Evidence for a long warm interglacial during Marine Isotope Stage 31: Comparison of two studies at proximal and distal marine sites in the Southern Ocean

L. Teitler,[1] G. Kupp,[1] D. Warnke,[1] and L. Burckle[2]

[1]Department of Geological Sciences, California State University, East Bay, Hayward, CA 94542, USA (lorateitler@yahoo.com).
[2]Lamont Doherty Earth Observatory, Columbia University, Palisades, NY

Summary We report here on studies of ice-rafted debris (IRD) from Marine Isotope Stages (MIS) 34-30 at distal Ocean Drilling Program (ODP) Site 177-1090 (subantarctic South Atlantic) and proximal ODP Site 188-1165 (Prydz Bay, Antarctica). The presence of the base of the Jaramillo Subchron (straddling MIS 31) facilitates correlation between sites. At the distal site, only very little IRD is present during MIS 31-33. At the proximal site in Prydz Bay, of these three stages, only MIS 31 can be identified. Here, during MIS 31, IRD is low, while foraminiferal percentages are high. This record is similar to that from Cape Roberts Project (CRP) drill site CRP-1 (Scherer et al., 2002). Therefore, MIS 31, and perhaps all of MIS 33-31, was a long, warm interval, and may have compromised the stability of the West Antarctic Ice Sheet.

Citation: Teitler, L., G. Kupp, D. Warnke, and L. Burckle (2007), Evidence for a long warm interglacial during Marine Isotope Stage 31: Comparison of two studies at proximal and distal ODP sites in the Southern Ocean, in Antarctica: A Keystone in a Changing World – Online Proceedings of the 10th ISAES X, edited by A. K. Cooper, C. R. Raymond et al., USGS Open-File Report 2007-1047, Extended Abstract 013, 4 p.

Introduction

Whether or not the West Antarctic Ice Sheet (WAIS) persisted or collapsed during past warm intervals is a matter of great interest to scientists and planners alike. Recently, evidence of a warm event from continental-shelf sediments in the McMurdo Sound (Pacific Ocean sector of Antarctica) has been interpreted as showing a possible collapse of at least the Ross Ice Shelf, and perhaps of the entire WAIS, during Marine Isotope Stage (MIS) 31 (Scherer et al., 2002). That MIS 31 was a very warm interglacial, preceded by a mild glacial, was first recognized by Froelich et al. (1991). MIS 31 occurred at the beginning of the mid-Pleistocene climate shift from the 40 kyr obliquity-based cycles to 100 kyr eccentricity-based cycles. The presence of MIS 31 at the base of the Jaramillo Subchron in the paleomagnetic stratigraphy greatly facilitates its identification. Such a well-defined marker allows direct and relatively confident comparison with the same interval at other sites. We have recently completed studies of ice-rafted debris (IRD) at two other sites that include the same time interval, with the base of the Jaramillo Subchron present to ensure proper correlation. The first site is at ODP Leg 177 Site 1090, in the distal subantarctic South Atlantic Ocean; the second site is at ODP Leg 188 Site 1165, on the Antarctic continental rise near Prydz Bay (Indian Ocean sector of Antarctica). Comparing our results with the results from the study by Scherer et al. (2002) thus provides the opportunity to form a broad picture of the Antarctic response during this climate interval.

Site description

ODP Leg 177 Site 1090 is located at 42º54.8´ S, 8º53.98´ E, in the Subantarctic Frontal Zone (between the Subantarctic Front and the Subtropical Front). The drill cores were raised from the southern slope of the Agulhas Ridge, from a water depth of 3702 m, thus near the boundary in this region between North Atlantic Deep Water and Circumpolar Deep Water. At this site, both the Jaramillo and Olduvai Subchrons are present and clearly identifiable within the Matuyama Reversed Chron (Shipboard Scientific Party, 1999).

ODP Leg 188 Site 1165 is located at 64º22.77´ S, 67º13.14´ E, on the Antarctic continental rise about 400 km NW of Prydz Bay. This core was drilled on a large sediment drift (the Wild Drift), at a water depth of 3537 m. At this site, a prolonged interval of normal polarity has been identified as containing the Jaramillo Subchron fused with the decapitated Olduvai Subchron. The intervening hiatus thus includes the entire reversed interval between the Jaramillo and the Olduvai, from MIS32 to ~MIS 67 near the top of the Olduvai (Florindo et al., 2003).

Methods

At ODP Site 177-1090, we analyzed samples for IRD for the time interval from about MIS 34 to the beginning of MIS 30. The size fraction we examined for IRD was defined as that of medium to coarse sand (150 microns to 2 mm), which was separated from the rest of the sample by sieving. This portion of the sample was then randomly split until about 1000 grains were obtained; these grains were counted under a binocular microscope. Categories were: quartz, feldspar, mafics, lithics, volcanic lithics, volcanic ash, diatoms, planktonic forams, benthic forams, radiolaria, and other. Counts of quartz, feldspar, lithics and mafics were then combined as IRD, and used to calculate the IRD Index: (#IRD/[#IRD + #planktonic forams]) X 100 (Poore and Berggren, 1975). IRD Apparent Mass Accumulation Rate

(AMAR) was calculated as [(dry bulk density × sedimentation rate) × %IRD], and reported as mg/cm^2/kyr. The term "apparent" is used because density differences between components were not considered.

For 188-1165, the portion of the drill core that included this same time interval was utilized for comparison. At this site, the same size fraction was examined (150 microns to 2 mm); the number of grains which were counted in each sample was about 500. Categories included IRD quartz, non-IRD quartz, lithics, mafics, feldspar, foraminifera, and radiolarians. Because of the near-continental location of this site, only IRD quartz clasts (defined as quartz clasts demonstrating features that indicate glacial transport, such as a high degree of angularity, conchoidal fracturing, etc.) were counted as IRD. This means that the true IRD counts were probably under-represented here, as rounded quartz clasts, volcanics, and other types of lithics, which may have arrived by means other than glacial transport, were all excluded. For this study, the percentage of IRD-quartz out of the total count, and the percentage of foraminifera out of the total count, were then calculated.

At both sites, volcanic glass and ash were not included in the count of IRD, because volcanic materials may arrive by means of transport other than ice-rafting. Some garnets (included in the count of mafics) are present at both sites. At 177-1090, a separate record was kept of the presence or absence of garnets either in the counted portion of the sample or as 'background rafting' (i.e., in the non-counted portion of the examined size fraction).

Results and discussion

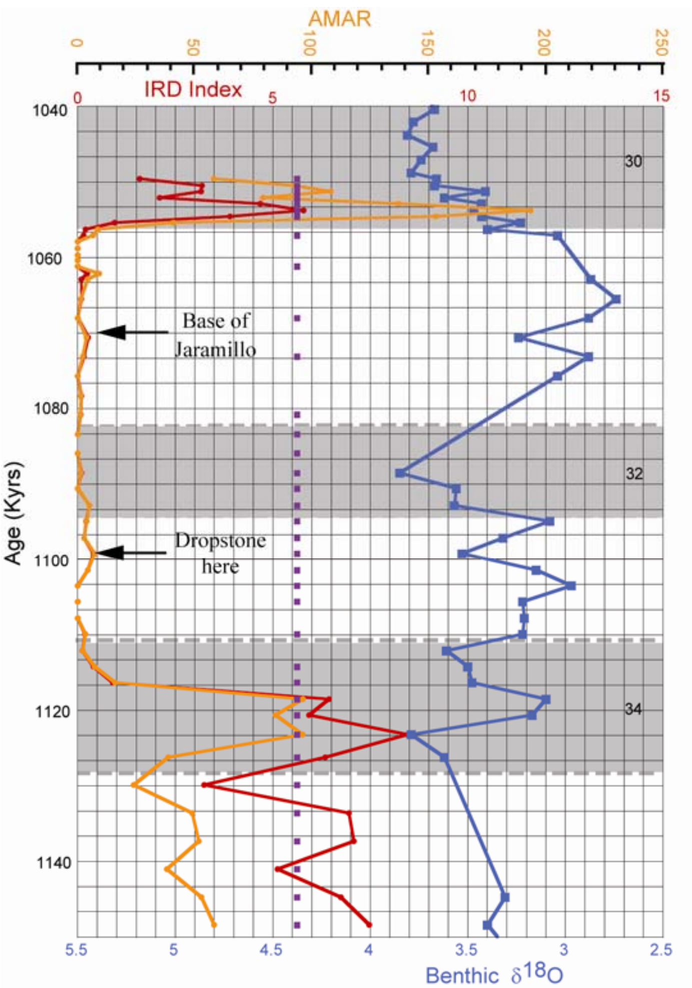

Figure 1. Site 1090 IRD Index in red, AMAR in orange, benthic oxygen isotopes (Shipboard Scientific Party, 1999) in blue, garnets in purple.

At 177-1090, we find a very low presence of IRD from MIS 33 to 31 (Fig. 1). However, there is some IRD present throughout this time, including some garnets. In contrast, IRD and especially garnets show a strong increase at the beginning of MIS 30. At this site, and in this eastern subantarctic sector of the South Atlantic Ocean generally, it has been shown by various studies (summarized in Diekmann et al., 2004) that sea surface temperatures have the strongest control on the survival of icebergs, thus on the deposition of IRD. The presence of garnet clasts at this distal location, even during warm times, is a strong argument for the provenance of the rafting icebergs from East Antarctica, the only reasonable source of icebergs large enough to survive travel over such great distances. During warm times, the ice on such relatively northerly locations as the Antarctic Peninsula, Patagonia, and the South Atlantic islands (the South Shetland Islands, Bouvier Island, etc.) would probably have greatly retreated, if not completely disappeared. Garnets are in many cases a component of formations that have been described from the metamorphic terrane of East Antarctica (for examples, see Tingey, 1991; also various reports included in symposia edited by Oliver et al., 1983, and Thomson et al., 1987). In addition, they are often mentioned as a component of glacial marine sediments around Antarctica, and interpreted as indicating a provenance from East Antarctica (Ehrmann and Polozek, 1999; Domack, 1982; Diekmann and Kuhn, 1999).

At 188-1165, the fused Jaramillo and Olduvai Subchrons form a relatively thick interval of normal polarity between 6.97 and 14.10 meters below sea floor (mbsf) (Florindo et al., 2003). The Jaramillo Subchron has been identified based on biostratigraphic evidence as present to about 8.46 mbsf (at least); the Olduvai Subchron has been similarly identified as present to at least 13.25 mbsf. In our record, there is a distinct interval from about 6.5 to 12 mbsf depth with very little IRD (interrupted by one spike in ice-rafting), and high percentages of foraminifera (Fig. 2), indicating an interval of increased warmth (Kupp, 2006). Further, information from a data report concerning 188-1165 shows a strong increase in $CaCO_3$ in the interval from about 6 to 10 mbsf (Warnke et al., 2004). Based on the lack of a reversed interval in the section between ~7-14 mbsf, plus other distinctive sedimentary features of this unit, we suggest as a working hypothesis that the interval from ~6-10 mbsf may correspond to MIS 31, and that the boundary between the fused Jaramillo and the Olduvai Subchron may be at ~10 mbsf.

At the Cape Roberts Project drill site 1 (CRP-1) in McMurdo Sound, a two meter thick unit (Lithostratigraphic Unit 3.1) of calcium-carbonate-rich sediment exists at the base of the Jaramillo Subchron (Scherer et al., 2002). This unit had reverse polarity in the lower part, and normal polarity in the upper part, with diatoms indicating warm conditions with reduced sea-ice. An ice-rafting event was included in Lithostratigraphic Unit 3.1, but the entire unit was nevertheless interpreted as representing a single interglacial, MIS 31. Thus the features of the record from CRP-1 are very similar to the record from 188-1165.

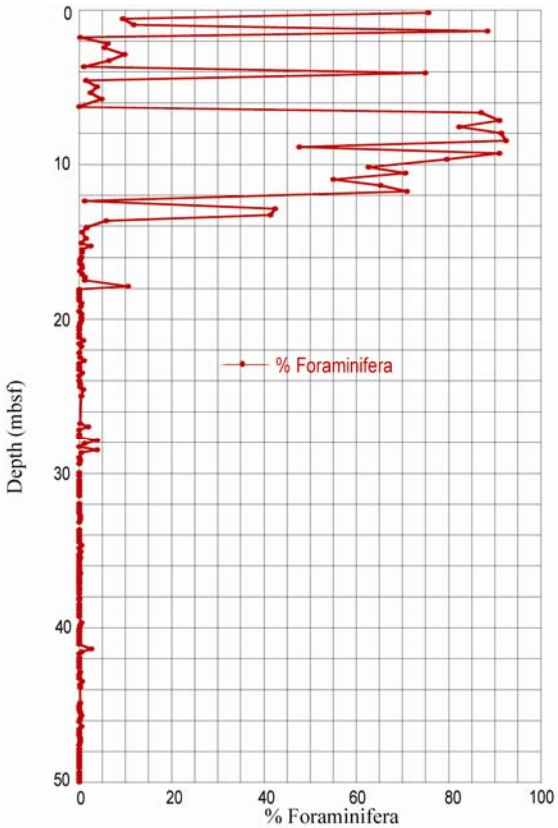

Figure 2. Site 1165 Foraminifera percentages (0-50m).

We argue that the record from 177-1090 shows that the entire interval from MIS 33 to 31 was one warm, long-lasting interglacial, with MIS 32 reduced to a stadial. The evidence from 188-1165 and from CRP-1, as well as that from 177-1090, supports the interpretation of MIS 31 as a significantly warm interval. The degree of similarity of the two proximal records (188-1165 and CRP-1) is good. The presence of some ice-rafting, particularly of garnets, throughout MIS 31-33 at 177-1090, however, means that somewhere in East Antarctica, large continental glaciers still reached the ocean and launched icebergs large enough to reach this distal site. This interpretation is also supported by the intervening spikes of IRD at both proximal sites. Thus, the combined evidence from these three sites indicates that East Antarctica had a dynamic ice margin, but a persistent central ice sheet throughout this time. The length of this entire MIS 31-33 interval from the well-dated 177-1090 record is about 50 kyr, similar to the length of MIS 11 (see Lisiecki and Raymo, 2005).

Summary

Evidence from proximal ODP site 188-1165 and distal subantarctic site 177-1090, combined with results from a previous study at proximal site CRP-1 (Scherer et al., 2002), indicates that MIS 31, or perhaps all of MIS 33-31, was a long warm interglacial, and that East Antarctica had a dynamic ice margin, but a persistent central ice sheet throughout this time. The interval MIS 33-31 lies near the beginning of the mid-Pleistocene climate shift from 40 kyr cycles to 100 kyr cycles, and needs to be studied at different sites in different environments to better characterize this time of transition.

Acknowledgements. This research used samples and/or data provided by the Ocean Drilling Program (ODP). ODP is sponsored by the US National Science Foundation (NSF) and participating countries under management of Joint Oceanographic Institutions (JOI), Inc. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors, and do not necessarily reflect the views of the NSF. We would like to acknowledge our collaborator, Winston Teitler. We would also like to acknowledge the Editor-in-Chief, Alan Cooper, and our co-editor, Dieter Fütterer.

References

Diekmann, B. and G. Kuhn (1999). Provenance and dispersal of glacial-marine surface sediments in the Weddell Sea and adjoining areas, Antarctica: ice-rafting versus current transport. Marine geology 158: 209-231.

Diekmann, B., D. K. Fütterer, H. Grobe, C. D. Hillenbrand, G. Kuhn, K. Michels, R. Petschick, and M. Pirrung (2004). Terrigenous sediment supply in the polar to temperate South Atlantic: Land-ocean links of environmental changes during the Late Quaternary. In: G. Wefer, S. Mulitza and V. Ratmeyer (Eds.) The South Atlantic in the Late Quaternary: Reconstruction of material budgets and current systems. Berlin: Springer-Verlag. Pp. 375-399.

Domack, E. W. (1982). Sedimentology of glacial and glacial marine deposits on the George V-Adelie continental shelf, East Antarctica. Boreas 11: 79-97.

Ehrmann, W. and K. Polozek (1999). The heavy mineral record in the Pliocene to Quaternary sediments of the CIROS-2 drill core, McMurdo Sound, Antarctica. Sedimentary Geology 128: 223-244

Florindo, F., S. Bohaty, P. Erwin, C. Richter, A. Roberts, P. Whalen, and J. Whitehead (2003). Magnetobiostratigraphic chronology and paleoenviromental history of Cenozoic sequences from ODP sites 1165 and 1166, Prydz Bay, Antarctica, Palaeogeography, Palaeoclimatology, Palaeoecology, v. 3118, pp. 1-32.

Froelich, P. N., P. N. Malone, D. A. Hodell, P. F. Ciesielski, D. A. Warnke, F. Westall, E. A. Hailwood, D. C. Nobles, J. Fenner, J. Mienert, C. J. Mwenifumbo, and D. W. Muller. Biogenic opal and carbonate accumulation rates in the subantarctic South Atlantic: The Late Neogene of Meteor Rise Site 704. In: Ciesielski, P.F., Kristoffersen, Y., et al., 1991. Proc. ODP, Sci. Repts., 114: College Station, TX (Ocean Drilling Program). doi:10.2973/odp.proc.sr.114.1991.

Kupp, Gary (2006). Analysis of ice-rafted debris from Ocean Drilling Program Site 1165, Hole B indicates occasional warm-water intrusions during the last five million years. Unpublished Master's thesis, CSU East Bay, Hayward, CA.

Lisiecki, L. E. and M. E. Raymo (2005). A Pliocene-Pleistocene stack of 57 globally distributed benthic $\delta^{18}O$ records, Paleoceanography, 20, PA1003, doi:10.1029/2004PA001071.

Oliver, R. L., P. R. James, and J. B. Jago (Eds.) (1983). Antarctic Earth Science. Cambridge: Cambridge University Press. Pp. 697.

Poore, R. Z. and W. A. Berggren (1975). Late Cenozoic planktonic foraminiferal biostratigraphy and paleoclimatology of Hatton-Rockall Basin: DSDP Site 116. Jl. of foraminiferal research, 5 (4): 270-293.

Scherer, R., S. Bohaty, D. Harwood, A. Roberts, and M. Taviani (2002). Sustained sea-ice free conditions in the Antarctic nearshore zone during Marine Isotope Stage 31 (1.07 ma), GSA Ann. Mtg. Abs. 73-14.

Shipboard Scientific Party (1999). Site 1090. In: Gersonde, R., Hodell, D.A., Blum, P., et al., Proc. ODP, Init. Repts., 177 [Online].

Thomson, M. R. A., J. A. Crame, and J. W. Thomson (Eds.) (1987). Geologic Evolution of Antarctica. Cambridge: Cambridge University Press. Pp. 722.

Tingey, R. J. (1991). The regional geology of Archaean and Proterozoic rocks in Antarctica. In: R. J. Tingey (Ed.) The Geology of Antarctica. Oxford: Clarendon Press. Pp. 1-73.

Warnke, D.A., C. Richter, F. Florindo, J. E. Damuth, W. L. Balsam, K. Strand, M. Ruikka, J. Juntila, K. Theissen, and P. Quilty (2004). Data report: HiRISC (High-Resolution Integrated Stratigraphy Committee) Pliocene-Pleistocene interval, 0-50 mbsf, at ODP Leg 188 Site 1165, Prydz Bay, Antarctica. In: Cooper, A.K., O'Brien, P.E., and Richter, C. (Eds.), Proc. ODP, Sci. Results [Online].