Kerguelen Plateau benthic foraminifera as a proxy for Late Neogene water mass history and Antarctic glacial-deglacial cycles

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Summary Past climate studies provide a context for assessing current and future climate variability. The Antarctic-Southern Ocean region is significant for paleoclimate studies because critical deep water production and extreme polar climatic conditions occur there. The Pliocene-Pleistocene represents a time during which climate oscillated between extremes of glacial-deglacial periods. This research interprets the paleoceanography and paleoclimate of the southern Kerguelen Plateau during the Late Neogene (<5 mya) using open ocean bathyal benthic foraminiferal assemblages, their population dynamics, and the record of hiatuses in the region. Ocean Drilling Program Leg 119 and 120 (Sites 747, 748, 751, and 744) materials are investigated. The major focus of this research is the responses of benthic foraminifera to a changing environment. A better understanding of the roles of water masses, bottom currents and surface water phenomena, and how they affect changes to the benthic ocean environment is achieved.

Citation: Johnson, K. (2007), Kerguelen Plateau benthic foraminifera as a proxy for Late Neogene water mass history and Antarctic glacial-deglacial cycles – Online Proceeding of the 10th ISAES X, edited by A.K. Cooper and C. R. Raymond et al., USGS Open-File Report 2007-1047, Extended Abstract 029, 4 p.

Introduction

Kerguelen Plateau, located in the southern Indian Ocean, represents a prime location for paleoclimate studies. The Ocean Drilling Program (ODP) drilled the first Kerguelen cores in 1987; thus, scientific studies from these cores were first published in the early 1990s. The rationale for drilling those sites was that Kerguelen Plateau (KP) is "strategically situated for high latitude paleoceanographic studies," (Barron, Larsen et al., 1989). KP is located in the southern Indian Ocean between the latitudes of 46º and 64º S and between the longitudes of 60º to 85ºE as shown in Figure 1. The Plateau is 2300 km long and 200-600 km wide. It is located proximal to the Antarctic, is under the influence of the Antarctic Circumpolar Current (ACC), and at depths Circumpolar Deep Water (CDW) dominates. It is a bathymetric high, due to its origin as an oceanic plateau. The plateau deepens to the south; however, even the southern domain is less than 3 km deep. Thus, it is above the carbonate compensation depth (CCD), allowing preservation of the calcareous tests of microfossils.

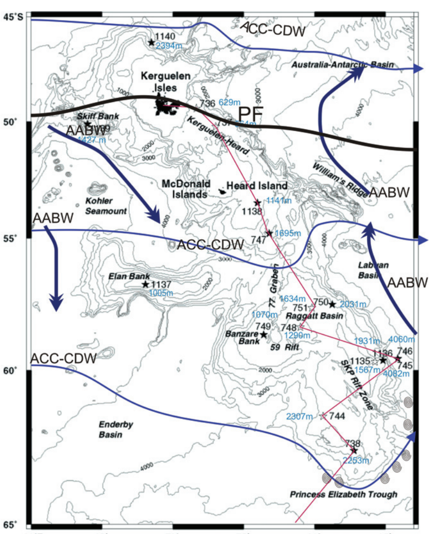

Figure 1. Map of Kerguelen Plateau. Oceanic fronts and water masses are drawn in. The red line indicates the cross section line drawn in Figure 2. ACC= Antarctic Circumpolar Current, AABW = Antarctic Bottom Water, PF = Polar Front (from Belkin and Gordon, 1996). Dark blue arrows indicate pathway of AABW; lighter blue arrows indicate pathway of ACC-CDW system (Dezileau et al., 2000). Spirals on southern flank indicate upwelling.

Environmental Setting

The locations used in this study are ODP Sites 744, 747, 748, and 751, shown in both Figures 1 and 2. Sites 748 and 751 are located within a basin of the Plateau. Site 748 (1290 m water depth) is on the southwestern flank of the Raggatt Basin, whereas Site 751 (1634 m water depth) is located in the center of the basin. Site 747 is located in the transition area between the northern and southern domains in a bathymetrically complex area at 1695 m water depth. Site 744 at 2307 m water depth is located on the far southern part of Kerguelen Plateau. It is hypothesized that all four of these sites are bathed in CDW. KP is separated from Antarctica by the Princess Elizabeth Trough, which is more than 3 km deep. In this area, circulation moves latitudinally, rather than meridionally.

At the northernmost site of interest, 747, the late Neogene record consists of ~34 m of foraminifer ooze (Wise, Schlich et al., 1989). Whereas short hiatuses have been identified through core description, biostratigraphy and magnetostratigraphy, no large, major hiatuses have been proposed at this site during the period of study (Harwood et al., 1992). Site 751 offers the thickest record of the Pliocene-Pleistocene of the sites studied, consisting of ~40 m of diatom ooze; however, the Pliocene is full of hiatuses (Harwood et al., 1992). Previous microfossil and geochemical studies show evidence of changing climatic conditions during the last 6 million years (e.g., Schröder-Adams,

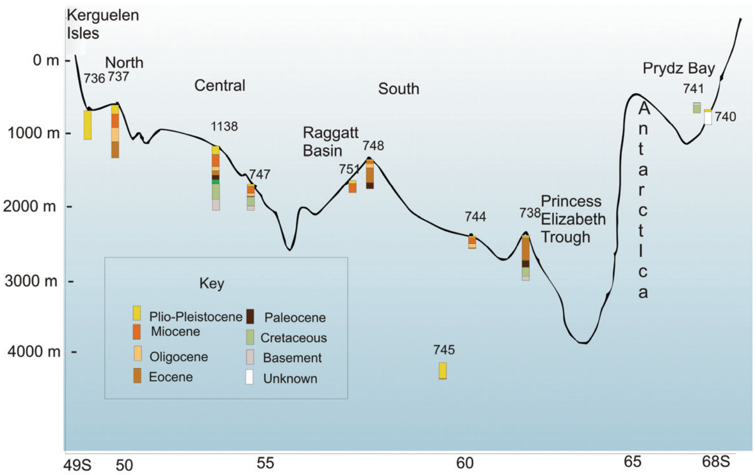

Figure 2. Cross section of KP. Red line from Figure 1 traces the cross section line. ODP cores are shown at their respective depths. Age of strata are color coded according to key. Site 745 is offset from the cross section to the east in Labuan Basin (see Figure 1). Vertical exaggeration is ~100X.

1991). The Late Neogene at Site 748 consists of ~16 m of diatom ooze and nannofossil ooze (Wise, Schlich et al., 1989). Very little of the Pliocene is present at Site748, due to erosional hiatuses (Harwood et al., 1992). The benthic foraminiferal assemblages differ in the Pliocene from those at Sites 751 and 747 (Mackensen, 1992). Site 744 consists of ~22 m of Pliocene-Pleistocene diatom ooze (Barron, Larsen et al., 1989). The stratigraphic record is more complete at this site for the period in question, with the only hiatus identified at 4.2-5.6 Ma (Barron, Larsen et al., 1991).

Benthic Foraminifera

Benthic forams live on the seafloor recording conditions at or just below the sediment-water interface and in the adjacent water column. Factors affecting faunal benthic foram assemblages are changing bottom water mass history, food supply, and bottom current activity (Mackensen et al., 1995). Benthic foram assemblages have the advantage over macrofossils and even ostracodes of being much more diverse and abundant, better represented through time, and thereby allow subtle population dynamics to be investigated. Benthic foram assemblages have been used within the Southern Ocean setting to explore questions of productivity and paleoceanographic change (e.g. Corliss, 1979). Because these microfossils are the most numerous of any benthic faunal component in this region, they are used as a proxy for changing conditions.

Methods

In order to investigate changing seafloor conditions and the water mass in which benthic forams live, a variety of biostratigraphic methods were used, e.g. FADs and LADs, and population content. Benthic forams have been counted for abundance, also noting preservation, total diversity, species richness, evenness and generic, and specific dominance within each population. At the taxonomic level of superfamily and family following Loeblich and Tappan (1988), populations from the different ODP Sites have been compared in order to identify fundamental dominance changes, faunal overturns, and environmental thresholds through time. Species have also been documented as either constant or intermittent in order to detect biogeographic province boundary interactions, contractions, expansions, and stasis. Benthic assemblages have also been subject to cluster analysis and ordination analysis.

Population data previously published in Mackensen (1992) were used for Sites 747, 748, and 751; whereas Site 744 samples were obtained and prepared for use in this study. Mackensen used 20 cm^3 samples, washed them over a 63 µm sieve, and used only the fraction larger than 125 µm counts (Mackensen, 1992). For Site 751, 39 samples were picked and counted, whereas for Sites 747 and 748 only 11 and 12 samples each were used (Mackensen, 1992). As with Mackensen's (1992) data, 20 cm^3 samples from Site 744 were used. For Site 744, 111 samples were picked and characterized. Sampling was at roughly 40 ky intervals throughout the time interval for Site 744.

Discussion

Fluctuations of the Antarctic Convergence

The northward shift of the Antarctic convergence by 300 km, occurring around 5 Ma, has been attributed to expansion of the Antarctic Ice Sheet (AIS) and was also accompanied by eustatic sea level depression (Kennett, 1977). If this event affected the deep ocean, which seems likely, it will be recorded in the populations of benthic forams. Deep-sea hiatuses also record this event at locations on KP. Geographic expansion and contraction of the AIS should influence bottom water production around Antarctica, as well as chemistry of the waters in which the forams lived. Thus, population changes will be detectable. The movement of the Polar Front across Site 744 in the early Pliocene is recorded as a period of biosiliceous productivity in which calcareous foram tests are not preserved.

Water Masses

The numerous ridges and basins of the Indian Ocean pose barriers to deep and bottom water (Mantyla and Reid, 1995). AABW flows around KP, causing the slightly less dense CDW to dominate the setting.

The ACC, a surface current driven in an eastwardly circular path by prevailing westerly winds around Antarctica for 24,000 km, transports the largest amount of water and heat of any current in the ocean (170 Sv) (Whitworth, 1988). As it becomes more or less vigorous, it will influence the record of sediments. The Southern Boundary of the ACC Front extends to the southern end of KP to about 63˚S today.

The Antarctic Polar Front (APF) is a convergence zone between cold, polar water and warmer, lighter sub-Antarctic water. In the region near KP, the northern limit of the APF varies over time but is usually between 49˚-55˚ S today (Moore et al, 1999). The APF demarcates the boundary of biogenic sediments; to the north they are carbonate, to the south they are siliceous. The front has changed position through time depending on paleoclimate.

It is assumed that the sites used in this investigation are bathed in CDW, with the ACC flowing above in the surface waters. Changes in benthic foram faunal composition may be due to changing water mass conditions, either at the surface where the food lived, in deep-water masses where they lived, or due to bottom currents.

Pliocene Warm Period (4.5-3.0 Ma)

Another objective of this investigation is to identify the deep ocean expression of the occurrence of the Pliocene Warm Period (4.5-3.0 Ma) (Dowsett et al., 1996). Evidence supports a climatic warming during the Pliocene, e.g., plant material and insects in the Sirius Group of Antarctica and dolphin fossils found on Antarctica dating from this time (e.g., Webb and Harwood, 1993). Silicoflagellate data from KP supports the notion of intervals of increased warmth during the Pliocene (e.g., Bohaty and Harwood, 1998). Raymo et al. (1996) hypothesized that thermohaline circulation was more vigorous then, explaining the climatic amelioration through ocean heat transport rather than through increased CO_2. Preliminary results from the first season of ANDRILL support a dynamic AIS during the Pliocene (co-chiefs weekly reports, www.andrill.org). Presumably the Pliocene "warm" period translates to the deep ocean as faunal reorganization. However, the benthic foram fauna on southern KP can be characterized as a cosmopolitan deep-sea fauna, rather than being either polar or subtropical. Faunal changes are subtle, detectable more through statistical methods and changes in dominance than through absolute replacement.

Hiatuses and Dissolution

Within the Southern Ocean, there are widespread hiatuses documented throughout the Pliocene (Kennett and Watkins, 1976). At all sites used in this study, a large hiatus occurs at or near the Miocene-Pliocene boundary. Sites 748, 751, and 747 have hiatuses at or very near the Pliocene-Pleistocene boundary. The Raggatt Basin sites (748, 751) have hiatuses in the late to middle Pleistocene. These erosional hiatuses are due to vigorous circulation (Rack and Palmer-Julson, 1992). Phenomena responsible for the hiatuses could be increased bottom currents, invigoration of the ACC, or increased thermohaline circulation.

There are also periods of increased siliceous productivity, identified by the abundance of radiolaria and diatoms within these samples. The increased silica in the water column and at the seafloor as these siliceous planktonic organisms die and sink to the bottom leads to poor preservation of calcareous organisms within these samples. There are two major events (500-300 ky long) of siliceous productivity within the Pliocene at Site 744 on the southern KP during which a geochemical threshold is reached that leads to poor preservation of the calcareous fauna. The speculated cause of the siliceous productivity during these periods is an expansion of the APF (Harwood et al., 1992).

Trophic Linkages/Paleoproductivity

Benthic forams eat phytoplankton and, thus, are affected by surface waters. Changes in productivity at the surface are felt by the benthos within days to weeks of the change (Graf, 1989). Changes on this time scale cannot be resolved in the geologic record of the deep sea. Too much siliceous productivity in the surface waters is toxic to the forams at the seafloor, leading to dissolution of tests. Sometimes relict assemblages can be identified by arenaceous taxa that were part of the more diverse biocoenosis (Mackensen, 1992).

At Sites 744, 751, and 747 there is a record of seasonal phytodetrital input. Site 744 has a continuous record of *Epistominella exigua*, a species known to prefer oligotrophic settings with seasonal blooms. *Epistominella exigua* has a preference for living in organic fluff (Mackensen, 1992). Throughout the Pliocene, Sites 747 and 751 also have *Epitominella exigua* dominated assemblages. The preservation is poor, because of the siliceous productivity.

Another group of interest is the *Cibicidoides* assemblages. Mackensen (1992) regarded them as indicative of high primary productivity and bottom current indicators. They are epibenthic and prefer to live on a substrate with relief (Mackensen, 1992). This taxon dominates at Site 748 during the early Pliocene. At Site 748, which sits at the edge of Raggatt Basin, higher than any of the other sites, it is hypothesized that the presence of this taxon is evidence for winnowing activity of the ACC during the late Miocene and early Pliocene (Mackensen, 1992).

Neither the *Trifarina angulosa* assemblage nor the *Bulimina aculeata* assemblage at 747, 748 and 751 is present at Site 744. The *Trifarina angulosa* assemblage indicates a sandy substrate with moderate bottom currents. The *Bulimina aculeata* assemblage indicates a calmer, more organic rich setting. Locally at Site 744, the paleoenvironmental conditions appear to have been different to the other sites. However, at Site 744, *Nuttallides umbonifer* may play a bigger role. This taxon is typical of a carbonate corrosive environment (Corliss et al., 1986).

At a location north and east of KP, within the Indian Ocean, foram assemblages from the late Pleistocene have been identified from piston cores that fluctuate from glacial to interglacial periods (Corliss, 1979). The fluctuation is caused by increased productivity during the glacials, enhanced preservation of organic carbon during these periods, or because of a change in the chemistry of CDW (Corliss et al., 1986). All of the southern KP sites show evidence for increased productivity and organic input in the Pleistocene (Mackensen, 1992).

Conclusions

In summary, Kerguelen Plateau is a large volcanic plateau with useful basins that collected a good Late Neogene record of paleoclimate. Sites 747, 748, 751, and 744 were influenced by organic flux from surface water, changing oceanographic fronts, bottom current activity, and perhaps subtle changes in bottom water. Kerguelen Plateau is located in a relatively isolated setting directly downstream from any Antarctic forcing. It is situated between the more studied purely polar realm and subtropical settings of Australia and New Zealand, offering a chance to link the realms.

Acknowledgements. Thanks are owed to IODP for samples, Andreas Mackensen for data, Peter Webb for guidance, and Bill Ausich for comments on the manuscript. Financial support of this dissertation research has been awarded through the Geological Society of America, the Cushman Foundation for Foraminiferal Research, the Paleontological Society, Byrd Polar Research Center at Ohio State University, and the Graduate School at Ohio State University.

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