This seems to be supported by our research, and oxygen isotope values only vary by ~0.2‰ within each sample interval. Values in intervals A, B, and C range between +3.6‰ and +3.8‰ (Fig. **F6**). Interval D shows similar variation (0.2‰) in isotope data with the exception that oxygen isotope values are slightly more positive, varying between +3.8‰ and +4.0‰.

Carbon isotope values show slightly more variability, although most analyses range between +0.0‰ and –0.5‰. Values in interval D are on the average slightly lower than those in intervals A, B, and C. We see no obvious correlation between the minor variation in isotope data and other proxies of MS or biota.

DISCUSSION OF HOLE 1098C

The upper two sample intervals (A and B) record similar environmental conditions, and the lower two intervals (C and D) record different sets of environmental conditions.

Intervals A and B

Interval A covers the period from ~2020 to 1380 cal. BP, and interval B was deposited between ~3390 and 2740 cal. BP (Fig. **F2**) (Domack et al., 2000). The increased MS values throughout the upper portion of Hole 1098C are most likely due to increased input of terrestrial materials to the basin resulting from glacial erosion of high magnetite-bearing bedrock (Brachfeld, 1999; Brachfeld and Banerjee, 2000) (Fig. **F2**). In all samples from intervals A and B, the abundance of the diatom *Fragilariopsis curta* (sea-ice indicator) is greater than *Fragilariopsis kerguelensis* (open-water indicator) (Fig. **F3**). These data suggest the surface water environment of the late Holocene was characterized by a significant increase in sea-ice and ice-edge production. Uniform composition of the agglutinated foraminifer fauna throughout the late Holocene suggests that the Palmer Deep Basin was continually influenced by modified UCDW (Hofmann and Klink, 1998) and there were no major changes in the bottom-water mass.

Susceptibility Lows

The low values of MS within intervals A and B are interpreted to represent an increased influx of diatoms (Leventer et al., 1996; Shipboard Scientific Party, 1999). In all cases, laminated sediments, because of rapid deposition of diatom blooms, characterize the susceptibility lows. The rapid deposition of diatoms results in good preservation of more fragile diatoms but can affect the benthos in two ways. First, the diatom decay uses oxygen and results in lowered bottom-water oxygen. Second, the decay of the organic matter lowers the pH, which results in $CaCO_3$ dissolution. Syndepositional calcareous carbonate dissolution due to reduced bottom-water pH is indicated during the MS lows. However, the presence of mobile epifaunal agglutinated foraminifers (Kaminski et al., 1995) in the susceptibility lows indicates oxygen was present and any anoxia that might have developed would have been short lived (Fig. **F4**).

The extensive laminations throughout Hole 1098C may themselves be a cause for decreased bioturbation. Laminations of mat-forming diatoms have been shown to suppress benthic activity regardless of bottom-water oxygen levels (Kemp and Baldauf, 1993; Boden and Backman, 1996; Pike and Kemp, 1999). These authors show that the macrobenthos were prevented from bioturbation through the intermeshed diatom frustules, which resulted in the increased preservation of the laminations even in well-oxygenated bottom waters.

Susceptibility Highs

Within intervals A and B, sediments with relatively higher MS are bioturbated and massive but weak laminations are present. The diatom assemblages of the susceptibility highs indicate a more diverse oceanic assemblage, suggesting a well-mixed ocean with average surface productivity and the reduced influence of meltwater. However, it must be remembered that even the "average productivity" of the Palmer Deep is still very high.

Less meltwater and surface stratification would result in fewer diatom blooms. The slight decrease in productivity allows for more bottom-water oxygen, enabling more vigorous macrobenthos bioturbation and the destruction of diatom frustules, which results in "poorer" diatom preservation. Poorer diatom preservation also results from the slower settling rate of the nonmat-forming diatoms. The reduced formation and deposition of diatom mats also created less $CaCO_3$ dissolution of calcareous benthic foraminifers in the massive sediments. Therefore, surface-water processes can be used to explain the greater numbers of calcareous foraminifers along with the agglutinated species in the susceptibility highs (Fig. **F6**).

Interval C

Interval C (14.42–15.81 mbsf) comes from the section of Hole 1098C that has low-amplitude MS fluctuations and the most strongly laminated sediments of the middle Holocene (~5920–5430 cal. BP) (Fig. **F2**) (Domack et al., 2001). Bioturbated sediments and relatively higher MS values are rare in interval C, and overall there is a very weak correlation between laminated sediments and MS (Fig. **F6**). In this interval of Hole 1098C, the decreased MS (Fig. **F2**) results from a low magnetite-bearing sediment source (Brachfeld, 1999; Brachfeld and Banerjee, 2000), as well as an overall dilution of the signal by an increased mass accumulation rate (MAR) during the Holocene Climatic Optimum (Domack et al., 2001).

Both the diatom (Table **T2**) and benthic foraminifer ABFAR (Table **T1**) data indicate the highest productivity rates of Hole 1098C, which explains the high MAR of this section at Site 1098 (Domack et al., 2001). The diatom assemblage records a relatively higher abundance of *F. kerguelensis* and lower values of *F. curta* (Fig. **F3**), which implies a lengthier season of open water and less sea-ice/meltwater influence. Therefore, during intervals C and D, the surface water was not as influenced by sea ice as during the late Holocene (intervals A and B).

Agglutinated benthic foraminifers do not record any assemblage changes, which suggests that environmental conditions were unchanging and that the same bottom-water mass (modified UCDW) likely influenced this site as during the late Holocene (Fig. **F4**). There is only a weak correlation between the dissolution of calcareous foraminifers and laminated sediments in interval C (Fig. **F5**), which is probably due to low carbonate values throughout this part of the hole. The dissolution of foraminifers in interval C is believed to be a result of decreased pH due to the decay of abundant organic matter deposited in this interval of increased productivity (Tables **T1, T2**) and was probably both syn- and postdepositional. Similar agglutinated faunas are found in other Antarctic diatom oozes (Schröder-Adams, 1990; Ishman and Domack, 1994; Harloff and Mackenson, 1997).

Interval D

Interval D (24.74–24.01 mbsf) similarly records the low-amplitude MS fluctuations in Hole 1098C during the early Holocene (~8880–8590 cal. BP) (Domack et al., 2001). In general, there is a correlation between laminated sediments, decreased calcareous foraminifers, and low MS that may be syndepositional (Fig. **F6**).

However, the biota of interval D records significant changes in both bottom and surface waters. Changes in the benthic foraminifer assemblage, including an increase in the number of minor calcareous species and reduced numbers of both *P. eltaninae* (agglutinated) and *B. pseudopunctata* (calcareous) in this interval, suggest a change in bottom-water conditions (Table **T7;** Fig. **F4**). In addition, a shift in the oxygen isotopes of benthic foraminifers suggests that a different bottom-water mass was influencing this site during interval D (Fig. **F6**).

Changes in the surface water are indicated by an increase in the number of planktonic foraminifers, implying an influx of more open-oceanic water (Table **T8**). The diatom assemblage records more *F. kerguelensis,* which implies more open-water and less sea-ice influence during this interval (Fig. **F3**). In addition, interval D contains an increased number of the asymmetric "more northerly" form of the diatom *E. antarctica* (Fryxell, 1989; Kaczmarska et al., 1993) (Table **T3**). All of this evidence points to the intrusion of more northerly open-ocean surface and bottom CDW and a reduced meltwater influence on the Antarctic Peninsula shelf during the early Holocene.

CONCLUSIONS

1. Documented dissolution of calcareous foraminifers in the core repository has affected the foraminifer content of the sediment (Table **T9**). Any interpretation of the calcareous foraminifers of this site is questionable, but the agglutinated species are presumed to be intact and can be used for paleoenvironmental interpretations. The overall trend of higher percentages of calcareous foraminifers in the bioturbated interval and lower percentages in the laminated interval is believed to be syndepositional but has also been altered by an unknown amount of postdepositional carbonate dissolution.
2. The presence of mobile epifaunal agglutinated benthic foraminifers in all samples from Hole 1098C indicates that the bottom water was oxygenated at all times and that laminated sediments

do not represent periods of anoxia (Fig. **F4**). The formation of the laminations by mat-forming diatoms may have suppressed bioturbation by macrobenthos (Pike and Kemp, 1999). The increased numbers of benthic foraminifers, possibly due to decreased competition from larger metazoans (Bernhard and Reimers, 1991), indicate that any anoxia that might have occurred was minor (seasonal, not decadal).

3. The climatic model proposed by Leventer et al. (1996) appears to be supported by data from our intervals A and B, but a revision of the foraminiferal interpretation is necessary (see conclusion 4, below). In intervals A and B, MS lows are characterized by laminated sediments and diatoms, indicating increased meltwater and a more stratified ocean (Fig. **F3**). Total dissolution of calcareous foraminifers in the low-susceptibility laminated sediments may be related in part to decreased bottom-water pH due to decay of diatom organic matter (Fig. **F6**).

   High values of magnetic susceptibility occur in massive bioturbated sediments, which contain a diatom assemblage indicating reduced meltwater stratification. Preservation of calcareous foraminifers during the susceptibility highs (Fig. **F6**) likely reflects normal bottom-water pH.
4. There are no major changes in the assemblage composition of the agglutinated benthic foraminifers or the isotopic values of the calcareous benthic foraminifers in the laminated and massive sediments within each sample interval (Figs. **F4, F6**). This suggests that the driving force behind the laminated sediments and the susceptibility fluctuations within each interval is probably not a change in the bottom-water mass but lies in changes in the diatom productivity of the surface water (see conclusion 3, above). It appears that UCDW was a feature of the AP continental shelf throughout the Holocene. Our results disagree with the idea that bottom-water fluctuations played a role in the climatic fluctuations of the Palmer Deep (Leventer et al., 1996).
5. Diatoms indicate that the early and middle Holocene climatic optimum (intervals C and D) was a time of reduced sea-ice formation. These conditions led to the highest accumulation rates of diatoms and benthic foraminifers and the greatest primary productivity occurrence during interval C (Tables **T1, T2**). During the late Holocene (intervals A and B), diatoms record increased meltwater stratification of the AP shelf water and expansion of sea-ice conditions.
6. Early Holocene interval D records a significantly different environmental condition. This conclusion is based on several lines of evidence. First, both the presence of the asymmetrical morphotype of *E. antarctica* (Table **T3**) and the presence of increased numbers of the planktonic foraminifer *N. pachyderma* (Table **T8**) suggest the intrusion of more open-ocean surface water into this region. Second, a change in the oxygen isotopic values of benthic foraminifers suggests a different bottom water. Third, a change in the faunal assemblage of benthic foraminifers, including a decrease in *P. eltaninae* and *B. pseudopunctata* and the increased percentage of rare calcareous species diversity (Fig. **F4;** Table **T7**), indicates a change in the bottom water mass. All the data suggest the presence of more open-ocean CDW on the AP continental shelf during the early Holocene.

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APPENDIX A

Benthic Foraminifer Reference List and Taxonomic Notes

Calcareous species in the taxonomic list are identified by an asterisk.

Adercotryma glomerata (Brady) = *Lituola glomerata* Brady, 1878. p. 433 (pl. 20, fig. 1).

Ammoscalaria tenuimargo (Brady) = *Haplophragminum tenuimargo* Brady, 1884 (pl. 33, figs. 13–16). Remarks: tentative identification of a very fragile primitive agglutinated foraminifer.

Amphritemoides granulosa (Brady) = *Astrohiza granulosa* Brady, 1884, p. 234 (pl. 20, figs. 14–23). Remarks: tentative identification of a very fragile primitive agglutinated foraminifer.

**Astrononion echolsi* Kennett, 1967, *Cushman Foundation for Foram. Res. Contrib.,* 18(3), p. 134 (pl. 11, figs. 8, 9).

Bathysiphon hirundinae (Heron-Allen and Earland) = *Hippocrepinella hirundinae* Heron-Allen and Earland, 1932, *Discovery Reports,* p. 258 (pl. 1, figs. 7–15).

**Bolivinellina pseudopunctata* Högland, 1947, *Uppsala Univ. Zool. Bidr.,* 26, p. 273 (pl. 24, fig. 5a, 5b). Remarks: elongate biserial test with optically radial walls; aperture is a basal loop with a narrow lip and internal toothplate. This is the second most commonly occurring calcareous species in Hole 1098C.

**Bulimina aculeata* d'Orbigny, 1826, *Ann. Nat. Science., Paris,* ser. 1, 7, p. 269 (pl. 12, figs. 10–12). Remarks: this is the most commonly occurring calcareous species in Hole 1098C.

**Cibicides refulgens* Montfort, 1808, *Conchylogie System. et Class. Method. des Coq.,* 1, pp. 122–123.

Cribrostomoides wiesneri (Parr) = *Labrospira wiesneri* Parr, 1950, p. 272 (pl. 4, figs. 25, 26). Remarks: this is included in "other agglutinated" on Tables **T4, T5, T6,** and **T7.**

Dentalina* sp. Remarks: one specimen found in Sample 178-1098C-1H-5, 85–86 cm. This is included in "other calcareous" on Tables **T4, T5, T6, and **T7.**

Deuterammina glabra (Heron-Allen and Earland) 1932 = *Trochammina glabra* Heron-Allen and Earland, 1932, *Discovery Reports,* 4 (pl. 7, figs. 26–28). Remarks: *Trochospiral planoconvex* with numerous chambers. Primary aperture interiomarginal with secondary apertures at the inner tip of the final chamber opening to the umbilicus with previous ones remaining open as well. This is the most common agglutinated species in Hole 1098C and was identified as *T. intermedia* by Ishman and Domack (1994).

Fissurina* sp. rare unidentified species. Remarks: this is included in "other calcareous" in Tables **T4, T5, T6, and **T7.**

**Fursenkoina pauciloculata* (Brady) = *Virgulina pauciloculata* Brady, 1884, p. 414 (pl. 52, figs. 4, 5). Remarks: this is a twisted biserial test with optically granular walls. The aperture is a narrow loop extending up the face of the final chamber, but the lower part may be closed and comma shaped. There is an internal tooth plate extending to previous foramen. This species contains an aperture up the face of last chamber that is visible from the top of the specimen. Additional remark: does not include *Fursenkoina fusiformis* (Williamson) = *Bulimina pupoides* var. *fusiformis* Williamson, 1858, *Ray Society,* London, p. 63 (pl. 5, figs. 129, 130), whose aperture consists of slit at the top of the specimen.

Globocassidulina biora* (Crespin) = *Cassidulina biora* Crespin, 1960, *Sci. Results Tohoku Univ.,* ser. 2 (Geol.), spec. vol. 4, p. 28 (pl. 3, figs. 1–10). Remarks: this is included in "other calcareous" on Tables **T4, T5, T6, and **T7.**

Globocassidulina subglobosa* (Brady) = *Cassidulina subglobosa* Brady, 1881, *Q. J. Miscroc. Sci.,* v. 21(3), p. 60 (pl. 54, fig. 17a–17c). Remarks: this is included in "other calcareous" on Tables **T4, T5, T6, and **T7.**

Hyperammina elongata Brady, 1878, *Ann. Mag. Nat. History,* ser. 5, 1, p. 433 (pl. 20, fig. 2a, 2b). Remarks: this is included in "other agglutinated" on Tables **T4, T5, T6,** and **T7.**

Lagena gracilis* (Williamson) = *Lagena vulgaris* var. *gracilis* Williamson, 1858, *Ray Society,* London (pl. 1, fig. 7). Remarks: this is included in "other calcareous" on Tables **T4, T5, T6, and **T7.**

Lagena laevis* (Montagu) = *Vermiculum laeve* Montagu, 1803, *Testacea Britannica,* p. 524 (pl. 1, fig. 9). Remarks: this is included in "other calcareous" on Tables **T4, T5, T6, and **T7.**

Lenticulina antarctica* Parr, 1950, *British and New Zealand Antarctic Research Expedition,* series B, v. 5, pt. 6, p. 323 (pl. 11a, 11b). Remarks: one specimen was found in Sample 178-1098C-1H-5, 95–96 cm. This is included in "other calcareous" on Tables **T4, T5, T6, and **T7.**

Martinotiella antarctica (Parr) = *Schenckiella antarctica* Parr, 1950, *British and New Zealand Antarctic Research Expedition,* series B, v. 5, pt. 6, p. 284 (pl. 5, fig. 27). Remarks: this is included in "other agglutinated" on Tables **T4, T5, T6,** and **T7.**

Milliammina arenacea (Chapman) = *Miliolina oblonga* var. *arenacea* Chapman, 1916, *Br. Antarctic Exped. 1907–1909, Rep. Sci. Invest., Geol.,* 2(3), p. 59 (pl. 1, fig. 7).

Minor calcareous species = designation on Tables **T4, T5, T6,** and **T7** that includes the total percentage of all calcareous species except *Bolivinellina pseudopunctata* and *Bulimina aculeata.*

Nonionella bradyi* (Chapman) = *Nonionella scapha* var. *bradii* Chapman, 1916, *Br. Antarctic Exped. 1907–1909, Rep. Sci. Invest., Geol.,* 2(3), p. 71 (pl. 5, fig. 42). Remarks: this is a longer species than *N. iridea* and is included in "other calcareous" on Tables **T4, T5, T6, and **T7.**

Nonionella iridea* Heron-Allen and Earland, 1932, *Discovery Reports,* 4, p. 438 (pl. 16, figs. 14–16). Remarks: this is included in "other calcareous" on Tables **T4, T5, T6, and **T7.**

Other agglutinated = designation on Tables **T4, T5, T6,** and **T7** that includes rare agglutinated species occurring in <4 samples.

Other calcareous = designation on Tables **T4, T5, T6,** and **T7** that includes rarely occurring calcareous species.

Oridorsalis umbonatus* (Reuss) = *Rotalina umbonatus* Reuss, 1851, *Zeitschrift der Deutschen Geoligischen Gesellschaft,* Berlin, vol. 3, p. 75 (pl. 5, fig. 35a–35c). Remarks: *O. umbonatus* includes individuals identified as *Eponides tener* by other authors. This is included in "other calcareous" on Tables **T4, T5, T6, and **T7.**

Portatrochammina antarctica (Parr) = *Trochammina antarctica* Parr, 1950, *Br. Antarctic N.Z., Antarctic. Res. Expedition* 1929–1931, Ser. B, 5(6), p. 279 (pl. 5, figs. 2–4).

Portatrochammina bipolaris (Brady) = *Haplophramium nanum* Brady, 1881, *Ann. Mag. Nat. Hist., London* (ser. 5), 8, p. 406 (pl. 21, fig. 1a–1c) (non-*H. nanum* Brady, 1881, *Q. J. Miscro. Sci., London* (n.s) 21, p. 31–71). Remarks: this is a low trochospiral to flat, small compressed species with six to eight chambers in the final whorl. The outline is elongate to ovate with wide and shallow umbilicus covered by a series of well-developed overlapping flaps.

Portatrochammina eltaninae R.J. Echols, 1971, *Antarctic Res. Ser,* v. 15, p. 148 (pl. 8, figs. 1, 2) (type genus). Remarks: test trochospiral, umbilicus covered by a flap extending from each successive chamber. Proteinaceous proloculus with later chamber agglutinated. Aperture is a low interior-marginal arch in the final septal face and extends along the entire border of the umbilical flap. Five chambers in final whorl.

**Pullenia bulloides* (d'Orbigny) = *Sphaeroidina bulloides* d'Orbigny, 1826, *Ann. Nat. Sci. Paris,* ser. 1, 7, p. 267.

Reophax spiculifer Brady, 1879, p. 54 (pl. 4, figs. 10, 11). Remarks: this is included in "other agglutinated" on Tables **T4, T5, T6,** and **T7.**

Rhabdammina sp. An unidentified fine-grained species.

Saccammina difflugiformis (Brady) = *Reophax difflugiformis* Brady, 1879, notes on some of the Reticularian Rhizopoda of the *Challenger* Expedition: *Q. J. Micros. Sci.,* new series, v. 19, p. 51 (pl. 4, fig. 3a, 3b).

Spiroplectammina biformis (Parker and Jones) = *Textularia agglutinans* var. biformis Parker and Jones, 1865, *Philantr. Trans. R. Soc.,* p. 155. (pl. 15, figs. 23, 24).

Textularia antarctica (Wiesner) = *Pseudobolivina antarctica* Wiesner, 1931, *Deutsche Südpolar Exped.,* 20 (Zool., 12), p. 99 (pl. 21, figs. 257, 258) (pl. 23, fig. C).

Textularia wiesneri Earland, 1933, *Discovery Reports.* 7, p. 114 (pl. 3, figs. 18–20).

Trifarina earlandi* (Parr) = *Anguligerina earlandi* Parr, 1950, *British and New Zealand Antarctic Research Expedition,* series B, v. 5, pt. 6, p. 341 (pl. 12, fig. 21). Remarks: this is included in "other calcareous" on Tables **T4, T5, T6, and **T7.**

Trochammina inconspicua Earland, 1934, *Discovery Reports,* v. 10, p. 102 (pl. 3, figs. 38–40).

Trochammina spp. includes rare unidentified specimens. Remarks: this is included in "other agglutinated" on Tables **T4, T5, T6,** and **T7.**

Verneuilinulla advena (Weisner, 1931) = *Verneuilina minuta* Weisner, 1931, *Deutsche Südpolar Expedition,* 20 (Zoology 12), p. 99 (pl. 13, fig. 155).

APPENDIX B

^{13}C and $\delta^{18}O$ Measurements on *Buliminia aculeata,* Hole 1098C

Core, section, interval (cm)	Depth (mbsf)	^{13}C (‰)	$\delta^{18}O$ (‰)
1H-2, 132-133	2.82	–0.42	3.62
1H-3, 37-38	3.37	–0.47	3.40
1H-3, 49-50	3.49	–0.02	3.67
1H-3, 52-53	3.52	–0.48	3.49
1H-3, 55-56	3.55	–0.57	3.56
1H-3, 58-59	3.58	–0.14	3.57
1H-3, 61-62	3.61	–0.25	3.59
1H-3, 64-65	3.64	–0.30	3.53
1H-3, 67-68	3.67	–0.29	3.58
1H-3, 73-74	3.73	–0.25	3.53
1H-3, 79-80	3.79	–0.33	3.67
1H-3, 103-104	4.03	0.32	3.59
1H-3, 105-106	4.05	–0.08	3.68
1H-3, 108-109	4.08	–0.38	3.59
1H-3, 111-112	4.11	–0.10	3.64
1H-3, 114-115	4.14	–0.06	3.66
1H-3, 117-118	4.17	0.01	3.48
1H-3, 120-121	4.20	–0.25	3.57
1H-3, 123-124	4.23	–0.21	3.61
1H-3, 126-127	4.26	–0.07	3.55
1H-5, 5-6	6.05	0.04	3.63
1H-5, 10-11	6.10	0.09	3.56
1H-5, 15-16	6.15	0.28	3.67
1H-5, 35-36	6.35	–0.36	3.54
1H-5, 40-41	6.40	0.62	3.66
1H-5, 46-47	6.46	–0.30	3.48
1H-5, 50-51	6.50	–0.18	3.61
1H-5, 55-56	6.55	–0.24	3.49
1H-5, 60-61	6.60	0.06	3.60
1H-5, 65-66	6.65	–0.14	3.56
1H-5, 70-71	6.70	–0.26	3.21
1H-5, 75-76	6.75	–0.27	3.58
1H-5, 80-81	6.80	0.07	3.61
1H-5, 85-86	6.85	–3.97	–2.99
1H-5, 90-91	6.90	–0.65	3.58
1H-5, 95-96	6.95	0.01	3.65
1H-5, 100-101	7.00	–0.41	3.57
1H-5, 105-106	7.05	–0.02	3.71

Core, section, interval (cm)	Depth (mbsf)	^{13}C (‰)	$\delta^{18}O$ (‰)
1H-5, 110-111	7.10	–0.29	3.70
1H-5, 115-116	7.15	–0.15	3.59
1H-5, 120-121	7.20	–0.09	3.65
1H-5, 125-126	7.25	–0.17	3.56
1H-5, 130-131	7.30	–0.08	3.66
1H-5, 135-136	7.35	–0.29	3.55
1H-5, 140-141	7.40	–0.07	3.60
1H-6, 5-6	7.55	–0.26	3.53
1H-6, 25-26	7.75	0.49	3.65
2H-5, 6-7	14.76	–0.14	3.59
2H-5, 12-13	14.82	–4.35	–2.71
2H-5, 21-22	14.91	–0.42	3.50
2H-5, 36-37	15.06	–0.15	3.64
2H-5, 42-43	15.12	–0.37	3.49
2H-5, 45-46	15.15	–0.16	3.67
2H-5, 48-49	15.18	0.18	3.59
2H-5, 54-55	15.24	–0.09	3.69
2H-5, 57-58	15.27	–0.08	3.59
2H-5, 81-82	15.51	–0.15	3.59
2H-5, 87-88	15.57	–0.33	3.50
2H-5, 90-91	15.60	0.03	3.46
2H-5, 93-94	15.63	–0.10	3.60
2H-5, 102-103	15.72	0.49	3.53
3H-4, 76.5-77.5	23.47	–0.11	3.80
3H-4, 82-83	23.52	–0.65	3.58
3H-4, 94-95	23.64	0.24	3.78
3H-4, 97-98	23.67	–0.46	3.72
3H-4, 100-101	23.70	–0.58	3.73
3H-4, 103-104	23.73	–0.26	3.76
3H-4, 106-107	23.76	–0.45	3.78
3H-4, 112-113	23.82	–0.50	3.76
3H-4, 121-122	23.91	–0.59	3.75
3H-4, 124-125	23.94	–0.13	3.77
3H-4, 127-128	23.97	–0.30	3.79
3H-4, 130-131	24.00	–0.56	3.81
3H-4, 133-134	24.03	–0.77	3.86
3H-4, 139-140	24.09	–0.85	3.68

Figure F1. Location map of Site 1098 in Palmer Deep, Antarctica Peninsula continental shelf. Bathymetric contours are in meters water depth.

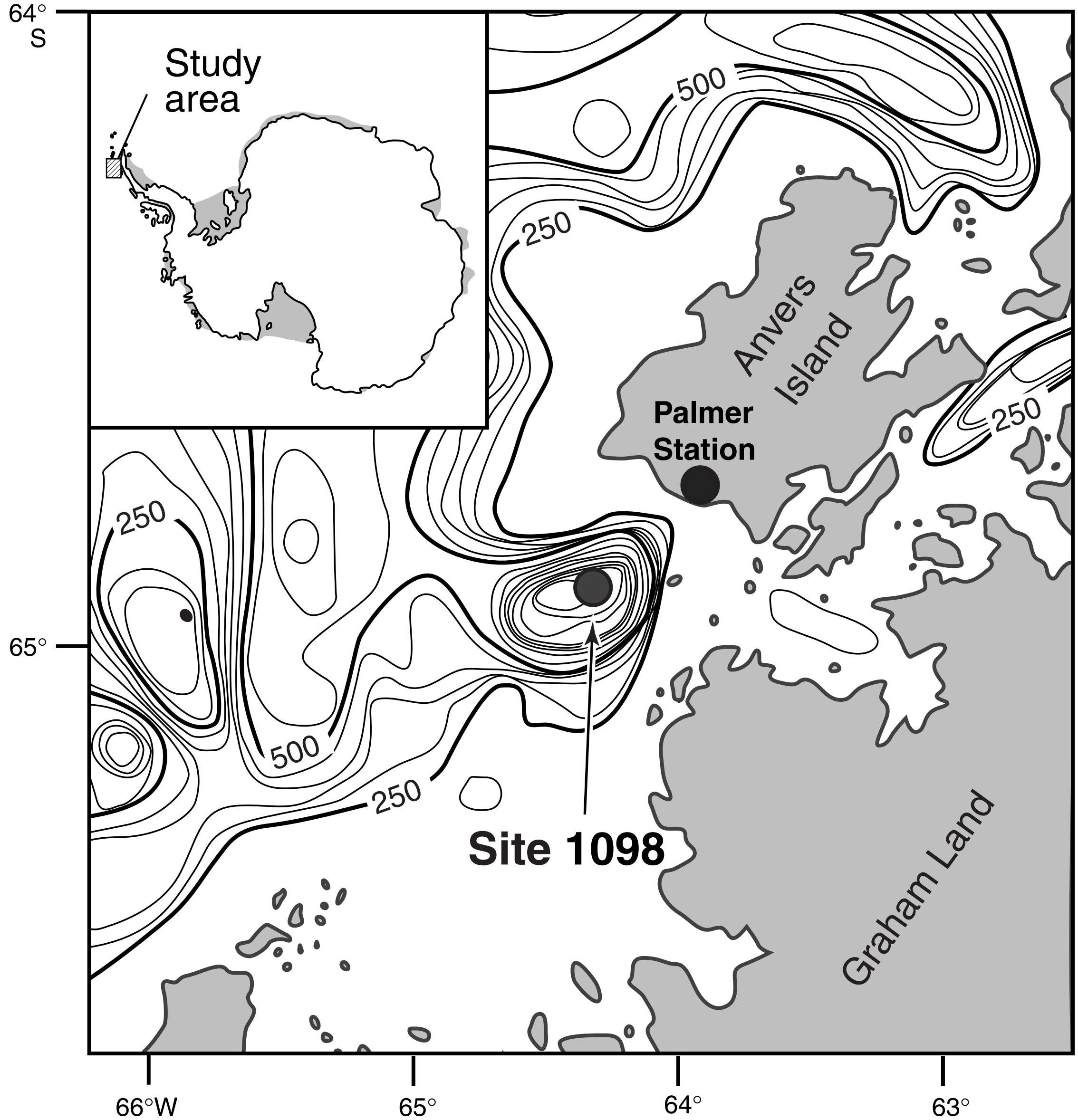

Figure F2. Magnetic susceptibility record and simplified core lithology for Hole 1098C (Shipboard Scientific Party, 1999) with the locations of intervals A, B, C, and D that were studied for this paper.

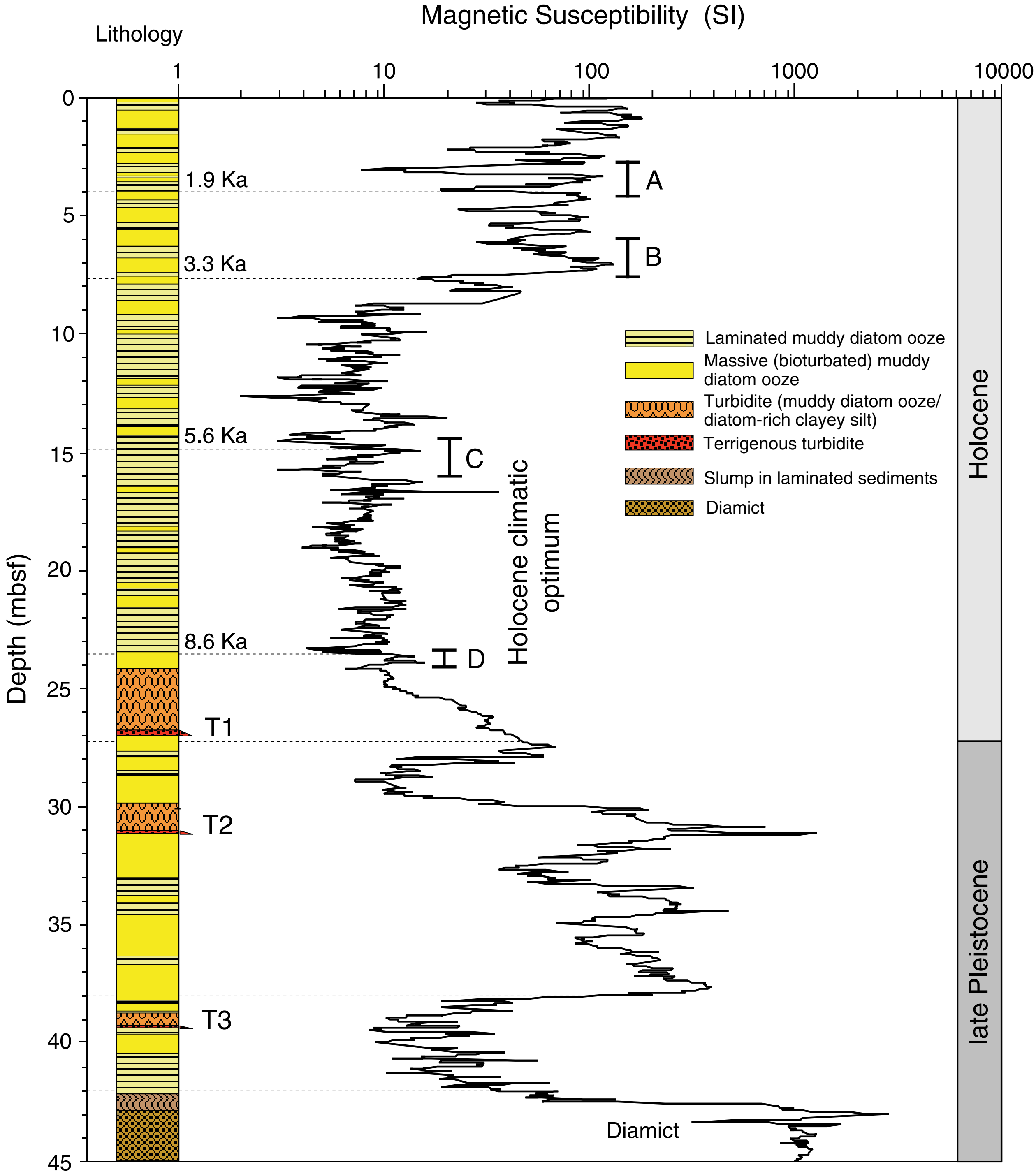

Figure F3. Percentage of the most common *Fragilariopsis* diatom species in Hole 1098C for each core interval from the counts of all *Fragilariopsis*, *Thalassiothrix*, and *Thalassionema*. The far right column shows counts of *Chaetoceros* spores. Interval depths along with a representation of the laminations identified from core photos are also shown. White = bioturbated sediments and black = the missing 5-cm core interval removed for interstitial water samples at the bottom of each core section. (**Figure shown on next page.**)

Figure F3 (continued). (Caption shown on previous page.)

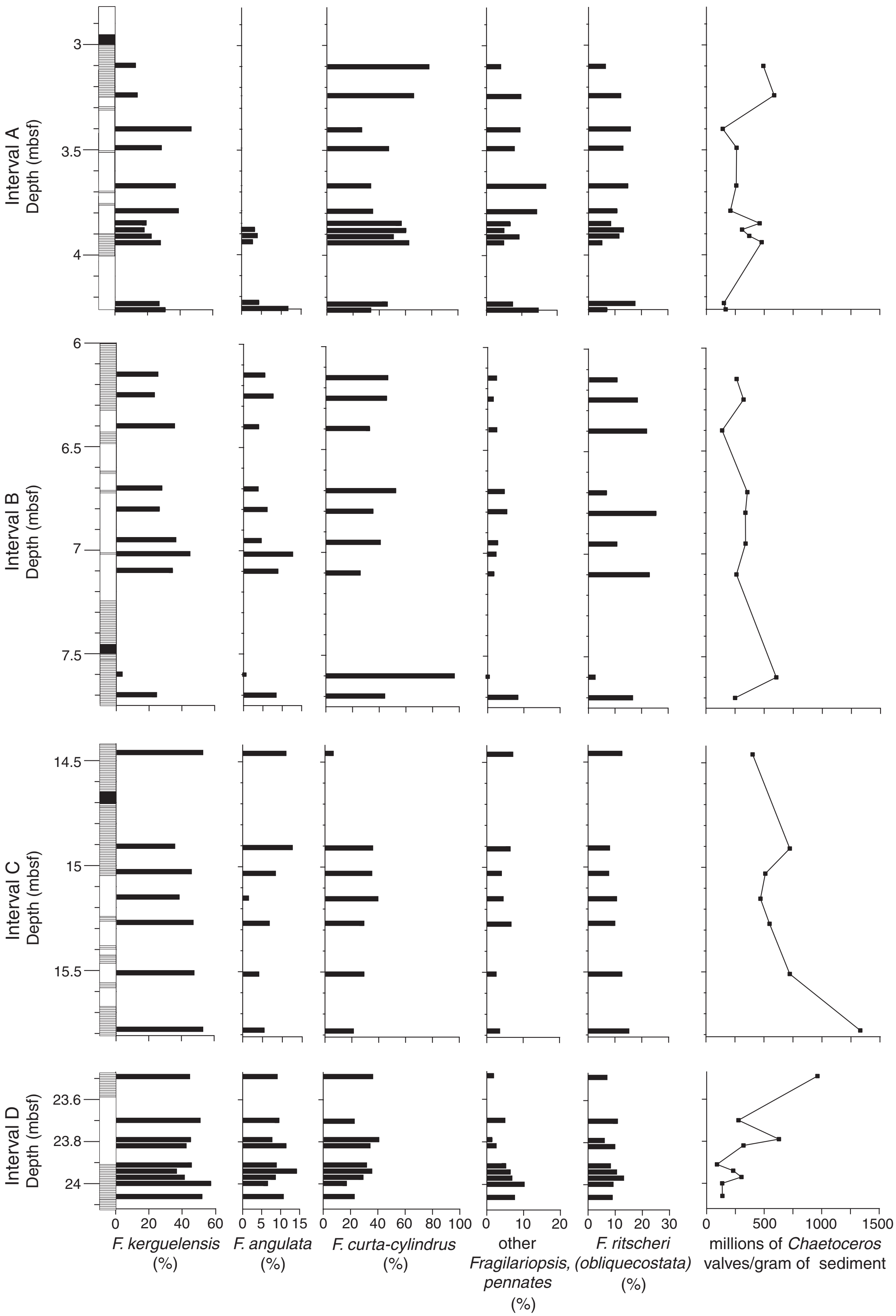

Figure F4. Percentage of major agglutinated benthic foraminifer species in the four intervals studied in Hole 1098C (*Deuterammina glabra, Milliammina arenecea, Portatrochammina eltaninae,* and *Textularia weisneri*) calculated as a percentage of the total agglutinated species. The percentage of these agglutinated species, calculated as a proportion of the total assemblage including calcareous foraminifers, can be found in Tables **T4,** p. 37, **T5,** p. 38, **T6,** p. 39, and **T7,** p. 40. Striped pattern = laminated sediments, white = bioturbated sediments, and black = the missing 5-cm core interval removed for interstitial water samples at the bottom of each core section. (**Figure shown on next page.**)

Figure F4 (continued). (Caption shown on previous page.)

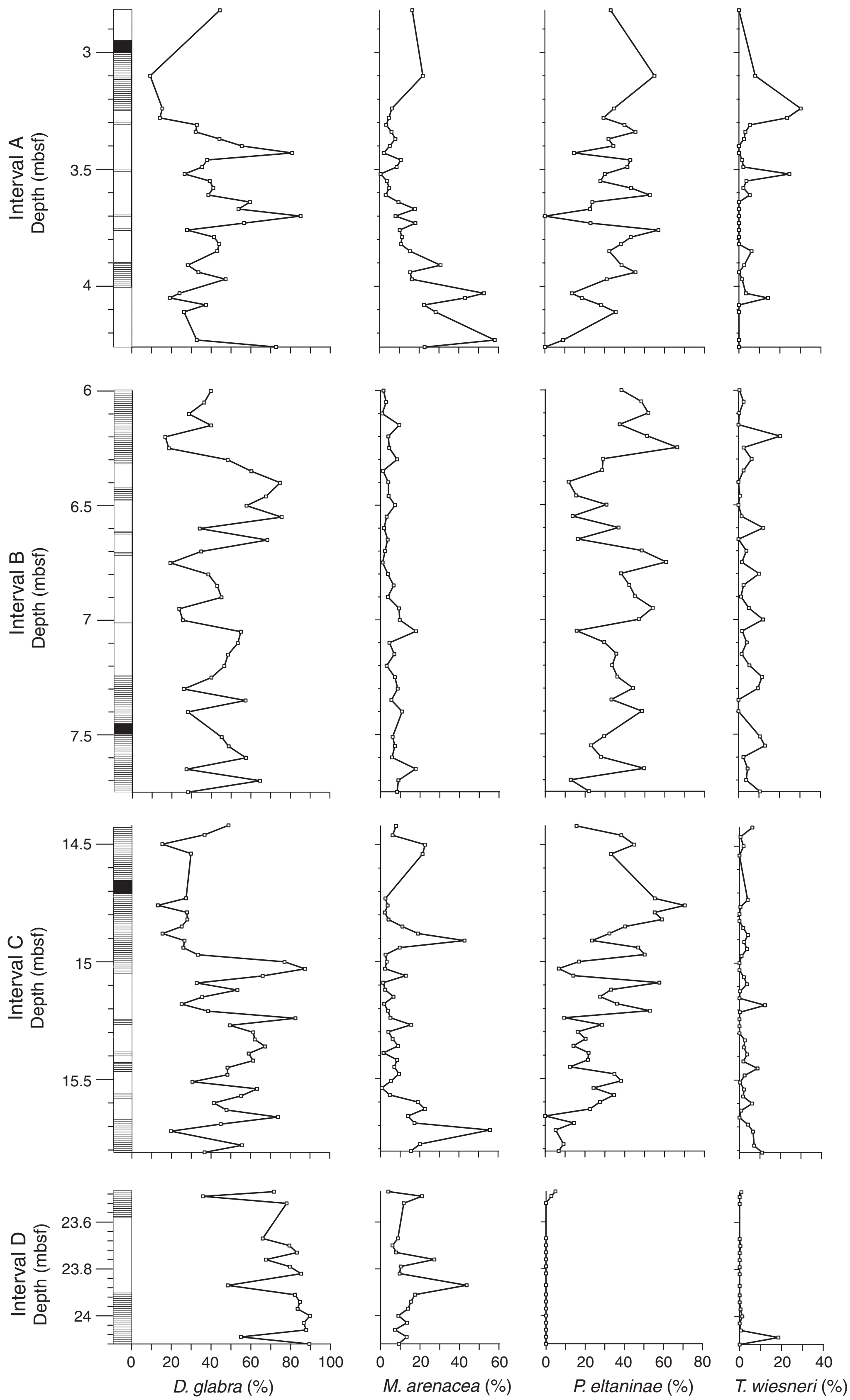

Figure F5. Results of the R-mode cluster analysis of the 24 most commonly occurring benthic foraminifer species from Tables T4, p. 37, T5, p. 38, T6, p. 39, and T7, p. 40. Three clusters identify the most common species associations. Cluster 1 = *Portatrochammina eltaninae* and *Textularia* spp., cluster 2 = *Deuterammina glabra* and *Milliammina arenacea,* and cluster 3 = all calcareous benthic foraminifer species.

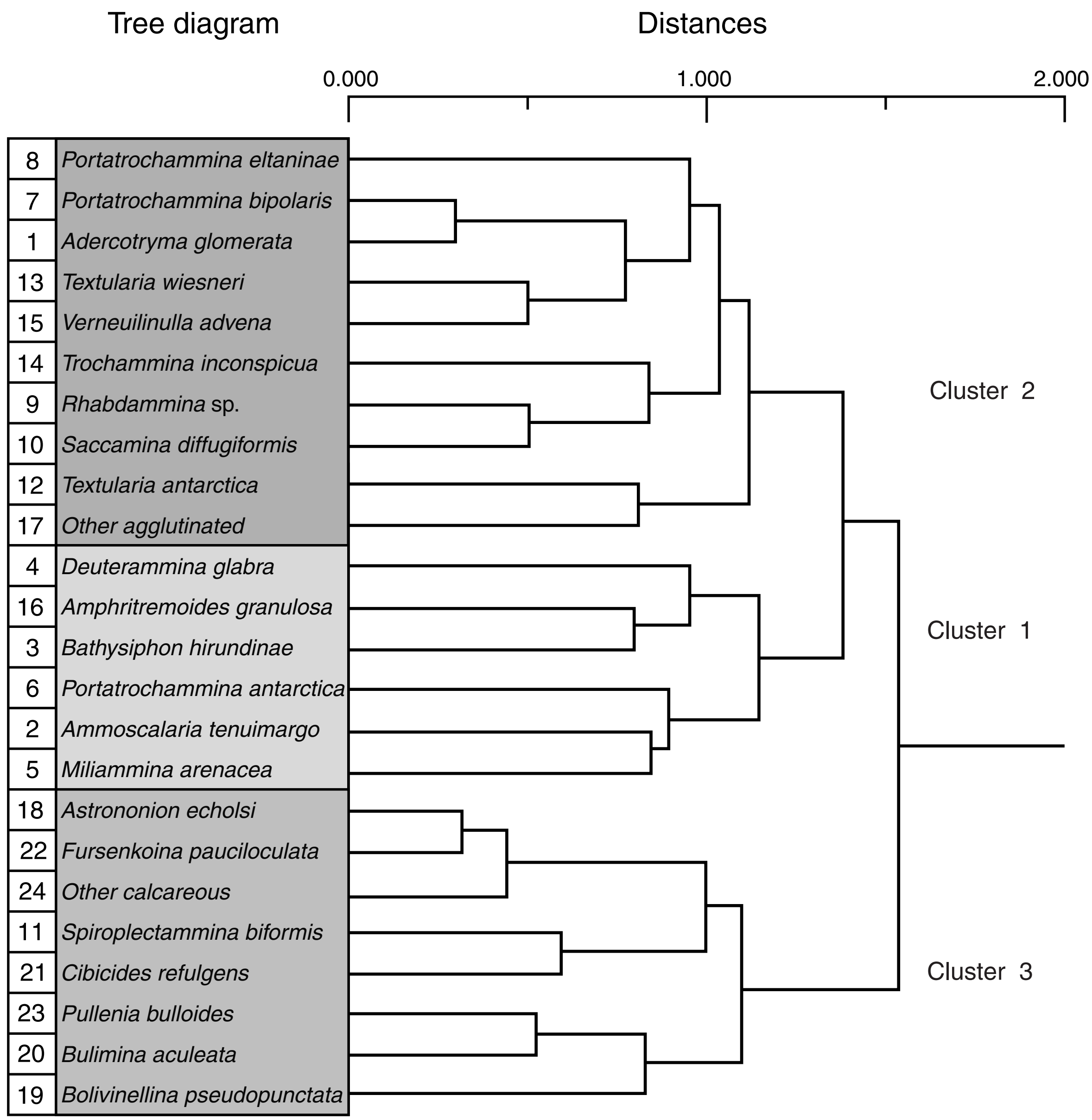

Figure F6. Magnetic susceptibility, calcareous foraminifers, and $\delta^{18}O$ results from the four core intervals. On depth axes: lines = laminations, white = bioturbated sediments, and black = the missing 5-cm core interval removed for interstitial water samples at the bottom of each core section. Each left column shows the shipboard magnetic susceptibility measured at 2-cm intervals. The center column shows the percent of total benthic foraminifer fauna composed of calcareous foraminifers (Tables **T4,** p. 37, **T5,** p. 38, **T6,** p. 39, **T7,** p. 40). Also shown on the center column are the results of Q-mode cluster analysis of 125 samples (Table **T1,** p. 32). Cluster 1 = squares, cluster 2 = circles, cluster 3 = diamonds. Three samples (small squares) included in the calcareous percentage curve of interval D were not included in the cluster analysis due to low numbers. The column on the far right shows the $\delta^{18}O$ values of *Bulimina aculeata*. (**Figure shown on next page.**)

Figure F6 (continued). (Caption shown on previous page.)

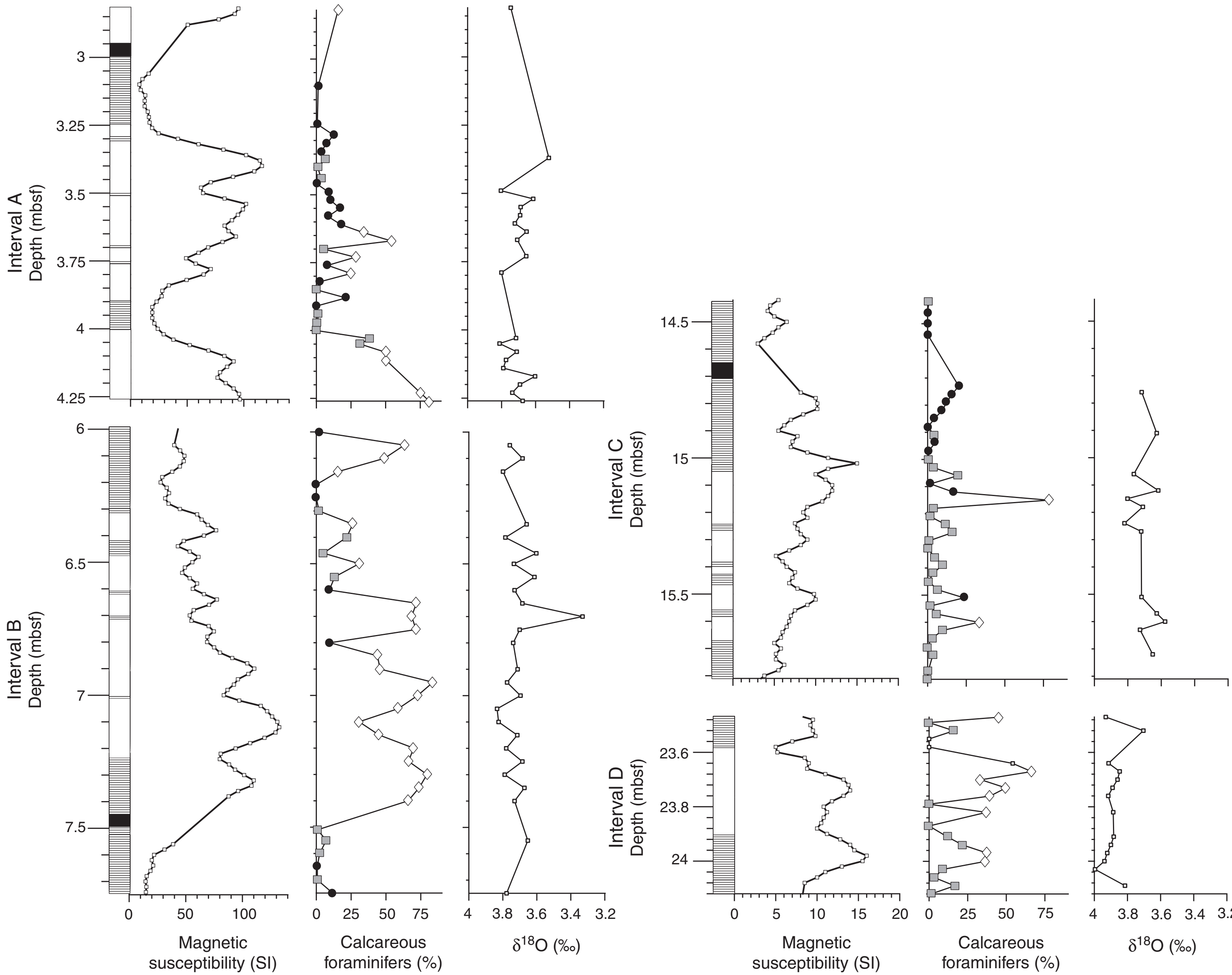

Table T1. Benthic foraminifers, Hole 1098C. (See table notes. Continued on next two pages.)

Core, section, interval (cm)	Depth (mbsf)	Depth (mcd)	Dry sample weight (g)	Sample examined (%)	CF (number)	ABF (number)	Total BF (*N*)	Number of species (S)	# H′	ABF (number/g)	ABFAR (number/ cm²/k.y.)	CF (number/g)	Calcareous BFAR (number/ cm²/k.y.)
178-1098C-													
1H-2, 132-133	2.82	2.72	ND	100	18	97	115	9	0.68	ND	ND	ND	ND
1H-3, 10-11	3.10	3.00	ND	100	2	151	153	9	0.59	ND	ND	ND	ND
1H-3, 24-25	3.24	3.14	2.110	100	2	292	294	12	0.74	**138.4**	5,402	0.9	37
1H-3, 28-29	3.28	3.18	1.056	100	12	85	97	11	0.89	80.5	1,573	11.4	222
1H-3, 31-32	3.31	3.21	3.075	100	20	238	258	12	0.78	77.4	4,403	6.5	370
1H-3, 34-35	3.34	3.24	3.524	100	11	**317**	328	15	0.70	90.0	**5,865**	3.1	204
1H-3, 37-38	3.37	3.27	3.899	100	11	163	174	11	0.72	41.8	3,016	2.8	204
1H-3, 40-41	3.40	3.30	2.596	100	2	195	197	8	0.48	75.1	3,608	0.8	37
1H-3, 43-44	3.34	3.24	4.009	100	7	193	200	6	0.34	48.1	3,571	1.7	130
1H-3, 46-47	3.46	3.36	3.630	100	1	308	309	11	0.59	84.8	5,698	0.3	19
1H-3, 49-50	3.49	3.39	2.611	100	18	186	204	12	0.73	71.2	3,441	6.9	333
1H-3, 52-53	3.52	3.42	2.332	100	23	203	226	11	0.80	87.0	3,756	9.9	426
1H-3, 55-56	3.55	3.45	3.472	100	45	219	264	15	0.87	63.1	4,052	13.0	833
1H-3, 58-59	3.58	3.48	3.268	100	17	185	202	10	0.65	56.6	3,423	5.2	315
1H-3, 61-62	3.61	3.51	3.575	100	49	228	277	8	0.59	63.8	4,218	13.7	907
1H-3, 64-65	3.64	3.54	2.790	100	22	42	64	5	0.58	15.1	777	7.9	407
1H-3, 67-68	3.67	3.57	3.465	100	125	106	231	11	0.71	30.6	1,961	36.1	2,313
1H-3, 70-71	3.70	3.60	3.128	100	5	87	92	6	0.34	27.8	1,610	1.6	93
1H-3, 73-74	3.73	3.63	3.425	100	65	166	231	7	0.67	48.5	3,071	19.0	1,203
1H-3, 76-77	3.76	3.66	1.223	100	7	79	86	8	0.58	64.6	1,462	5.7	130
1H-3, 79-80	3.79	3.69	3.520	100	41	123	164	9	0.71	34.9	2,276	11.6	759
1H-3, 82-83	3.82	3.72	3.347	100	5	168	173	9	0.59	50.2	3,108	1.5	93
1H-3, 85-86	3.85	3.75	1.990	100	0	65	65	5	0.56	32.7	1,203	**0.0**	**0**
1H-3, 88-89*	3.88	3.78	2.680	100	9	33	42	7	*	**12.3**	610	3.4	169
1H-3, 91-92	3.91	3.81	2.470	100	0	78	78	4	0.51	31.6	1,443	0.0	0
1H-3, 94-95	3.94	3.84	2.730	100	2	143	145	7	0.55	52.4	2,646	0.7	37
1H-3, 97-98	3.97	3.87	2.034	100	1	129	130	8	0.55	63.4	2,387	0.5	19
1H-3, 100-101*	4.00	3.90	2.816	100	**0**	**15**	**15**	1	*	5.3	**276**	0.0	0
1H-3, 103-104	4.03	3.93	2.724	100	148	237	**385**	11	0.66	87.0	4,385	54.3	2,738
1H-3, 105-106	4.05	3.95	3.297	100	75	162	237	11	0.77	49.1	2,997	22.7	1,388
1H-3, 108-109	4.08	3.98	4.141	100	107	107	214	12	0.83	25.8	1,980	25.8	1,980
1H-3, 111-112	4.11	4.01	4.434	100	155	152	307	12	0.80	34.3	2,812	35.0	2,868
1H-3, 123-124	4.23	4.13	1.330	100	**167**	55	222	8	0.54	41.4	1,018	**125.6**	**3,090**
1H-3, 126-127	4.26	4.16	1.680	100	97	22	119	8	0.56	13.1	407	57.7	1795
Average: interval A					37	148	184	9		53.0	2,764	16.0	722
178-1098C-													
1H-5, 0-1	6.00	5.90	3.191	100	4	204	208	11	0.62	63.9	4,539	1.3	89
1H-5, 5-6	6.05	5.95	4.139	100	481	280	761	12	0.66	67.6	6,230	116.2	10,702
1H-5, 10-11	6.10	6.00	5.223	100	470	**489**	959	14	0.67	93.6	**10,880**	90.0	10,458
1H-5, 15-16	6.15	6.05	3.442	100	30	158	188	11	0.72	45.9	3,516	8.7	668
1H-5, 20-21	6.20	6.10	3.116	100	0	432	432	11	0.62	**138.6**	9,612	**0.0**	**0**
1H-5, 25-26	6.25	6.15	3.945	100	**0**	320	320	9	0.49	81.1	7,120	0.0	0
1H-5, 30-31	6.30	6.20	5.177	100	4	203	207	10	0.64	39.2	4,517	0.8	89
1H-5, 35-36	6.35	6.25	4.826	100	57	161	218	12	0.68	33.4	3,582	11.8	1,268
1H-5, 40-41	6.40	6.30	6.954	100	50	179	229	10	0.61	25.7	3,983	7.2	1,113
1H-5, 46-47	6.46	6.36	4.463	100	8	148	156	12	0.59	33.2	3,293	1.8	178
1H-5, 50-51	6.50	6.40	5.775	100	97	218	315	7	0.67	37.7	4,851	16.8	2,158
1H-5, 55-56	6.55	6.45	3.731	100	20	131	151	9	0.51	35.1	2,915	5.4	445
1H-5, 60-61	6.60	6.50	3.607	100	23	223	246	9	0.72	61.8	4,962	6.4	512
1H-5, 65-66	6.65	6.55	5.808	100	499	196	695	9	0.62	33.7	4,361	85.9	11,103
1H-5, 70-71	6.70	6.60	6.107	100	674	310	984	14	0.63	50.8	6,898	110.4	14,997
1H-5, 75-76	6.75	6.65	6.169	100	**1,215**	483	**1,698**	12	0.65	78.3	10,747	197.0	27,034
1H-5, 80-81	6.80	6.70	4.453	100	27	247	274	12	0.71	55.5	5,496	6.1	601
1H-5, 85-86	6.85	6.75	6.291	100	95	121	216	13	0.70	19.2	2,692	15.1	2114
1H-5, 90-91	6.90	6.80	5.061	100	138	164	302	12	0.74	32.4	3,649	27.3	3071
1H-5, 95-96	6.95	6.85	5.242	100	719	139	858	15	0.58	26.5	3,093	137.2	15,998
1H-5, 100-101	7.00	6.90	4.905	100	914	341	1,255	12	0.65	69.5	7,587	**186.3**	**20,337**
1H-5, 105-106	7.05	6.95	6.663	100	391	273	664	**17**	0.75	41.0	6,074	58.7	8,700
1H-5, 110-111	7.10	7.00	6.349	100	99	223	322	16	0.76	35.1	4,962	15.6	2,203
1H-5, 115-116	7.15	7.05	4.770	100	211	258	469	16	0.77	54.1	5,741	44.2	4,695
1H-5, 120-121	7.20	7.10	5.316	100	304	131	435	13	0.58	24.6	2,915	57.2	6,764
1H-5, 125-126	7.25	7.15	5.120	100	460	235	695	14	0.62	45.9	5,229	89.8	10,235
1H-5, 130-131	7.30	7.20	4.473	100	491	127	618	14	0.47	28.4	2,826	109.8	10,925
1H-5, 135-136	7.35	7.25	6.154	100	776	274	1,050	13	0.64	44.5	6,097	126.1	17,266
1H-5, 140-141	7.40	7.30	3.784	100	124	**64**	188	11	0.59	**16.9**	**1,424**	32.8	2,759
1H-6, 1-2	7.51	7.41	2.746	100	1	115	**116**	8	0.64	41.9	2,559	0.4	22

Table T1 (continued).

Core, section, interval (cm)	Depth (mbsf)	Depth (mcd)	Dry sample weight (g)	Sample examined (%)	CF (number)	ABF (number)	Total BF (*N*)	Number of species (S)	# H′	ABF (number/g)	ABFAR (number/ cm^2/k.y.)	CF (number/g)	Calcareous BFAR (number/ cm^2/k.y.)
1H-6, 5-6	7.55	7.45	4.692	100	31	402	433	11	0.72	85.7	8,945	6.6	690
1H-6, 10-11	7.60	7.50	3.443	100	5	207	212	11	0.56	60.1	4,606	1.5	111
1H-6, 15-16	7.65	7.55	3.894	100	2	270	272	7	0.53	69.3	6,008	0.5	45
1H-6, 20-21	7.70	7.60	2.683	100	1	133	134	8	0.54	49.6	2,959	0.4	22
1H-6, 25-26	7.75	7.65	3.463	100	38	287	325	11	0.90	82.9	6,386	11.0	846
Average: interval B					242	233	474	12		52.0	5,179	45.0	5,378
178-1098C-													
2H-4, 122-123	14.42	14.08	1.883	100	1	127	**128**	9	0.69	67.4	3,620	0.5	29
2H-4, 126-127	14.46	14.12	2.252	100	0	196	196	7	0.62	87.0	5,586	**0.0**	**0**
2H-4, 130-131	14.50	14.16	3.037	50	0	299	299	9	0.64	98.5	8,522	98.5	8,522
2H-4, 134-135	14.54	14.20	2.206	100	0	154	154	8	0.64	69.8	4,389	0.0	0
2H-5, 3-4	14.73	14.39	3.340	100	82	325	407	10	0.65	97.3	9,263	24.6	2,337
2H-5, 6-7	14.76	14.42	3.516	50	78	419	497	11	0.61	119.2	11,942	163.5	16,388
2H-5, 9-10	14.79	14.45	3.952	33.3	46	327	373	7	0.60	82.7	9,320	200.7	22,604
2H-5, 12-13	14.82	14.48	4.163	50	46	446	492	7	0.57	107.1	12,711	129.2	15,333
2H-5, 15-16	14.85	14.51	3.007	100	22	485	507	11	0.70	161.3	13,823	7.3	627
2H-5, 18-19	14.88	14.54	3.518	33.3	1	511	512	9	0.69	145.3	14,564	291.8	29,256
2H-5, 21-22	14.91	14.57	2.644	100	13	301	314	8	0.63	113.8	8,579	4.9	371
2H-5, 24-25	14.94	14.60	3.636	50	12	246	258	10	0.70	67.7	7,011	74.3	7,695
2H-5, 27-28	14.97	14.63	3.533	100	1	198	199	10	0.57	56.0	5,643	0.3	29
2H-5, 30-31	15.00	14.66	4.517	100	2	258	260	7	0.34	57.1	7,353	0.4	57
2H-5, 33-34	15.03	14.69	4.363	100	7	176	183	8	0.30	40.3	5,016	1.6	200
2H-5, 36-37	15.06	14.72	4.485	100	56	233	289	10	0.65	52.0	6,641	12.5	1,596
2H-5, 39-40	15.09	14.75	4.039	100	8	446	454	9	0.50	110.4	12,711	2.0	228
2H-5, 42-43	15.12	14.78	5.304	100	60	302	362	**13**	0.68	56.9	8,607	11.3	1,710
2H-5, 45-46	15.15	14.81	5.035	50	**276**	**76**	352	12	0.51	**15.1**	**2,166**	**124.7**	**17,898**
2H-5, 48-49	15.18	14.84	4.726	77.8	30	**649**	**679**	11	0.73	137.3	**18,497**	47.4	6,384
2H-5, 51-52	15.21	14.87	5.057	100	9	568	577	10	0.48	112.3	16,445	1.8	0
2H-5, 54-55	15.24	14.90	5.016	100	29	219	248	12	0.44	43.7	6,242	5.8	827
2H-5, 57-58	15.27	14.93	5.769	100	67	358	425	9	0.69	62.1	10,203	11.6	1,910
2H-5, 60-61	15.30	14.96	4.811	100	2	251	253	8	0.52	52.2	7,154	0.4	57
2H-5, 63-64	15.33	14.99	4.621	100	**0**	261	261	9	0.53	56.5	7,439	0.0	0
2H-5, 66-67	15.36	15.02	4.342	100	10	190	200	10	0.56	43.8	5,415	2.3	285
2H-5, 69-70	15.39	15.05	4.022	100	28	266	294	8	0.62	66.1	7,581	7.0	798
2H-5, 72-73	15.42	15.08	5.294	100	9	261	270	10	0.57	49.3	7,439	1.7	257
2H-5, 75-76	15.45	15.11	4.532	100	3	385	388	9	0.67	85.0	10,973	0.7	86
2H-5, 78-79	15.48	15.14	4.684	100	22	319	341	10	0.61	68.1	9,092	4.7	627
2H-5, 81-82	15.51	15.17	4.452	100	98	317	415	12	0.81	71.2	9,035	22.0	2,793
2H-5, 84-85	15.54	15.20	4.454	100	3	177	180	8	0.49	39.7	5,045	0.7	86
2H-5, 87-88	15.57	15.23	4.469	100	18	277	295	9	0.54	62.0	7,895	4.0	513
2H-5, 90-91	15.60	15.26	4.356	100	174	353	527	11	0.74	81.0	10,061	39.9	4,959
2H-5, 93-94	15.63	15.29	4.040	100	37	345	382	12	0.69	85.4	9,833	9.2	1,055
2H-5, 96-97	15.66	15.32	3.727	100	7	279	286	8	0.41	74.9	7,952	1.9	200
2H-5, 99-100	15.69	15.35	3.503	100	0	312	312	8	0.68	89.1	8,892	0.0	0
2H-5, 102-103	15.72	15.38	2.889	100	20	573	593	8	0.61	**198.3**	16,331	6.9	570
2H-5, 108-109	15.78	15.44	3.725	100	1	293	294	8	0.59	78.7	8,351	0.3	29
2H-5, 111-112	15.81	15.47	2.344	100	0	207	207	**6**	0.69	88.3	5,900	0.0	0
Average: interval C					32	310	342	9		81.0	8,831	33.0	3,658
178-1098C-													
3H-4, 76.5-77.5	23.47	24.09	5.580	100	**292**	355	**647**	13	0.63	63.6	**7,633**	52.3	6,278
3H-4, 79-80	23.49	24.11	3.807	100	**0**	295	295	7	0.57	**77.5**	6,343	0.0	0
3H-4, 82-83	23.52	24.14	3.024	100	13	68	81	5	0.46	22.5	1,462	4.3	280
3H-4, 85-86*	23.55	24.17	5.712	100	0	**5**	**5**	2	*	**0.9**	**108**	0.0	0
3H-4, 88-89*	23.58	24.20	3.027	100	0	38	38	3	*	12.6	837	0.0	0
3H-4, 94-95*	23.64	24.26	5.703	100	13	11	24	5	*	1.9	237	2.0	280
3H-4, 97-98	23.67	24.29	5.040	50	180	91	271	13	0.50	18.1	1,957	**89.5**	**9,697**
3H-4, 100-101	23.70	24.32	6.037	100	142	281	423	11	0.58	46.5	6,042	23.6	3,075
3H-4, 103-104	23.73	24.35	6.133	100	199	201	400	9	0.52	32.8	4,322	32.4	4,279
3H-4, 106-107	23.76	24.38	6.807	100	151	231	382	8	0.58	33.9	4,967	22.2	3,247
3H-4, 109-110	23.79	24.41	5.824	100	0	88	88	4	0.31	15.1	1,892	0.0	0
3H-4, 112-113	23.82	24.44	5.953	100	116	197	313	10	0.48	33.1	4,236	19.5	2,494
3H-4, 117-118	23.87	24.49	5.750	100	0	250	250	6	0.41	43.5	5,375	**0.0**	**0**
3H-4, 121-122	23.91	24.53	5.680	100	33	246	279	7	0.36	43.3	5,289	5.8	710
3H-4, 124-125	23.94	24.56	6.534	100	58	208	266	5	0.41	31.8	4,472	8.9	1,247
3H-4, 127-128	23.97	24.59	5.610	100	143	236	379	15	0.64	42.1	5,074	25.5	3,118
3H-4, 130-131	24.00	24.62	6.063	100	134	232	366	11	0.55	38.3	4,988	22.1	2,881
3H-4, 133-134	24.03	24.65	ND	100	16	171	187	6	0.31	ND	ND	ND	ND

Table T1 (continued).

Core, section, interval (cm)	Depth (mbsf)	Depth (mcd)	Dry sample weight (g)	Sample examined (%)	CF (number)	ABF (number)	Total BF (*N*)	Number of species (S)	# H′	ABF (number/g)	ABFAR (number/ cm²/k.y.)	CF (number/g)	Calcareous BFAR (number/ cm²/k.y.)
3H-4, 136-137	24.06	24.68	ND	100	6	164	170	7	0.28	ND	ND	ND	ND
3H-4, 139-140	24.09	24.71	ND	100	30	151	181	5	0.62	ND	ND	ND	ND
3H-4, 142-143	24.12	24.74	ND	100	2	151	153	6	0.20	ND	ND	ND	ND
Average: interval D					73	175	244	8		33.0	3,837	18.0	2,211

Notes: * = statistically small sample not included in cluster analysis. Bold = maximum and minimum values in each interval. CF = calcareous foraminifers, ABF = agglutinated benthic foraminifers, BF = benthic foraminifers, BFAR = benthic foraminifer accumulation rate, ABFAR = agglutinated benthic foraminifer accumulation rate, ND = no data. # Shannon-Wiener diversity: $H' = \sum_{i=1}^{S} p_i \log p_i$.

Table T2. Percentage of major diatom species, actual number of diatoms counted in each sample, and diatom abundance.

	Diatom species (%)							Diatoms counted (number/sample)										Abundance (millions of valves/g sediment)	
Depth (mbsf)	*Fragilariopsis kerguelensis*	*Fragilariopsis angulata*	*Thalassionema* and *Thalassiothrix*	*Fragilariopsis curta* and *Fragilariopsis cylindrus*	other *Fragilariopsis* pennates	*Fragilariopsis ritscheri* and *Fragilariopsis obliquecostata*	*Fragilariopsis separanda*	*Chaetoceros*: vegetative and other	*Fragilariopsis cylindrus*	*Thalassiosira* spp.	*Fragilariopsis* spp.	*Rhizosolenia* spp.	Other species	Freshwater diatoms	Benthic diatoms	Counted	FOV	Diatoms	*Chaetoceros*
3.10	11.5	*	1.0	76.0	3.5	5.5	2.5	3	7.5	7	3.5	1	2	1	0	177.0	10	573.3	492.3
3.24	12.6	*	1.0	64.7	9.2	11.1	1.4	3	2.5	4	2.0	7	1	0	0	213.5	10	644.9	586.0
3.40	45.5	*	3.0	24.8	8.9	14.9	3.0	0	0.5	5	5.5	1	1	0	0	57.0	10	182.7	141.0
3.49	27.4	*	2.7	45.3	7.2	11.7	5.8	3	3.5	7	4.0	3	1	0	0	99.5	10	332.5	260.7
3.67	36.0	*	1.9	31.8	16.1	14.2	0.0	2	1.5	6	0.5	1	1	0	1	101.0	10	296.5	258.3
3.79	37.7	*	3.9	33.3	13.5	10.1	1.4	2	1.5	4	2.0	0	1	0	1	79.5	10	242.5	207.4
3.85	17.9	*	2.7	54.0	6.3	7.6	11.6	5	6.0	6	2.0	1	0	0	0	168.0	10	522.6	460.4
3.88	16.5	3.0	2.0	59.0	4.0	12.5	3.0	2	3.0	1	1.0	1	1	0	1	114.0	10	337.9	308.3
3.91	21.1	3.3	1.0	48.8	8.6	10.5	6.7	1	4.0	1	4.0	0	2	0	1	125.0	10	413.4	370.4
3.94	26.7	2.4	0.0	60.2	4.4	4.4	1.9	4	6.5	13	2.0	2	1	0	2	176.5	10	577.6	477.8
4.23	26.0	4.0	2.6	43.6	6.6	16.7	0.4	0	4.0	5	0.5	4	2	0	1	68.5	10	199.2	151.2
4.26	29.8	11.2	2.4	32.2	14.1	6.3	3.9	1	0.0	7	4.0	2	0	1	0	69.0	10	212.5	166.3
6.15	24.0	5.1	5.5	45.2	1.8	10.1	8.3	1	0.0	2	1.0	0	1	0	0	93.0	10	278.3	263.3
6.25	22.1	7.2	1.0	44.2	1.0	17.8	6.7	0	11.0	4	4.0	0	3	0	1	133.0	10	390.5	323.0
6.40	34.5	3.4	3.0	31.5	2.0	21.2	4.4	1	3.5	5	3.0	4	0	0	1	59.5	10	196.8	138.9
6.50	ND	ND	ND	ND	ND	ND	ND	2	3.5	5	4.5	1	1	0	0	243.0	10	ND	ND
6.70	26.7	3.3	3.7	51.0	4.1	6.2	4.9	0	5.5	3	6.0	0	1	0	0	127.5	10	404.6	355.4
6.80	25.2	5.6	0.0	34.0	4.8	24.8	5.6	2	1.0	3	6.0	3	1	0	0	126.0	10	388.1	338.8
6.95	35.2	4.1	1.4	39.3	2.3	10.0	7.8	2	4.5	2	0.5	2	0	0	0	115.0	10	176.3	340.3
7.10	33.2	8.4	5.0	24.4	1.3	22.3	5.5	0	4.0	6	4.5	0	4	0	0	108.5	10	315.6	261.8
7.60	2.1	0.2	0.3	94.9	0.0	1.8	0.7	47	6.0	4	2.5	0	2	0	2	263.5	10	796.0	604.2
7.70	23.0	7.8	1.4	42.4	7.8	15.7	1.8	3	4.0	5	4.5	1	1	0	0	100.5	10	306.5	250.1
14.46	51.7	10.4	1.0	4.5	6.5	11.9	13.9	2	3.0	1	2.5	2	0	0	0	138.5	10	435.1	402.1
14.91	34.6	12.0	1.9	33.7	5.8	7.2	4.8	3	8.0	7	3.5	1	1	0	0	251.5	10	797.1	722.6
15.03	44.9	7.8	0.5	33.2	3.4	6.8	3.4	1	1.5	0	2.0	0	0	0	0	162.5	10	526.3	511.7
15.15	37.4	1.0	3.0	37.9	3.9	9.9	6.9	4	2.0	5	4.5	1	1	0	0	171.5	10	523.1	469.7
15.27	45.7	6.2	1.9	27.1	6.2	9.0	3.8	1	2.0	3	6.5	0	1	0	0	191.5	10	589.8	548.2
15.51	46.5	3.5	2.0	27.7	2.0	11.9	6.4	1	3.0	8	6.5	0	1	0	0	249.5	10	783.8	722.5
15.78	52.0	5.0	1.5	19.3	3.0	14.4	5.0	4	1.0	2	2.5	0	1	0	0	408.5	10	1365.3	1330.2
23.49	43.3	8.5	2.2	34.8	1.3	6.3	3.6	3	2.0	0	2.5	1	0	0	1	331.5	10	991.8	963.4
23.70	49.5	9.0	1.9	21.2	4.2	9.9	4.2	1	2.0	4	4.0	1	1	0	0	101.0	10	317.3	276.5
23.79	44.1	7.1	0.9	39.3	0.9	5.2	2.4	0	1.0	4	2.0	2	1	0	2	214.0	10	665.6	628.2
23.82	41.3	10.9	3.0	32.8	2.0	9.0	1.0	1	2.5	3	3.5	2	2	0	0	124.0	10	360.7	320.0
23.91	44.5	8.3	3.2	30.3	4.6	7.3	1.8	2	3.0	3	1.5	2	0	0	0	41.5	10	124.2	89.8
23.94	35.3	13.7	1.5	33.8	5.9	9.8	0.0	0	1.0	1	1.0	0	1	1	0	77.0	10	246.8	230.8
23.97	40.1	8.0	1.4	27.4	6.1	12.3	4.7	0	1.0	4	4.0	0	2	0	0	115.0	10	334.5	302.5
24.00	56.2	6.0	1.4	15.7	9.7	8.3	2.8	1	2.0	0	4.0	1	2	0	0	56.0	10	164.4	135.0
24.06	50.9	10.1	1.4	21.1	6.9	8.3	1.4	1	0.5	3	5.0	2	2	0	0	57.5	10	178.9	136.9

Notes: * = *Fragilariopsis angulata* counted with Fragilariopsis kerguelensis, FOV = fields of view, ND = no data.

Table T3. Ratio of symmetric to asymmetric forms of *Eucampia antarctica* in two samples from interval D.

Core, section, interval (cm)	Depth (mbsf)	*E. antarctica* symmetric/ asymmetric	Number counted
178-1098C-			
3H-4, 100-101	23.70	0.64	18
3H-4, 136-137	24.06	0.65	43

Table T4. Percentage of agglutinated and calcareous benthic foraminiferal species from interval A, Hole 1098C.

Core, section, interval (cm)	Depth (mbsf)	Dry sample weight (g)	Sample examined (%)	Agglutinated foraminifers (%) *Adercotryma glomerata*	*Ammoscalaria tenuimargo*	*Amphritemoides granulosa*	*Bathysiphon hirundinae*	*Deuterammina glabra*	*Miliammina arenacea*	*Portatrochammina antarctica*	*Portatrochammina bipolaris*	*Portatrochammina eltaninae*	*Rhabdammina* sp.	*Saccammina difflugiformis*	*Spiroplectammina biformis*	*Textularia antarctica*	*Textularia wiesneri*	*Trochammina inconspicua*	*Verneuilinulla advena*	Other agglutinated	Calcareous foraminifers (%) *Astrononion echolsi*	*Bolivinellina pseudopunctata*	*Bulimina aculeata*	*Cibicides refulgens*	*Fursenkoina pauciloculata*	*Pullenia bulloides*	Other calcareous	Total foraminifers (*N*)	Minor calcareous species (%)
178-1098C-																													
1H-2, 132-133	2.82	*	100	1.74	0	0	0	37.39	13.91	0	0.87	27.83	0	0	0	0	0	0.87	1.74	0	0	1.74	13.91	0	0	0	0	115	0
1H-3, 10-11	3.10	*	100	0	0	0	0	9.15	21.57	0	0.65	54.25	0	0	0	0.65	7.84	0.65	3.92	0	0	1.31	0	0	0	0	0	153	0
1H-3, 24-25	3.24	2.11	100	2.72	0	0	0.34	15.31	6.12	0	1.02	34.35	0.68	0	0	0	29.93	3.40	5.44	0	0	0.68	0	0	0	0	0	294	0
1H-3, 28-29	3.28	1.056	100	10.31	0	0	0	12.37	4.12	0	2.06	25.77	0	1.03	0	3.09	20.62	4.12	4.12	0	0	12.37	0	0	0	0	0	97	0
1H-3, 31-32	3.31	3.075	100	3.10	0	0	0.78	30.23	3.10	0	0.78	36.82	0	3.10	0	1.55	5.04	5.43	2.33	0	0	7.75	0	0	0	0	0	258	0
1H-3, 34-35	3.34	3.524	100	2.44	0	0	0.30	31.10	5.79	1.22	0.61	43.90	0	0.61	0	0	3.05	3.66	3.66	0.30	0	2.74	0.61	0	0	0	0	328	0
1H-3, 37-38	3.37	3.899	100	0	0	0	0	41.38	7.47	0	1.15	29.89	0	1.15	0	5.17	2.30	3.45	0	1.72	0	3.45	2.87	0	0	0	0	174	0
1H-3, 40-41	3.40	2.596	100	0	0	0	0	54.82	5.08	0	0	34.01	0	1.52	0	2.03	0	0	1.52	0	0	0.51	0.51	0	0	0	0	197	0
1H-3, 43-44	3.43	4.009	100	0	0	0	0	78.00	2.00	0	0	14.00	0	0	0	0	0	0	2.50	0	0	1.50	2.00	0	0	0	0	200	0
1H-3, 46-47	3.46	3.63	100	0	0.97	0	0	37.86	10.68	1.29	0	42.72	0	0.32	0	0	1.62	1.29	2.27	0.65	0	0	0.32	0	0	0	0	309	0
1H-3, 49-50	3.49	2.611	100	0	4.41	0	0	32.35	7.84	3.92	0	37.75	0	0.49	0	0.49	1.96	1.47	0	0.49	0	2.45	6.37	0	0	0	0	204	0
1H-3, 52-53	3.52	2.332	100	0	6.19	0	0	23.89	0.44	3.98	0	26.99	0	0	0	0	22.12	2.21	3.10	0.88	0	0.88	9.29	0	0	0	0	226	0
1H-3, 55-56	3.55	3.472	100	0	1.52	0	0	32.58	3.03	0.76	0	23.11	1.14	4.55	0	1.14	3.03	10.98	1.14	0	1.14	11.74	3.03	0	0	1.14	0	264	2.27
1H-3, 58-59	3.58	3.268	100	0	0	0	0	37.62	4.46	4.46	0	39.60	0	0	0	0	1.98	3.47	0	0	0.50	2.97	4.46	0	0	0.50	0	202	0.99
1H-3, 61-62	3.61	3.575	100	0	0	0	0	31.77	2.53	0	0.36	43.32	0	0	0	0	4.33	0	0	0	0	1.44	15.88	0	0	0.36	0	277	0.36
1H-3, 64-65	3.64	2.79	100	0	0	0	0	39.06	6.25	0	0	15.63	0	0	0	4.69	0	0	0	0	0	0	34.38	0	0	0	0	64	0
1H-3, 67-68	3.67	3.465	100	0	0	0	0.43	24.68	8.23	0.43	0	10.39	0	0.43	0	0	0	0.87	0	0.43	0	20.35	33.33	0	0	0.43	0	231	0.43
1H-3, 70-71	3.70	3.128	100	0	0	0	0	80.43	7.61	0	0	0	0	0	0	0	0	0	4.35	2.17	0	2.17	3.26	0	0	0	0	92	0
1H-3, 73-74	3.73	3.425	100	0	0	0	0	40.69	12.99	0	0	16.45	0	0	0	0.43	0	1.30	0	0	0	9.09	19.05	0	0	0	0	231	0
1H-3, 76-77	3.76	1.223	100	0	0	0	0	25.58	9.30	0	0	52.33	0	1.16	0	1.16	0	2.33	0	0	0	6.98	1.16	0	0	0	0	86	0
1H-3, 79-80	3.79	3.52	100	0	0	0	0	31.10	8.54	0	0	32.32	0	0	0	0.61	0	2.44	0	0	3.66	3.05	17.68	0	0.61	0	0	164	4.27
1H-3, 82-83	3.82	3.347	100	0	0	0	0	42.77	10.40	0.58	0	36.99	0	0.58	0	1.16	0	3.47	1.16	0	0	0	2.89	0	0	0	0	173	0
1H-3, 85-86	3.85	1.99	100	0	0	0	0	43.08	15.38	0	0	32.31	0	0	0	0	6.15	3.08	0	0	0	0	0	0	0	0	0	65	0
1H-3, 91-92	3.91	2.47	100	0	0	0	0	28.21	30.77	0	0	38.46	0	0	0	0	2.56	0	0	0	0	0	0	0	0	0	0	78	0
1H-3, 94-95	3.94	2.73	100	0	0	0	0	33.10	15.17	0	0	44.83	0	0	0	4.83	0	0	0	0.69	0	0.69	0.69	0	0	0	0	145	0
1H-3, 97-98	3.97	2.034	100	0	0	0	0	46.92	16.15	0	0.77	30.77	0	0	0	0	1.54	2.31	0.77	0	0	0.77	0	0	0	0	0	130	0
1H-3, 103-104	4.03	2.724	100	0	2.08	0	0	14.81	32.47	0	0.26	8.31	0	0	0	0	2.08	0	1.30	0.26	0.26	0.78	37.40	0	0	0	0	385	0.26
1H-3, 105-106	4.05	3.297	100	0	0	0	0	13.08	29.54	0	0.42	12.66	0	0	0	2.11	9.70	0	0	0.84	0	2.11	27.85	0	1.69	0	0	237	1.69
1H-3, 108-109	4.08	4.141	100	0	0	0	0	18.69	11.21	0	0	14.02	0	3.27	0	1.40	0	0.93	0	0.47	0.93	21.03	25.70	0	0.93	1.40	0	214	3.27
1H-3, 111-112	4.11	4.434	100	0	0.98	0	0	13.03	14.01	0	0.65	17.59	0	1.30	0	0	0	1.95	0	0	0.33	28.99	18.89	0	0.65	1.63	0	307	2.61
1H-3, 123-124	4.23	1.33	100	0	0	0	0	8.11	14.41	0	0	2.25	0	0	0	0	0	0	0	0	1.35	12.16	60.81	0	0	0.45	0.45	222	2.25
1H-3, 126-127	4.26	1.68	100	0	0	0	0	13.45	4.20	0	0.84	0	0	0	0	0	0	0	0	0	1.68	23.53	53.78	0	0.84	0	1.68	119	4.20

Table T5. Percentage of agglutinated and calcareous benthic foraminiferal species from interval B, Hole 1098C.

Core, section, interval (cm)	Depth (mbsf)	Dry sample weight (g)	Sample examined (%)	Agglutinated foraminifers (%)																	Calcareous foraminifers (%)							Total foraminifers (*N*)	Minor calcareous species (%)
				Adercotryma glomerata	*Ammoscalaria tenuimargo*	*Amphritemoides granulosa*	*Bathysiphon hirundinae*	*Deuterammina glabra*	*Miliammina arenacea*	*Portatrochammina antarctica*	*Portatrochammina bipolaris*	*Portatrochammina eltaninae*	*Rhabdammina* sp.	*Saccammina difflugiformis*	*Spiroplectammina biformis*	*Textularia antarctica*	*Textularia wiesneri*	*Trochammina inconspicua*	*Verneuilinulla advena*	Other agglutinated	*Astrononion echolsi*	*Bolivinellina pseudopunctata*	*Bulimina aculeata*	*Cibicides refulgens*	*Fursenkoina pauciloculata*	*Pullenia bulloides*	Other calcareous		
178-1098C-																													
1H-5, 0-1	6.00	3.191	100	0	12.02	0	0.48	38.94	1.44	5.29	0	37.5	0	0	0	0	0.48	0.96	0.48	0.48	0	1.92	0	0	0	0	0	208	0
1H-5, 5-6	6.05	4.139	100	0	0	0	0.26	13.4	1.05	1.18	0	17.74	0	0	0	0	0.92	1.97	0.26	0	0.13	19.05	43.89	0	0	0.13	0	761	0.26
1H-5, 10-11	6.10	5.223	100	0	0.94	0	0	14.6	0.42	1.67	0	26.38	0.1	0.21	0.31	0	0.21	5.94	0.21	0	0.1	42.54	6.36	0	0	0	0	959	0.1
1H-5, 15-16	6.15	3.442	100	0	0.53	0	0.53	33.51	7.98	2.66	0	31.38	0	0	0	0	0	6.91	0	0.53	0	1.06	14.36	0	0	0	0.53	188	0.53
1H-5, 20-21	6.20	3.116	100	0	1.39	0	0	16.67	3.94	0.69	0	51.16	0	0	0.46	0	20.37	2.08	2.78	0.46	0	0	0	0	0	0	0	432	0
1H-5, 25-26	6.25	3.945	100	0	0.63	0	0.31	18.44	4.38	1.25	0	66.25	0	0	0	0	2.5	4.69	1.56	0	0	0	0	0	0	0	0	320	0
1H-5, 30-31	6.30	5.177	100	0	0.48	0	0.48	47.34	8.21	0	0	28.5	0	0	0	1.45	6.28	2.42	2.9	0	0	1.93	0	0	0	0	0	207	0
1H-5, 35-36	6.35	4.826	100	0	0.92	0.92	0	44.5	0.92	0.46	0	21.1	0	0	0	0.46	1.83	1.38	1.38	0	0	7.8	18.35	0	0	0	0	218	0
1H-5, 40-41	6.40	6.954	100	0	0	3.06	0.44	58.52	3.06	2.18	0	9.17	0	0	0	0	0	0.87	0.87	0	0	6.99	14.85	0	0	0	0	229	0
1H-5, 46-47	6.46	4.463	100	0	3.21	2.56	0.64	64.1	3.85	1.92	0	14.74	0	0	0	0	0.64	1.92	1.28	0	0	3.21	1.92	0	0	0	0	156	0
1H-5, 50-51	6.50	5.775	100	0	0	0	0	40	5.08	0	0	21.27	0	0	0	0	0	2.86	0	0	0	16.83	13.65	0	0	0	0.32	315	0.32
1H-5, 55-56	6.55	3.731	100	0	0	0	0	65.56	2.65	1.32	0	11.92	0	0	0	0	1.32	3.31	0.66	0	0	0.66	12.58	0	0	0	0	151	0
1H-5, 60-61	6.60	3.607	100	0	0.41	0	0	30.89	1.63	0	0	33.33	0	0	0	0	10.98	11.79	1.63	0	0	2.03	7.32	0	0	0	0	246	0
1H-5, 65-66	6.65	5.808	100	0	0	0	0.14	19.28	1.01	0.29	0	4.6	0	0	0	0	0	2.88	0	0	0	27.77	42.16	0	0	1.87	0	695	1.87
1H-5, 70-71	6.70	6.107	100	0	0	0	0	10.98	0.71	2.03	0	15.24	0	0	0.1	0	1.22	0.91	0.2	0.1	0.1	51.73	15.55	0	0.1	1.02	0	984	1.22
1H-5, 75-76	6.75	6.169	100	0	0	0	0	5.48	0.29	0.35	0	17.26	0	0	0	0	0.47	4.36	0.24	0	1.06	48.65	18.85	0	0	2.94	0.06	1698	4.06
1H-5, 80-81	6.80	4.453	100	0	0.36	0.36	0.36	34.67	3.28	1.09	0	34.31	0	0	0	0	9.12	4.38	2.19	0	0	0	9.49	0	0	0.36	0	274	0.36
1H-5, 85-86	6.85	6.291	100	0	0.46	0	0	24.07	3.7	0.93	0	23.61	0	0.46	0	0	1.39	0.93	0.46	0	0	3.24	37.96	0	0	2.31	0.46	216	2.78
1H-5, 90-91	6.90	5.061	100	0	0	0	0	24.5	1.99	0	0	24.5	0	1.66	0	0	0.66	0.66	0.33	0	1.32	14.9	27.15	0	0.33	1.99	0	302	3.64
1H-5, 95-96	6.95	5.242	100	0	0	0	0.12	3.85	1.52	0.12	0	8.74	0	0	0	0	0.82	0.47	0.58	0	1.86	22.73	57.23	0	0	1.63	0.35	858	3.85
1H-5, 100-101	7.00	4.905	100	0	0	0	0.08	6.93	2.63	0	0	12.75	0	0	0	0	3.27	0.96	0.56	0	0.24	41.75	30.52	0	0	0.24	0.08	1255	0.56
1H-5, 105-106	7.05	6.663	100	0	0.45	0.15	0.15	22.59	7.38	0.45	0	6.48	0	0	0.15	0	0.75	2.26	0.15	0.15	1.05	27.71	29.67	0	0	0.3	0.15	664	1.51
1H-5, 110-111	7.10	6.349	100	0	0.31	0.93	0.62	36.96	3.11	0.62	0	20.5	0	0.62	0.31	0	2.8	1.55	0.93	0	0.62	4.35	24.84	0	0	0.62	0.31	322	1.55
1H-5, 115-116	7.15	4.77	100	0	0.21	0.21	0	26.65	3.84	1.07	0	19.62	0	0.64	0	0	0.85	1.28	0.64	0	0.21	21.32	22.17	0	0.21	0.85	0.21	469	1.49
1H-5, 120-121	7.20	5.316	100	0	0.46	0	0.23	14.02	0.92	0	0	10.11	0	0	0	0	1.61	1.61	1.15	0	0.23	5.98	62.07	0	0	1.38	0.23	435	1.84
1H-5, 125-126	7.25	5.12	100	0	0	0	0	13.53	2.45	0.29	0	12.23	0	0	0	0	3.88	1.15	0.29	0	0.29	5.61	57.99	0.14	0.14	1.87	0.14	695	2.59
1H-5, 130-131	7.30	4.473	100	0	0	0.16	0	5.34	1.78	0	0	9.06	0	0.16	0.32	0	1.94	1.29	0.49	0	0.32	2.75	73.79	0	0	2.43	0.16	618	2.91
1H-5, 135-136	7.35	6.154	100	0	0	0	0	14.95	1.43	0	0	8.67	0	0.1	0	0	0	0.57	0.38	0	1.81	32.57	38.48	0.1	0	0.86	0.1	1050	2.86
1H-5, 140-141	7.40	3.784	100	0	0	0	1.06	9.57	3.72	0.53	0	16.49	0	0	0	0	0	2.13	0.53	0	1.06	3.72	60.11	0	0	1.06	0	188	2.13
1H-6, 1-2	7.51	2.746	100	0	0	0	0	44.83	6.03	1.72	0	29.31	0	0	0	0	10.34	2.59	4.31	0	0	0	0.86	0	0	0	0	116	0
1H-6, 5-6	7.55	4.692	100	0	0	0	0.23	45.27	6.7	1.39	0	21.25	0	0	0	0	12.01	2.54	3.46	0	0	3	3.93	0	0.23	0	0	433	0.23
1H-6, 10-11	7.60	3.443	100	0	0.94	0	0.94	56.13	5.66	1.42	0	27.36	0	0	0.47	0	2.36	1.89	0.47	0	0	2.36	0	0	0	0	0	212	0
1H-6, 15-16	7.65	3.894	100	0	0	0	0	27.21	17.65	0.37	0	49.26	0	0	0	0	4.41	0	0.37	0	0	0.74	0	0	0	0	0	272	0
1H-6, 20-21	7.70	2.683	100	0	0	0	0	64.18	8.96	0.75	0	12.69	0	0	0	0	3.73	4.48	4.48	0	0	0.75	0	0	0	0	0	134	0
1H-6, 25-26	7.75	3.463	100	0	6.77	0	0.31	24.92	7.38	0.31	0	19.38	0	0	0	0	9.23	13.54	6.46	0	0	7.08	4.62	0	0	0	0	325	0

Table T6. Percentage of agglutinated and calcareous benthic foraminiferal species from interval C, Hole 1098C.

Core, section, interval (cm)	Depth (mbsf)	Dry sample weight (g)	Sample examined (%)	Agglutinated foraminifers (%)																	Calcareous foraminifers (%)							Total foraminifers (N)	Minor calcareous species (%)
				Adercotryma glomerata	*Ammoscalaria tenuimargo*	*Amphritemoides granulosa*	*Bathysiphon hirundinae*	*Deuterammina glabra*	*Miliammina arenacea*	*Portatrochammina antarctica*	*Portatrochammina bipolaris*	*Portatrochammina eltaninae*	*Rhabdammina* sp.	*Saccammina difflugiformis*	*Spiroplectammina biformis*	*Textularia antarctica*	*Textularia wiesneri*	*Trochammina inconspicua*	*Verneuilinulla advena*	Other agglutinated	*Astrononion echolsi*	*Bolivinellina pseudopunctata*	*Bulimina aculeata*	*Cibicides refulgens*	*Fursenkoina pauciloculata*	*Pullenia bulloides*	Other calcareous		
178-1098C-																													
2H-4, 122-123	14.42	1.883	100	0	7.81	0	0	48.44	7.81	11.72	0	15.63	0	0	0.78	0	6.25	0	0.78	0	0	0.78	0	0	0	0	0	128	0
2H-4, 126-127	14.46	2.252	100	0	8.67	0	0	36.73	6.12	6.63	0	38.27	0	0	0	3.06	0.51	0	0	0	0	0	0	0	0	0	0	196	0
2H-4, 130-131	14.50	3.037	50	0	3.34	0	0	15.38	22.74	10.70	0.67	44.82	0	0	0	0	2.01	0	0.33	0	0	0	0	0	0	0	0	299	0
2H-4, 134-135	14.54	2.206	100	0	0.65	0	0.65	29.87	21.43	12.34	0	33.12	0	0	0	1.30	0	0	0.65	0	0	0	0	0	0	0	0	154	0
2H-5, 3-4	14.73	3.34	100	0	1.72	0	0.25	21.87	1.97	6.63	0	43.98	0	0	0	0	3.19	0	0.25	0	0	19.66	0.49	0	0	0	0	407	0
2H-5, 6-7	14.76	3.516	50	0	0	0	0	11.07	3.02	0.80	0	59.15	0	0	0	0	0.40	9.66	0.20	0	0	6.64	7.44	0	0	1.41	0.20	497	1.61
2H-5, 9-10	14.79	3.952	33.3	0	0	0	0	24.40	1.88	2.95	0.54	48.26	0	0	0	0	0	9.65	0	0	0	12.33	0	0	0	0	0	373	0
2H-5, 12-13	14.82	4.163	50	0	0	0	0.61	25.41	3.66	7.72	0	53.25	0	0	0	0	0	0	0	0	0	2.03	7.32	0	0	0	0	492	0
2H-5, 15-16	14.85	3.007	100	0	2.76	0	0.20	24.06	10.65	17.16	0	38.46	0	0	0.20	0	1.78	0	0	0.39	0	4.14	0.20	0	0	0	0	507	0
2H-5, 18-19	14.88	3.518	33.3	0	26.56	0	0.39	15.43	19.14	1.17	0	32.23	0	0	0	0	4.10	0	0.78	0	0	0.20	0	0	0	0	0	512	0
2H-5, 21-22	14.91	2.644	100	0	0.96	0	0	25.48	41.08	3.50	0	22.61	0	0	0	0	2.23	0	0	0	0	0.96	3.18	0	0	0	0	314	0
2H-5, 24-25	14.94	3.636	50	0	8.91	0	0.78	24.81	9.30	2.71	0	44.57	0	0	0	0	3.49	0	0.78	0	0	2.33	2.33	0	0	0	0	258	0
2H-5, 27-28	14.97	3.533	100	0	5.03	0	0	33.17	2.51	4.52	0	49.75	0	0	0	0.50	1.01	1.01	2.01	0	0	0.50	0	0	0	0	0	199	0
2H-5, 30-31	15.00	4.517	100	0	0.77	0	0	76.54	3.08	0	0	16.92	0	0	0	0	0	1.54	0.38	0	0	0.77	0	0	0	0	0	260	0
2H-5, 33-34	15.03	4.363	100	0	2.19	0	0	84.15	2.19	0.55	0	6.56	0	0	0	0	0	0	0.55	0	0	2.19	1.64	0	0	0	0	183	0
2H-5, 36-37	15.06	4.485	100	0	1.04	0	0	53.29	10.38	1.38	0	11.42	0	0	0	0	1.73	1.38	0	0	0	3.81	15.22	0	0	0.35	0	289	0.35
2H-5, 39-40	15.09	4.039	100	0	0.88	0	0	32.16	1.32	2.20	0	56.39	0	0	0	0	3.52	1.10	0.66	0	0	1.76	0	0	0	0	0	454	0
2H-5, 42-43	15.12	5.304	100	0	0.28	0	0	44.48	1.93	1.93	0	27.62	0	0	0	0	0.28	6.08	0.83	0	0	3.59	11.05	0	0	0.83	1.10	362	1.93
2H-5, 45-46	15.15	5.035	50	0	0.28	0	0	7.67	1.42	1.70	0	5.97	0	0	0	0	0	4.26	0.28	0	0	7.10	69.60	0	0	0.28	1.42	352	1.70
2H-5, 48-49	15.18	4.726	77.78	0	19.73	0	0	24.01	1.77	1.47	0	34.46	0.15	0	0	0	11.93	0.29	1.77	0	0	3.53	0.88	0	0	0	0	679	0
2H-5, 51-52	15.21	5.057	100	0	0.17	0	0.17	37.95	3.64	2.08	0	51.82	0	0	0	0	0.17	1.73	0.69	0	0	1.56	0	0	0	0	0	577	0
2H-5, 54-55	15.24	5.016	100	0	0.40	0	0.40	72.98	4.44	0.40	0	8.47	0	0	0	0	0	0.40	0.81	0	0	0.81	10.08	0	0	0.40	0.40	248	0.81
2H-5, 57-58	15.27	5.769	100	0	2.82	0	0	41.65	13.18	1.18	0	24.00	0	0	0	0	0	0.94	0.47	0	0	8.24	7.53	0	0	0	0	425	0
2H-5, 60-61	15.30	4.811	100	0	1.19	0	0.40	60.87	3.95	1.98	0	16.21	0	0	0	0	0	14.62	0	0	0	0.79	0	0	0	0	0	253	0
2H-5, 63-64	15.33	4.621	100	0	1.15	0	0.38	62.07	6.13	1.53	0	20.31	0	0	0	0	2.68	2.30	3.45	0	0	0	0	0	0	0	0	261	0
2H-5, 66-67	15.36	4.342	100	0	1.50	0	0.50	64.00	8.50	1.00	0	13.50	0	0	0	0	2.00	1.50	2.50	0	0	5.00	0	0	0	0	0	200	0
2H-5, 69-70	15.39	4.022	100	0	6.46	0	0	53.40	1.36	5.44	0	19.73	0	0	0	0	3.40	0	0.68	0	0	9.52	0	0	0	0	0	294	0
2H-5, 72-73	15.42	5.294	100	0	3.33	0	0	59.26	8.15	2.22	0	20.74	0	0	0	0	1.85	0	0.74	0.37	0	2.22	1.11	0	0	0	0	270	0
2H-5, 75-76	15.45	4.532	100	0	18.81	0	0	47.94	6.96	2.32	0	12.37	0	0	0	0	8.76	0	2.06	0	0	0.52	0.26	0	0	0	0	388	0
2H-5, 78-79	15.48	4.684	100	0	0	0	0.29	45.16	8.80	2.93	0	32.55	0	0	0	0	2.35	1.17	0	0.29	0	5.87	0.59	0	0	0	0	341	0
2H-5, 81-82	15.51	4.452	100	0	2.41	0	0	23.37	4.10	2.41	0	29.16	0	0	0	0	0.24	13.49	0.96	0.24	0	6.27	16.39	0	0	0.96	0	415	0.96
2H-5, 84-85	15.54	4.454	100	0	2.78	0	0	62.22	0.56	5.56	0	23.89	0	0	0	0	2.22	0	1.11	0	0	0	1.67	0	0	0	0	180	0
2H-5, 87-88	15.57	4.469	100	0	2.03	0	0	51.86	4.41	0.68	0	32.54	0	0	0.34	0	1.69	0	0	0.34	0	0	6.10	0	0	0	0	295	0
2H-5, 90-91	15.60	4.356	100	0	1.90	0	0	27.70	12.71	0.76	0	18.41	0	0	0	1.14	4.17	0	0	0.19	0.19	2.28	30.55	0	0	0	0	527	0.19
2H-5, 93-94	15.63	4.04	100	0	2.88	0	0	43.19	20.42	0.26	0	20.42	0	0	1.31	0	0.79	0	1.05	0	0	1.31	6.28	0.26	1.83	0	0	382	2.09
2H-5, 96-97	15.66	3.727	100	0	0.35	0	0	72.03	13.64	9.44	0	0	0	0	0	0.35	0	1.40	0.35	0	0	2.45	0	0	0	0	0	286	0
2H-5, 99-100	15.69	3.503	100	0	13.14	0	0	44.87	17.31	1.60	0.64	14.42	0	0	0	3.85	4.17	0	0	0	0	0	0	0	0	0	0	312	0
2H-5, 102-103	15.72	2.889	100	0	10.12	0	0	19.06	53.96	1.35	0	5.06	0	0	0	0.67	6.41	0	0	0	0	0	3.37	0	0	0	0	593	0
2H-5, 108-109	15.78	3.725	100	0	2.04	0	0	55.44	20.07	4.08	0	9.18	0	0	0	0	7.14	0	1.70	0	0	0.34	0	0	0	0	0	294	0
2H-5, 111-112	15.81	2.344	100	0	4.83	0	0	36.71	15.46	25.12	0	6.76	0	0	0	0	11.11	0	0	0	0	0	0	0	0	0	0	207	0

Table T7. Percentage of agglutinated and calcareous benthic foraminiferal species from interval D, Hole 1098C.

				Agglutinated foraminifers (%)																	Calcareous foraminifers (%)								
Core, section, interval (cm)	Depth (mbsf)	Dry sample weight (g)	Sample examined (%)	*Adercotryma glomerata*	*Ammoscalaria tenuimargo*	*Amphritemoides granulosa*	*Bathysiphon hirundinae*	*Deuterammina glabra*	*Miliammina arenacea*	*Portatrochammina antarctica*	*Portatrochammina bipolaris*	*Portatrochammina eltaninae*	*Rhabdammina* sp.	*Saccamina difflugiformis*	*Spiroplectammina biformis*	*Textularia antarctica*	*Textularia wiesneri*	*Trochammina inconspicua*	*Verneuilinulla advena*	Other agglutinated	*Astrononion echolsi*	*Bolivinellina pseudopunctata*	*Bulimina aculeata*	*Cibicides refulgens*	*Fursenkoina pauciloculata*	*Pullenia bulloides*	Other calcareous	Total foraminifers (*N*)	Minor calcareous species (%)
178-1098C-																													
3H-4, 76.5-77.5	23.47	5.58	100	0	4.33	0	0.31	39.26	2.16	2.78	0	2.63	0	0	0	0	0.46	2.16	0.77	0	0	0.46	41.27	0	0	3.25	0.15	647	3.40
3H-4, 79-80	23.49	3.807	100	0	2.37	0	0.68	35.93	21.02	36.61	0	2.71	0	0	0	0	0	0	0.68	0	0	0	0	0	0	0	0	295	0
3H-4, 82-83	23.52	3.024	100	0	4.94	0	0	65.43	9.88	0	0	0	0	0	0	0	0	0	3.70	0	0	0	16.05	0	0	0	0	81	0
3H-4, 97-98	23.67	5.04	50	0	4.43	0	0.37	22.14	2.95	3.32	0	0	0	0	0	0	0	0.37	0	0	0.37	0.74	63.84	0	0.37	0	1.11	271	1.85
3H-4, 100-101	23.70	6.037	100	0	0	0	0.71	52.72	4.02	0	0	0	0	0	0	0	0.24	7.33	1.18	0.24	0.47	0	27.66	0	0	5.20	0.24	423	5.91
3H-4, 103-104	23.73	6.133	100	0	0	0	0	41.75	4.00	0	0	0	0	0	0	0	0	4.00	0.50	0	0	0	44.25	0.25	0	4.75	0.50	400	5.50
3H-4, 106-107	23.76	6.807	100	0	2.09	0	0.26	40.84	16.49	0	0	0	0	0	0	0	0	0.79	0	0	0	0	34.29	0	0	4.19	1.05	382	5.24
3H-4, 109-110	23.79	5.824	100	0	0	0	0	79.55	10.23	0	0	0	0	0	0	0	0	7.95	0	2.27	0	0	0	0	0	0	0	88	0
3H-4, 112-113	23.82	5.953	100	0	1.60	0	0.32	53.67	6.07	0	0	0	0	0	0	1.28	0	0	0	0	0.64	0	35.46	0	0	0.32	0.64	313	1.60
3H-4, 117-118	23.87	5.75	100	0	7.20	0	0.40	48.40	43.60	0	0	0	0	0	0	0	0	0.40	0	0	0	0	0	0	0	0	0	250	0
3H-4, 121-122	23.91	5.68	100	0	0	0	0	72.40	15.41	0	0	0	0	0	0	0.36	0	0	0	0	0	0	10.75	0	0	0.36	0.72	279	1.08
3H-4, 124-125	23.94	6.534	100	0	0	0	0	66.17	12.03	0	0	0	0	0	0	0	0	0	0	0	1.13	0	19.92	0	0	0.75	0	266	1.88
3H-4, 127-128	23.97	5.61	100	0	0	0	0	51.98	8.71	0	0	0	0	0	0.53	0.53	0.26	0.26	0	0	4.75	2.11	23.48	0	3.69	0.53	3.17	379	12.14
3H-4, 130-131	24.00	6.063	100	0	0	0	0	56.83	5.74	0	0	0	0	0	0	0	0.82	0	0	0	4.92	1.09	25.96	0	1.91	1.09	1.64	366	9.56
3H-4, 133-134	24.03	*	100	0	0	0	0	79.14	12.30	0	0	0	0	0	0	0	0	0	0	0	1.07	0	6.42	0	0	0.53	0.53	187	2.14
3H-4, 136-137	24.06	*	100	0	0	0	0.59	84.71	7.06	0	0	0	0	0	0	0	0.59	2.94	0.59	0	0	0	3.53	0	0	0	0	170	0
3H-4, 139-140	24.09	*	100	0	11.05	0	0	45.86	11.05	0	0	0	0	0	0	0	15.47	0	0	0	0	0	16.57	0	0	0	0	181	0
3H-4, 142-143	24.12	*	100	0	0	0	0.65	88.24	9.15	0	0	0	0	0	0	0	0	0.65	0	0	0	0	0.65	0	0	0.65	0	153	0.65

Table T8. Occurrence of *Neogloboquadrina pachyderma*(s), Hole 1098C.

Core, section, interval (cm)	Depth (mbsf)	*N. pachyderma* (s) (number)
178-1098C-		
1H-3, 34-35	3.34	1
1H-3, 105-106	4.05	1
1H-3, 111-112	4.11	1
1H-3, 123-125	4.23	2
1H-5, 70-71	6.70	1
1H-5, 75-76	6.75	2
1H-5, 90-91	6.90	1
1H-5, 95-96	6.95	8
1H-5, 100-101	7.00	1
1H-5, 105-106	7.05	1
1H-5, 125-126	7.25	9
1H-5, 135-136	7.35	7
1H-5, 140-141	7.40	1
2H-5, 36-37	15.06	1
2H-5, 42-43	15.12	1
2H-5, 45-46	15.15	2
2H-5, 81-82	15.51	3
3H-4, 76.5-77.5	23.47	4
3H-4, 97-98	23.67	5
3H-4, 100-101	23.70	9
3H-4, 103-104	23.73	6
3H-4, 106-107	23.76	12
3H-4, 112-113	23.82	2
3H-4, 124-125	23.94	16
3H-4, 127-128	23.97	11
3H-4, 130-131	24.00	7

Note: (s) = sinistral.

Table T9. Comparison of samples collected in August 1998 and May 1999, showing the loss of calcareous foraminifers due to dissolution in the core repository.

Core, section, interval (cm)	Depth (mbsf)	Calcareous foraminifers August 1998 (number/13 cm^3)	 May 1999 (number/25 cm^3)
178-1098C-			
1H-3W, 67-68	3.67	125	
1H-3A, 66-68	3.66		1
1H-3W, 123-124	4.23	167	
1H-3A, 123-125	4.23		2
1H-5W, 5-6	6.05	481	
1H-5W, 7-9	6.07		13
1H-5W, 10-11	6.10	470	
1H-5W, 130-131	7.30	491	
1H-5W, 132-134.5	7.32		18
1H-5W, 135-136	7.35	776	
2H-5W, 45-46	15.15	276	
2H-5A, 44-46	15.14		0
2H-5W, 90-91	15.60	174	
2H-5A, 89-91	15.59		0
3H-4W, 76.5-77.5	23.47	292	
3H-4A, 76-78	23.47		0
3H-4W, 103-104	23.73	199	
3H-4A, 103-105	23.73		70

Note: W = working half of core, A = archive half of core.

Table T10. Size and number of calcareous and agglutinated foraminifers in one sample from interval D.

Test composition	>100-µm fraction		100- to 63-µm fraction		>63-µm fraction total sample	
	Number	Percent	Number	Percent	Number	Percent
178-1098C-3H-4, 76.5-77.5 cm						
Calcareous foraminifers	287	87	5	2	292	46
Agglutinated foraminifers	42	13	313	98	355	54
Total foraminifers	329		318		647	

Table T11. Comparison of benthic foraminiferal statistics in comparable intervals of core PD92-30 and Hole 1098C.

Hole/core	Depth (mbsf)	Number of samples	Calcareous foraminifers (number/sample)	Calcareous foraminifers (number/g)	Agglutinated foraminifers (number/sample)	Agglutinated foraminifers (number/g)	Foraminifers (*N*)	Foraminifers (*N*/g)	Species (*S*)
178-1098C, interval A	2.82-4.26	32	0-167	0-36	15-317	5-138	15-385	5-167	1-15
			37	**15**	**148**	**53**	**184**	**68**	**9**
PD92-30*	1.82-2.84	11	0-185	0-21	0-23	0-3	0-208	0-24	2-6
			40	**5**	**5**	**1**	**45**	**6**	**3**
178-1098C, interval B	6.0-7.75	35	0-1215	0-197	64-489	17-139	116-1698	33-275	7-17
			242	**45**	**233**	**51**	**474**	**97**	**12**
PD92-30*	4.82-6.04	13	0-766	0-76	0-25	0-2	0-791	0-79	0-10
			124	**14**	**5**	**1**	**129**	**15**	**4**

Notes: * = data from Leventer et al. (1996). Bold type = average values.

Table T12. Comparison of core PD92-30 samples collected six months postcruise and in August 1999.

Depth (cm)	Sample weight* (g)	Calcareous foraminifers (number)	Agglutinated foraminifers† (number)	Calcareous foraminifers (number/g)	Agglutinated foraminifers† (number/g)
August 1999					
302-304	7.2	24	85	3.33	11.81
385-387	3.6	1	27	0.28	7.50
562-563	6.6	1	43	0.15	6.52
625-626	2	0	9	0.00	4.50
Leventer et al. (1996)					
302-304	5.89	671	32	113.92	5.43
382-384	6.69	596	1	89.09	0.15
562-563	7.96	92	6	11.56	0.75
622-624	6.52	1420	3	166.67	0.35

Note: * = August 1999 samples were processed wet to maintain faunal preservation. Samples from 1996 were processed dry. † = since these data were generated to determine carbonate dissolution, a full and complete count of agglutinated foraminifers was not done. The number of agglutinated foraminifers represents minimum values.