# MID-HOLOCENE WARMTH IN THE ANTARCTIC PENINSULA

# ANALOG TO GLOBAL WARMING?

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### Abstract

In light of recent controversies over climate change, paleoclimate indicators in the Antarctic Peninsula are being studied through a multi-proxy analysis of a 20.1 meter long Jumbo Piston core recovered from the Gerlache Strait region. The Antarctic Peninsula is ideal for such paleoclimate records as it is known to be highly sensitive to climate change. Magnetic susceptibility, ice rafted debris measurements, quantitative diatom analysis, grain size analysis, and SEM photographs provide evidence that the mid-Holocene was a time of dramatic climate change. A series of proposed varves in the lower section of the core was identified and is the result of increased primary productivity and terrigenous input. Sequences of repeated, regular couplets were observed. Biogenic layers were deposited during the spring bloom while the terrigenous layers are the result of sediment accumulation the rest of the year. Grain size measurements and SEM photographs support this conclusion and show that the biogenic layers are dominated by *Chaetoceros* resting spores. This mid-Holocene peak in biologic productivity tentatively is the result of melting glacial ice, suggesting that glaciers were proximal to the Gerlache Strait at this time.

## Introduction

Recent concerns about global warming and its impact on oceanographic and biological systems in the Antarctic Peninsula have been highlighted by the disappearance of the more northerly ice shelves over the past 50 years (Rott et al., 1996; Vaughan and Doake, 1996). Their retreat is thought to be related to increasing temperatures, which leads to instability of the ice, through the formation of large cracks and melt pools. While southern hemisphere land-based surface air-temperatures exhibit an average long-term warming trend of about 0.5 degrees C over the past century, a warming of 4-5 degrees C over the past 50 years has been recorded in mid-winter surface air-temperatures in the Peninsula (Stark, 1994). In addition, changes in the distribution of Antarctic biota have been linked to twentieth century warming. Fraser et al. (1992), for example, suggest that the changing distribution of Chinstrap and Adelie penguins may be a result of decreased winter sea ice extent.

While most scientific data support the occurrence of global warming over the past century (Jones et al., 1986; Jones, 1994), disagreement exists over the role of anthropogenic input of greenhouse gases into the atmosphere as a forcing for the recent temperature rise. The primary goal of this project is to examine the range of natural climate variability over the past 10,000 years in a region which has been identified as being highly sensitive to changes in greenhouse gas concentrations in the atmosphere (Santer, 1995). The rationale behind this study is that evaluation of a high-resolution record of climate since the last glacial maximum may provide a way to distinguish the relative contribution of natural versus anthropogenic processes to recent climate change. Specifically, this study focuses on the mid-Holocene warmth and its relationship to glacial expansion and the formation of varves.

The marine sediment core selected for study was chosen for several reasons. First, at 20.1 meters in length, the core is the longest piston core yet recovered on the Antarctic continental shelf. The presence of fine-scale laminations indicates minimal disturbance by bioturbation and the potential for annual- to decadal-scale resolution. Finally, the core has abundant carbonate, with *in-situ* bivalves and foraminifera. The presence of carbonates permits higher quality radiocarbon dating than normally achieved with Antarctic cores and the development of a reliable chronology.

The data used in this study include information on the lithology and magnetic susceptibility of the sediments, digital color data, quantitative assessment of the downcore concentration of ice-rafted debris, and qualitative and quantitative evaluation of the diatom assemblages in the core. Changes in the downcore composition of the sediments will be used to construct a paleoclimatic history for the Antarctic Peninsula region. Initial work on other cores from the region have demonstrated that these proxies can be used successfully to reconstruct paleoceanographic conditions and climate in the Southern Ocean (Leventer et al., 1996). However, regional-scale reconstructions depend on greater geographic distribution of the data sets. It is hoped that this study will help fill the data sets and provide greater understanding of the response of the Southern Ocean to natural changes in climate.

## Materials and Methods

Jumbo Piston Core (JPC) NBP9903-JPC 28, a 20.1 meter long Jumbo Piston core, was recovered during April 1999 aboard the *RVIB Nathaniel B. Palmer* at 64°38' S and 62°52' W at a depth of 673 meters (Figure 1). Magnetic susceptibility (MS) and P-wave velocity measurements were taken immediately after core recovery at 5 cm increments. In order to maintain core integrity for subsequent geochemical work, the cores were shipped refrigerated to the Antarctic Research Facility at Florida State University to be curated. After being split in July 1999, magnetic susceptibility measurements were taken every 2 cm by a Bartington MS-2B core sensor and expressed as x $10^{-6}$ in cgs units (Figure 2). The core was run through a Geotek multi-sensor track which measured spectral qualities, P-wave velocities and MS every 5 cm. Color data was measured in terms of absolute blue, green and red between 0 – 255. P-wave velocity measurements are expressed as meters/second. The core was then photographed, described, and sub-sampled for micropaleontologic and geochemical analysis. Core lithology was described by Dr. Eugene Domack. In order to assess downcore changes in productivity, sub-samples for diatom analysis were collected at magnetic highs and lows in the upper half of the core. In the lower part of the core, visual assessment of laminations suggested the possibility of a varved sequence. Similar sediments were observed at ODP Leg 178 site 1098. Quantitative diatom analysis of site 1098 sediments demonstrate a distinct and repeated alternation of diatom abundance (Figure 3) (McAndrews et al., submitted); similar quantitative analysis are performed on alternating laminae in NBP9903-JPB 28. Quantitative diatom slides were made using the settling technique described by Scherer (1995) and permanent slides were made using Norland Optical Adhesive.

Samples for radiocarbon analysis were collected at intervals identified as having abundant calcium carbonate. Seven *in-situ* pelecypod samples and 3 samples were collected for concentration of foraminifera for radiocarbon work. The samples were washed through a 150μm sieve and rinsed through a filter for drying. The material was dried in an oven overnight at <50° C. The >150 μm samples were then picked for calcitic benthic and planktic foraminifera. The siliceous-tested species *Milliamina aranacea* was removed from all samples. Ten samples, 7 pelecypod and 3 foraminifera, were sent for accelerator-radiocarbon dating at the University of Arizona Accelerator Mass Spectrometer Lab in Tucson. Finally, U-channel samples for paleomagnetic analyses were X-rayed. U-channels were chosen to be X-radiographed as they are of uniform width and height, unlike the curved half of the split core. In addition, due to their size (5 cm wide) 3 u-channels could be x-rayed at one time, reducing the amount of x-ray film and photographic chemicals needed. Ice-rafted debris was identified on each of the x-rays. All pebbles greater than 2 mm in size were assumed to be ice-rafted. Grain size analysis was done at Hamilton University and measured by laser diffractometry with a Malvern Master Sizer E. Grain size analyses were completed on the same samples as those for quantitative diatom analysis.

## Results

### Lithologic Data

Sediments from core NBP9903-JPC28 are primarily biosiliceous mud and ooze (Figure 2). Calcareous material is present throughout the core, including abundant benthic and planktonic foraminifera and *in-situ* pelecypod shells. Coarser-grained ice-rafted debris is observed throughout the core. In the upper 13.6 meters, the core is alternately laminated versus bioturbated. The olive brown laminated intervals are comprised of diatom ooze. Smear slide analysis indicates that individual laminations are composed of relatively monospecific diatom assemblages. The more massive intervals are dark gray to grayish brown, and are clearly mottled, indicating bioturbation. These sections are also diatom-rich, but appear to have a higher terrigenous content. Between 13.6 to 18.4 meters, the core is rhythmically laminated diatom ooze and silty mud. The silty mud ranges in color from dark gray to grayish brown and the ooze is olive brown. The laminations are very thin, with the thickest laminae (2-3 cm) between 14.2

and 14.9 meters. Evidence of bioturbation is apparent between 16.2 and 16.4 meters. At 17.6 meters, a 11 cm dark gray silt-rich layer occurs. Between 18.4 – 18.7 meters is continuous diatom silt. A bioturbated, dark grayish-brown diatom mud is observed between 18.7 and 19.3 meters. Laminated black diatom silt and ooze occurs between 19.3 and 19.4 meters. Associated with these laminations at the bottom of the core is fine pyrite. From 18.0 – 19.4 meters the core was distinctively black when opened and changed color, or oxidized, upon contact with air. Both the presence of pyrite and rapid color changes upon exposure to oxygen are typical of reduced environments.

## Magnetic Susceptibility

The magnetic susceptibility (MS) of core NBP9903-JPC28 can be divided into an upper section, from 0-11.6 meters, which consists of a series of alternating magnetic highs and lows, and a lower section, below 11.6 meters, which has uniformly low MS (Figure 2). From 0-6.5 meters, the magnetic cycles reach approximately the same peak height. From 6.5-11.6 meters, there is a gradual decrease in the peak height. At 11.6, the MS reaches the uniformly low value observed for the lower section of the core, but a narrow isolated peak in MS occurs between 11.6-11.8 meters. Between 18.5 and 19.4 meters, another peak is observed which corresponds with the increased abundance of ice rafted debris.

## Color

Color data show very little correlation with other proxies. An observable similarity with MS, however, occurs at 6.5 meters, during the transition period seen in MS between the upper and lower sections (Figure 2). At this point, there is an increased separation between the blue measurements and the red and green. This separation continues and increases downcore. In general, however, these data are highly variable with definite peaks and troughs observed but with no correlation to the highs and lows of the MS. Upon analysis, $r^2$ values indicate little or no correlation between MS data and color data.

## Ice-rafted Debris

The IRD data are highly variable but a few trends are observed. Above 8 meters, a lower concentration of ice-rafted debris is measured (Figure 2 and Table 1). From 8 meters to 14 meters, IRD content remains variable, but the maximum concentration is higher than the overlying 8 meters. This series of highs and lows in IRD measurements is associates with the transition between the upper and lower sections in the MS data. Between 14-17.5 meters, IRD values are low. This corresponds to the rhythmically bedded section of the core. Below 17.5 meters, there is a slight increase in IRD values. This small peak roughly matches the small peak in MS.

## Diatoms

The diatom analysis of the potentially varved sequence in the lower section of core NBP9903-JPC28 shows distinct differences between the alternating biogenic and terrigenous layers (Figures 3, 4 and Table 2). These layers were identified initially by color differences. Diatom counts on 10 pairs of laminae reveal that absolute diatom abundances are higher for biogenic layers and lower for terrigenous layers. The most common diatom species found was *Chaetoceros* resting spores. Also found were *Thalassiosira antartica* and *Fragilariopsis curta*. The average diatom abundance for biogenic laminae is 743 millions valves/gram as compared to 266 millions valves/gram for terrigenous laminae. Diatoms abundances for terrigenous laminae have a smaller range size (~150-400 valves/gram) than biogenic layers (570-1040 valves/gram).

## Radiocarbon Dates

Accelerator mass spectrometric radiocarbon dates based on in-situ pelecypod shells are shown in Table 3. The data, which show no age reversals, indicate a sedimentation rate that increases downcore from 0.40 to 0.95 cm/year. Assuming a sedimentation rate of 0.4 cm/year for the uppermost section of the core, an uncorrected age of 1560 +/- 45 years can be calculated for the coretop. Based on radiocarbon dates of ~1260 years on living mollusks from the Antarctic Peninsula (REF), a reservoir correction of 1260 years is applied to the data. This suggests a loss of about 20-25 cm (~50 years) of surface material during the coring process. Based on these data the core extends back to 3558 ybp. However, calibration will alter the ages by a maximum of 400 years (Stuiver and Reiman, 1993).

### Grain Size and SEM pictures

Grain size was measured on the same samples as those analyzed microscopically. These data show a distinct relationship with average diatom abundance (Figure 5). Biogenic layers have peaks which, in previous studies (Katz, in prep.), have been shown to be characteristic of sediments overwhelmingly dominated by *Chaetoceros* resting spores. These peaks are unimodal and centered at ~10 µm, the maximum dimension for the *Chaetoceros* spores which dominate the biogenic layers. SEM photos show that the resting spores dominate the biogenic layers while the terrigenous layers consist predominantly of diatom fragments and terrigenous material (Figure 6). Grain size measurements show that the terrigenous layers are bimodal in terms of grain size and have a broader range of grain sizes which is characteristic of fragmented diatoms. The wider variety of particles results in a broader grain size distribution.

## Discussion

The magnetic susceptibility profile of core NBP9903-JPC28 is similar to other well-studied cores recovered from the Antarctic. For example, cores from the Palmer Deep (PD) and Andvord Bay (AB), are characterized by similar susceptibility profiles though they are situated in different oceanographic regimes and are spread over approximately 100 km along the Antarctic Peninsula (AAP) (Sjunneskog and Taylor, submitted; Leventer et al., 1996; Domack et al., 1993). In addition, core lithologies and diatom assemblages through the mid to late Holocene are also comparable, suggesting that similar sedimentary processes influence these regions and that their response to climate change over the past 5000-6000 years is similar as well. Cores from both ODP Leg 178 (site 1098) and Polar Duke cruise 92 (PD92-30) were recovered from the Palmer Deep, a deep (>1000m) basin located on the western continental shelf of the Antarctic Peninsula. This setting is exposed to the open waters of the Bellingshausen Sea. Andvord Bay, located along the Palmer Land coast, is a more restricted oceanographic setting. The Gerlache Strait represents a more intermediate environment. It is an important connection between the Bellingshausen Sea waters and Weddell Sea waters (Hofmann et al., 1996) and a strong northeasterly flowing current is observed. However, nutrient measurements on water flowing from the Gerlache Strait northward document low nitrate and phosphate levels, indicating a water mass not associated with the nutrient rich Weddell sea waters. Preliminary studies have shown that the Gerlache Strait has unique warm surface temperature (>2.0°C) water, which is associated with high productivity (Domack and Ishman, 1993). The Gerlache Strait is also located further north than the PD or the AB.

Given the broad similarities in sediment records among these three sites, initial assessment of regional changes in oceanographic conditions as a function of paleoclimate variability of the Holocene can be made. Proxy date from sediment cores from Palmer Deep, Andvord Bay and now the Gerlache Strait, all indicate changes in paleoproductivity as controlled by the retreat and advance of both glacial and sea ice as a function of climate change.

Similar to cores from the Palmer Deep and Andvord Bay, the MS record from the upper part of JPC 28 demonstrates a distinct alternation of susceptibility highs and lows. Initial interpretations from the PD and AB suggest the cycles are driven by a combination of changes in terrigenous input and paleoproductivity. MS lows are characterized by sediments with high organic content, low bulk density and diatom assemblages characteristic of intense plankton blooms. MS highs, on the other hand, have lower organic content, higher bulk density and diatom assemblages characteristic of less productive oceanographic settings (Figure 2) (Leventer et al., 1996). Through the late Holocene, dominant modes of sedimentation alternated between these two different styles. The underlying force driving these alternations, which occur on a century time scale, are not yet understood, but similar cyclicity in many other proxy records and in the $^{14}$C record suggest a global mechanism and a possible link to solar forcing (Leventer et al., 1996).

This study focused on the distinctive laminations in the lower part of core JPC 28. This section has uniformly low MS. However, a clear alternation of layers was visually obvious (Figure 7) and easily apparent in x-ray. Initial smear slide analyses suggested a regular pattern of more biogenic layers versus more terrigenous layers. Based on the regular alternation of laminations, pairs of laminations were initially suspected to be varves. Varves are defined as couplets of laminations, which have been deposited within a single year and represent differences in seasonal sedimentation.

Varves are uncommon in the sedimentation record for several reasons. First, varves rarely occur in oceanic settings because the formation of varves usually requires a relatively closed system. Second, regularly repeated climate signals with clear seasonality are needed. Seasonal productivity clearly occurs in Antarctica, but a sedimentary layer distinguishing one summer bloom from the next is very rare in Antarctic marine sediments. Finally, preservation of a regularly repeated seasonal pattern requires an undisturbed and non-bioturbated setting. Given the tight set of constraints under which varves may be formed and preserved, it is not surprising that only one case of varved sediments has been reported for the Antarctic marine system, the deglacial sediments of the PD (McAndrews et al., submitted). Determining that the laminations in the bottom section of JPC 28 are varves is important, first, because varves are instrumental in the development of an ultra high-resolution (annual) paleoclimate record. Second, identification of varves from the mid Holocene of the Gerlache Strait sediments suggests comparisons between the deglacial setting of the PD and the mid Holocene setting of the Gerlache Strait.

McAndrews et al. (submitted) demonstrated the likelihood that sequences in the PD similar to those in the Gerlache Strait are varves. In Core 1098, from ODP Leg 178, the 150-year varved sequence occurs at the transition between glacial and interglacial environments. Biogenic laminations were formed as a result of intense summer/spring blooms, dominated by a single species of diatom, *Chaetoceros*. The 'terrigenous' layers, which are more variable in composition and include ice rafted debris, terrigenous material, and diatom fragments, are interpreted to be the influx of sediment the rest of the year. The key to formation of varves appears to be proximity to melting glacial ice as it retreated shoreward during the transition from glacial to interglacial conditions. Once the glacial ice retreated to a point distant from the core site, terrigenous input decreased, and varve formation stopped. Interest in the potentially varved sequence in JPC 28 arose because the same facies as in 1098 is observed, but this facies occurs at a different stratigraphic interval. While the PD varves occur ~12,000 ybp (McAndrews, 1999), the similar sequence in the GS is clearly mid-Holocene. Because these sequences are so rarely seen in marine sediments, it would suggest that a similar environmental setting occurred during the boundary between glacial and interglacial in the Palmer Deep and during the mid-Holocene in the Gerlache Strait.

One of the main goals of this project was to determine if the laminations seen in core JPC 28 are varves. While laminations are apparent throughout the core, the laminations from 13.6 – 17 meters (Figure 2) are different because of their regular alternation and the dominance of the single diatom species, *Chaetoceros*, in the biogenic layer. Absolute diatom abundance counts, grain size analysis, and SEM photos suggest that pairs of laminations were formed annually (Figures 3, 4, 5, and 6). As in core 1098, the biogenic laminations are characterized by significantly increased diatom abundance and are composed mainly of *Chaetoceros* resting spores (r.s.). Because this single species dominates the biogenic layers, it suggests that this specific diatom is able to exploit this unique environment, which may be stratified by low salinity glacial meltwater. The presence of resting spores, as opposed to vegetative cells, indicates environmental stress. Previous work has shown that spore formation is associated with nutrient depletion as a result of intense productivity such as might be expected in an oceanic setting with a shallow mixed layer (Leventer, 1991). Grain size data (Figure 6) from biogenic layers demonstrate a strong, sharp peak in average grain size at 10 μm, the maximum dimension of *Chaetoceros* r.s. In addition, SEM photos (Figure 5) visually demonstrate the overwhelming dominance of this species of diatom in the biogenic layers. In contrast, SEM photos indicate that the terrigenous layers are composed of a combination of *Chaetoceros* r.s., diatom fragments and terrigenous material. Absolute diatom abundance is on average ~64% lower. The grain size data show a broader peak in mean grain size, reflecting the more varied composition of the terrigenous layers.

Based on the radiocarbon data (Table 1), sedimentation rates from the varved section of the core are at least double that of the rest of the core. In addition to calculations of sedimentation rates based on radiocarbon data, pairs of laminations were counted on the x-radiographs to estimate sedimentation rates. For example, 11 couplets are observed between 15.6 and 16.0 m, giving a rate of 3.6 cm/year.

As mentioned, the stratigraphic position of the varved section in JPC 28 is not time correlative to the deglacial varve sequence seen in core 1098, suggesting that while the paleo-environmental settings are most likely similar, they occurred at different times. Seismic data over the core site in the Gerlache Strait region show that a significant amount of soft sediment occurs below the depth to which core JPC 28 penetrates (Figure 8). During the Last Glacial Maximum, the ice sheet was grounded on this part of the Antarctic shelf (Rebesco, et al., 1998), suggesting that the sequence of soft sediment in the Gerlache Strait must be post-glacial. In addition, radiocarbon dates (Table 1) clearly document a mid-Holocene time frame for the deposition of the 'varved' unit in JPC 28. If the 'varved' sequence in JPC 28 was formed under conditions similar to the older sequence in the Palmer Deep, in proximity to retreating glacial ice, this then suggests ice expansion in the mid-Holocene in the Gerlache Strait.

Initial analysis on a core from the Andvord Drift indicates time correlative facies present similar to those of JPC 28, implying that glacial expansion due to a mid-Holocene climatic optimum is documented elsewhere in the Antarctic Peninsula. Shevenell et al. (1996) document a climatic optimum in Lallemand Fjord, located approximately 300 km south of the Gerlache Strait, between ~4200 - 2700 yBP, through study of total organic carbon (TOC) and grain size analysis. Additional work diatom assemblages from the same Lallemand Fjord cores (Sjunneskog and Taylor, submitted) similarly suggest mid-Holocene warmth. Taylor (1999), working on cores from the East Antarctic margin document a *Chaetoceros* rich facies during the mid-Holocene which she associates with ice shelf retreat and a climatic optimum. In Prydz Bay, also on the East Antarctic margin, lithologic studies of ODP Site 740 identified glacial retreat and advance occurring during the mid-Holocene, associated with a climatic optimum (Domack et al., 1996).

Based on these studies, a mid-Holocene climatic optimum is inferred for the Gerlache Strait. The "varved" sequence in JPC 28, which is dated to ~3200 ybp thus most likely formed during a warm phase of the Holocene. Similarities between the varved sequences in 1098 and JPC 28 suggest a single mode of origin. In 1098, proximity to retreating glacial ice at the transition between the last glacial and the present interglacial created conditions for the formation and preservation of varves. Domack et al. (1991) suggest that mid-Holocene warmth along the East Antarctic Margin was associated with an expansion of glacial ice. In JPC 28, mid-Holocene glacial expansion is proposed also. It is possible that ice expansion resulted from enhanced evaporation and resultant precipitation. However, given the warmth, increased glacial meltwater may have also been present, resulting in an environmental setting similar to that experienced during deglaciation. This hypothesis needs to be researched further.

Speculation of mid-Holocene warmth and glacial expansion leads to the question of the immediate or short term response of the modern Antarctic system to rising temperatures. The association of ice expansion with slightly warmer temperatures may be an initial response to warming. Current studies of ice balance in the Antarctic document a slight increase in the ice balance on the Antarctic continent (Jacobs, 1992), though certain locations in Antarctica are experiencing ice contraction instead of expansion. Studies, like this one in the Gerlache Strait, may be important in understanding why ice sheet contraction may not be observed to be occurring synchronously with modern day global warming.

## Conclusion

Analysis of sediment samples from a jumbo piston core from the Gerlache Strait provides data that suggest mid-Holocene warmth and glacial expansion. Proximity to glacial meltwater is implied by the occurrence of a varved sequence in JPC 28 that is nearly identical to deglacial sediments found in the Palmer Deep, 30 km to the south. The presence of varves is indicated by the rhythmic, alternating laminations of a *Chaetoceros* rich biogenic layer and a ‘terrigenous’ layer. Together, these laminations form an annual indicator of a depositional setting that is close to glacial meltwater. A comparable and time correlative facies is seen in a core from the Andvord Drift, additional documentation of glacial expansion in response to mid-Holocene warmth. These findings are important because they may show that ice expansion is Antarctica’s immediate response to increasing temperatures. This response may be analogous to current conditions, but recent studies conclude that it is too early to tell whether the ice balance is increasing or decreasing.

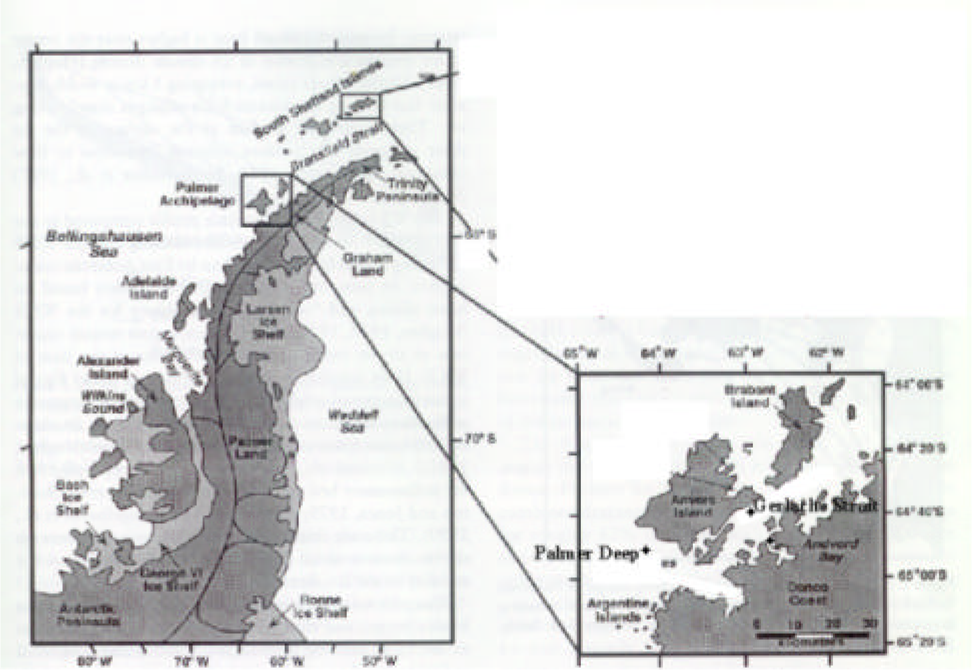

Figure 1. Map of Antarctic Peninsula.  From Anderson (1999).

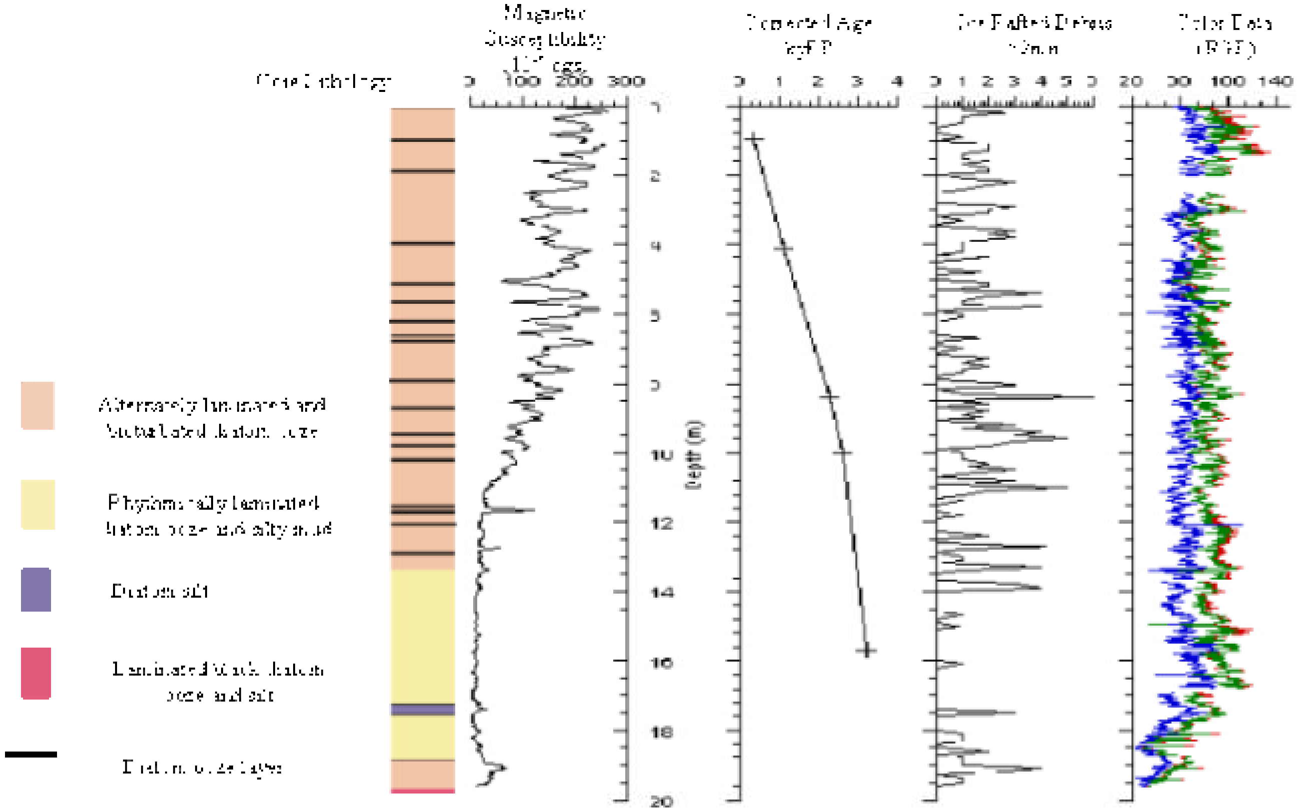

Figure 2. Core lithology, magnetic susceptibility, corrected age, ice rafted debris, and color data from core JPC 28, Gerlache Strait.

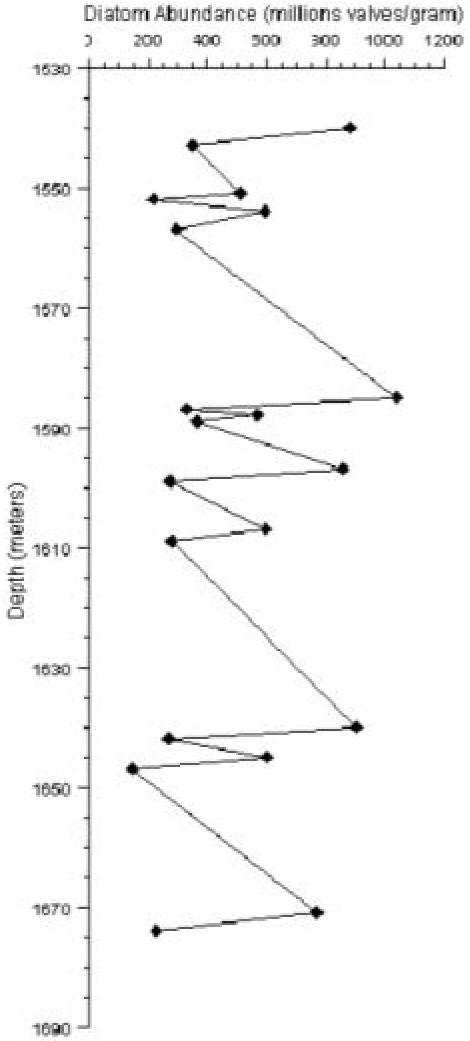

Figure 3. Average diatom abundance counts. “B” indicates biogenic lamination and “T” indicates “terrigenous” lamination.

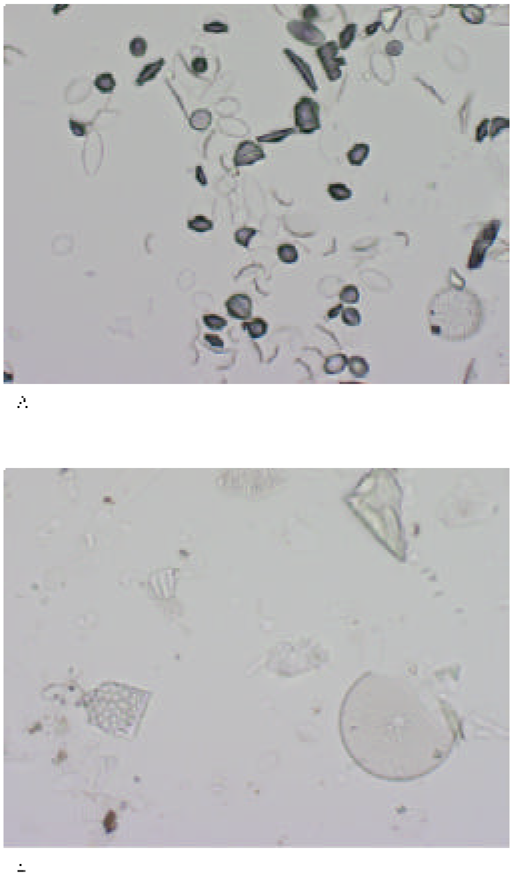

Figure 4. Photographs of quantitative diatom slides of A. biogenic lamination material (1640 cm) and B. “terrigenous” lamination material (1643 cm) at 400x.

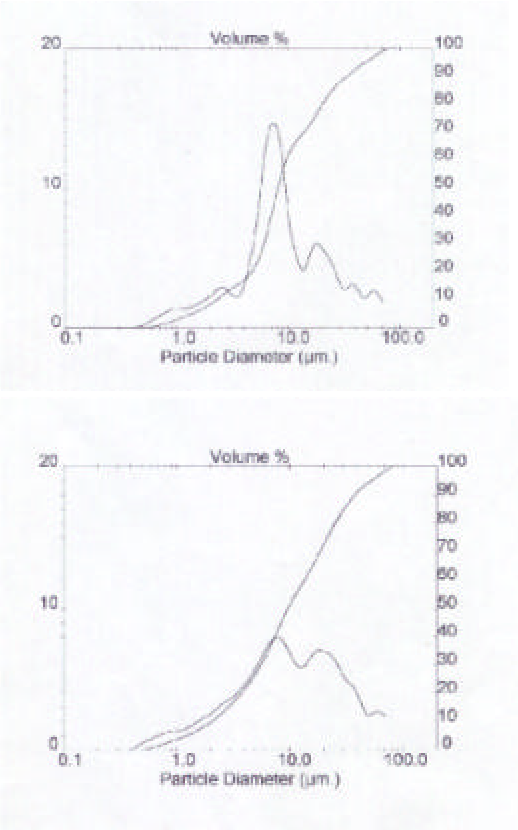

Figure 5. Grain size charts of A. biogenic lamination (1540 cm) and B. “terrigenous” lamination (1543 cm).

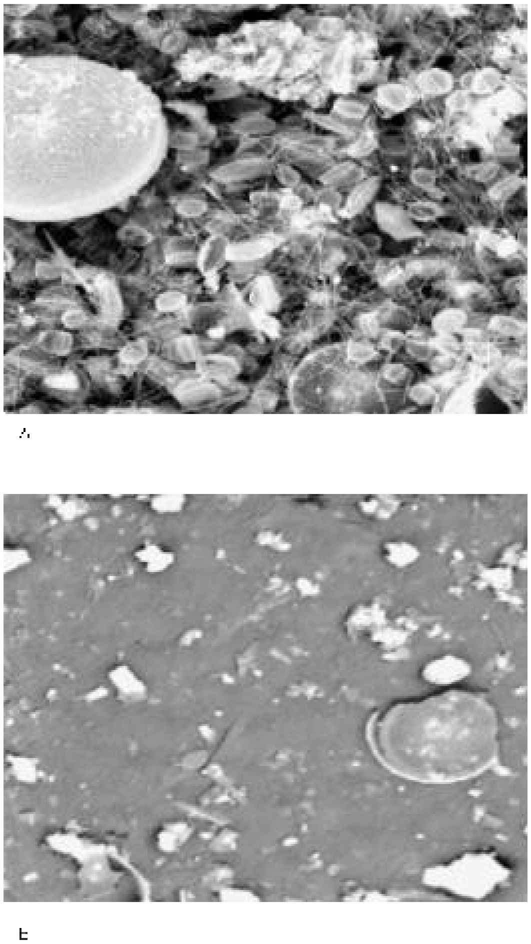

Figure 6. SEM photographs of A. biogenic lamination material and B. “terrigenous” lamination material.

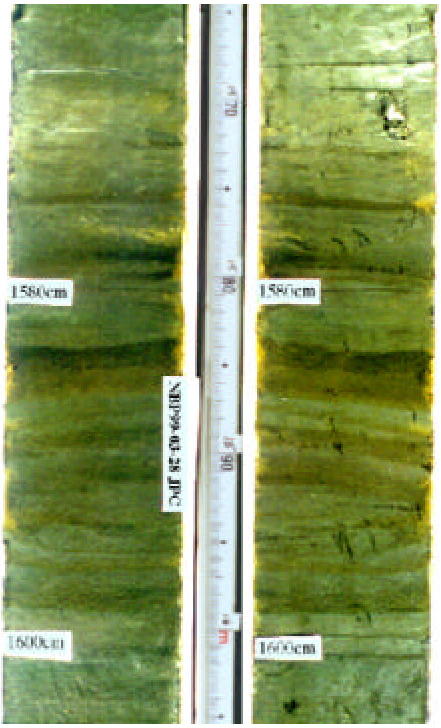

Figure 7. Photograph of JPC 28 from 15.6 to 16.6. meters.

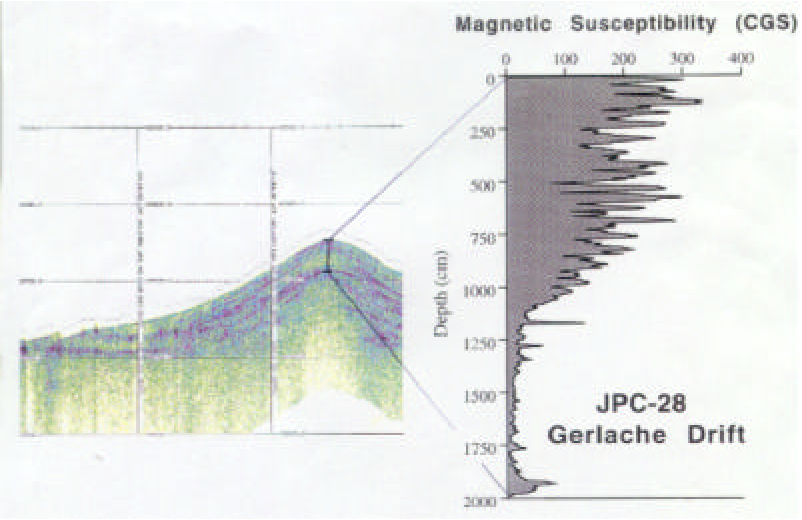

Figure 8. Seismic record and magnetic susceptibility from site JPC 28, Gerlache Strait. From Domack, 1999.

| Depth (cm) | IRD | depth (cm) | IRD | depth (cm) | IRD | depth (cm) | IRD |
|---|---|---|---|---|---|---|---|
| 0 | 1 | 510 | 2 | 1020 | 1 | 1530 | 0 |
| 10 | 1 | 520 | 2 | 1030 | 2 | 1540 | 0 |
| 20 | 3 | 530 | 0 | 1040 | 1 | 1550 | 0 |
| 30 | 1 | 540 | 4 | 1050 | 3 | 1560 | 0 |
| 40 | 1 | 550 | 2 | 1060 | 1 | 1570 | 0 |
| 50 | 1 | 560 | 1 | 1070 | 0 | 1580 | 0 |
| 60 | 0 | 570 | 1 | 1080 | 3 | 1590 | 0 |
| 70 | 0 | 580 | 4 | 1090 | 0 | 1600 | 0 |
| 80 | 0 | 590 | 0 | 1100 | 5 | 1610 | 1 |
| 90 | 1 | 600 | 1 | 1110 | 2 | 1620 | 0 |
| 100 | 0 | 610 | 1 | 1120 | 1 | 1630 | 0 |
| 110 | 2 | 620 | 0 | 1130 | 0 | 1640 | 0 |
| 120 | 2 | 630 | 0 | 1140 | 1 | 1650 |  |
| 130 | 2 | 640 | 0 | 1150 | 0 | 1660 |  |
| 140 | 1 | 650 | 0 | 1160 | 0 | 1670 |  |
| 150 | 1 | 660 | 0 | 1170 | 0 | 1680 |  |
| 160 | 2 | 670 | 2 | 1180 | 1 | 1690 |  |
| 170 | 1 | 680 | 0 | 1190 | 0 | 1700 |  |
| 180 | 2 | 690 | 0 | 1200 | 0 | 1710 |  |
| 190 | 2 | 700 | 1 | 1210 | 0 | 1720 | 0 |
| 200 | 0 | 710 | 0 | 1220 | 0 | 1730 | 0 |
| 210 | 1 | 720 | 0 | 1230 | 0 | 1740 | 0 |
| 220 | 3 | 730 | 2 | 1240 | 2 | 1750 | 3 |
| 230 | 2 | 740 | 1 | 1250 | 0 | 1760 | 0 |
| 240 | 1 | 750 | 2 | 1260 | 0 | 1770 | 0 |
| 250 | 0 | 760 | 1 | 1270 | 5 | 1780 | 0 |
| 260 | 0 | 770 | 1 | 1280 | 1 | 1790 | 0 |
| 270 | 0 | 780 | 0 | 1290 | 0 | 1800 | 0 |
| 280 | 0 | 790 | 0 | 1300 | 1 | 1810 | 1 |
| 290 | 3 | 800 | 3 | 1310 | 1 | 1820 | 1 |
| 300 | 2 | 810 | 3 | 1320 | 0 | 1830 | 1 |
| 310 | 2 | 820 | 0 | 1330 | 4 | 1840 | 0 |
| 320 | 0 | 830 | 1 | 1340 | 1 | 1850 | 0 |
| 330 | 1 | 840 | 6 | 1350 | 0 | 1860 | 2 |
| 340 | 0 | 850 | 0 | 1360 | 0 | 1870 | 0 |
| 350 | 0 | 860 | 2 | 1370 | 0 | 1880 | 1 |
| 360 | 3 | 870 | 0 | 1380 | 3 | 1890 | 1 |
| 370 | 2 | 880 | 2 | 1390 | 4 | 1900 | 1 |
| 380 | 3 | 890 | 1 | 1400 | 0 | 1910 | 4 |
| 390 | 1 | 900 | 2 | 1410 | 0 | 1920 | 2 |
| 400 | 1 | 910 | 0 | 1420 | 0 | 1930 | 0 |
| 410 | 1 | 920 | 3 | 1430 | 0 | 1940 | 1 |
| 420 | 1 | 930 | 1 | 1440 | 0 | 1950 | 1 |
| 430 | 0 | 940 | 4 | 1450 | 0 | 1960 | 0 |
| 440 | 2 | 950 | 3 | 1460 | 0 |  |  |
| 450 | 0 | 960 | 5 | 1470 | 1 |  |  |
| 460 | 0 | 970 | 3 | 1480 | 0 |  |  |
| 470 | 0 | 980 | 2 | 1490 | 0 |  |  |
| 480 | 2 | 990 | 0 | 1500 | 1 |  |  |
| 490 | 0 | 1000 | 1 | 1510 | 0 |  |  |
| 500 | 0 | 1010 | 1 | 1520 | 0 |  |  |

Table 1. Counts of ice rafted debris (>2mm) from x-radiographs of JPC 28, Gerlache Strait.

| Depth | Average diatom abundance |
|---|---|
| | (Million valves/gram) |
| 1540-1541cm B | 880.9 |
| 1543-1544cm T | 349.2 |
| 1551-1552cm B | 509.8 |
| 1552-1553cm T | 216.1 |
| 1554-1555cm B | 591.7 |
| 1557-1558cm T | 292.5 |
| 1585-1586cm B | 1039.9 |
| 1587-1588cm T | 329.9 |
| 1588-1589cm B | 569.1 |
| 1589-1590cm T | 362.6 |
| 1597-1598cm B | 857.2 |
| 1599-1600cm T | 273.8 |
| 1607-1608cm B | 595.4 |
| 1609-1610cm T | 278.7 |
| 1640-1641cm B | 902.5 |
| 1642-1643cm T | 269.7 |
| 1645-1646cm B | 599.6 |
| 1647-1648cm T | 146.2 |
| 1671-1672cm B | 767.6 |
| 1674-1675cm T | 225.3 |

Table 2. Average Diatom Abundance counts.

| *Depth (cm)* | *Uncorrected $^{14}$C age (yBP)* | *Corrected Age (yBP)* | *Calculated Sedimentation Rate* |
|---|---|---|---|
| 97-98 | 1560+/- 45 | 300+/- 45 | 0.53cm/yr |
| 325-327 | 2040+/- 50 | 780+/- 50 | 0.29cm/yr |
| 411-412 | 2340+/- 45 | 1080+/- 45 | 0.37cm/yr |
| 841-842 | 3500+/- 50 | 2240+/- 50 | 0.33cm/yr |
| 866-867 | 3575+/- 60 | 2315+/- 60 | 0.53cm/yr |
| 1003-1004 | 3835+/- 60 | 2575+/- 60 | 0.95cm/yr |
| 1569-1570 | 4430+/- 65 | 3170+/- 65 | |

Table 3.Radiocarbon dates from core JPC28, Gerlache Strait, from the University of Arizona Accelerator Mass Spectrometer Lab. Sedimentation rates calculated between radiocarbon date intervals.

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