

not show the large and rapid D14C changes previously recorded in a stalagmite from the Bahamas (Beck et al., Science 2001). The D14C values estimated from M1-2 are significantly higher than those estimated from a marine 14C record (foraminifera) from Cariaco Basin for the same time period (Hughen et al. in prep). In the latter, D14C values decrease to near 0 at about 44 ky BP. The most likely reason for this discrepancy are the two different time scales used; the Cariaco Basin is matched to the GISP2 timescale, which is approximately 5000 years younger than indicated by the stalagmite U/Th chronology (Burns et al., Science 2003). When the Cariaco basin record is adjusted to the M1-2 timescale, the D14C values for both datasets are similar.

PP32B-0299 1330h POSTER

Late Quaternary Vegetation History and Paleoclimate of the U.S.A.-Mexico Borderlands Region From Two New Packrat Midden Series

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Two new packrat midden (*Neotoma* spp.) chronologies reveal glacial to interglacial changes in vegetation and climate in the Playas and San Simon Valleys in the U.S.A.-Mexico Borderlands. The Borderlands, where the states of Arizona and New Mexico intersect with each other and the Mexican states of Chihuahua and Sonora, are characterized by several north-west-southeast trending and tilted fault-block ranges separated by closed topographic basins. These basins now contain ephemeral playas, but held pluvial lakes (Animas, Cloverdale, Cochise, Goodright, Hachita, Palomas, Playas) during the Pleistocene and lesser lakes sporadically in the Holocene. Plant macrofossil and pollen assemblages from middens indicate vegetation along pluvial lake margins consisted of open pinyon-juniper communities dominated by *Pinus edulis*, *Juniperus scopulorum*, *Juniperus cf. coahuilensis* and a rich understorey of C4 annuals and grasses. Although both lake and pinyon-juniper expansion across the lowlands have been attributed to greater winter precipitation, the summer-flowering understorey, characteristic of modern desert grassland in the Borderlands, indicates at least moderate summer precipitation during the late glacial. The U.S.A.-Borderlands may have been the only area in the western half of the coterminous United States to "green-up" in July and August, and may have offered seasonal refuge from the dry fire season to the north. Late glacial summer precipitation in the Borderlands may explain the concentration of megafauna and paleoindian sites dating from this period in the area. A transition to a warmer, drier climate is inferred from the extirpation of *Pinus edulis* from the lowlands of the Playas and San Simon Valleys by 10,300 14C yr B.P. The disappearance of pinyon and change to more xeric oak-juniper communities is contemporaneous with other midden sites in the northern Chihuahuan Desert and may have occurred abruptly during the "Clovis-aged Drought" when the water table at nearby Murray Springs dropped to unusually low levels just before 10,900 14C yr B.P. Few middens in our series dated from the middle Holocene (8000 - 4000 14C yr B.P.), a period during which middens are scarce across the Southwest. The gap was previously attributed to hydrologic drought during the middle Holocene and declines in woody perennials and packrat populations. However, beach ridge and lacustrine deposits from Laguna El Fresnal and Laguna Santa Maria indicate wetter than present conditions in the Borderlands during the middle Holocene. The late Holocene is marked by the arrival of Chihuahuan Desert scrub elements and few departures. Desertscrub elements begin to appear by about 4000 14C yr B.P., marking the transition to present-day vegetation. *Laurea tridentata* and *Fouquieria splendens*, two of the dominant desert species present at the sites today; both appear later than in surrounding areas.

PP32B-0300 1330h POSTER

Historic Carbon Isotopic Shifts in Pinyon Pines and Woodland Junipers are Unprecedented During the Quaternary History of These Taxa

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Packrat (*Neotoma*) midden macrofossil records from arid and semiarid western North America provide evidence that pinyon pines and woodland junipers have grown together for at least the past 50,000 radiocarbon years. The midden records show that this association was sustained despite large-scale changes in climate and atmospheric CO₂ concentrations over the past 50 millennia. Reconstruction of physiological parameters, using ¹³C analysis of a select sample of pinyon pine and juniper macrofossils from radiocarbon-dated ancient packrat middens, shows distinct physical responses to these changes despite a offset between the carbon isotopic values of the two genera, with pinyon pines having consistently lower ¹³C values than junipers. Remarkably, analysis of historic (from herbarium sheets) and present-day (from field collections) materials from northern Arizona and the Four-Corners region indicates that the long-term offset between the carbon isotopic values of pinyon pines and woodland junipers has inverted; with the junipers now providing isotopically lighter values than the pinyon pines. This reversal began in the late 1800's to early 1900's and has widened over the past century. The inverted isotopic offsets in the historic period may be due to the unprecedented levels of carbon dioxide and other trace gases in the atmosphere.

PP32C MCC: 3004 Wednesday 1340h

Southern Ocean Climatic Evolution: The Marine Geologic Record II (joint with OS, C, GC)

Presiding: N Exon, Geoscience Australia; D A Warnke, California State University, Hayward

PP32C-01 1340h

A History of Water Mass Circulation in the Paleogene Southern Ocean from Nd Isotopes

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Using fossil fish teeth from ODP site 689 (2080m, Maud Rise) we have generated a 28 Myr record of Nd isotope ratios and concentrations for the early middle Eocene to early Miocene at an average resolution of 250-300 kyr. $\epsilon_{Nd}(T)$ values documented in this time series range from -9.5 to -7.35, and demonstrate a pattern of secular variations that is remarkably similar to benthic foraminiferal $\delta^{13}C$ records from this site. This correlation suggests that secular variations of $\epsilon_{Nd}(T)$ values observed at site 689 are related to changes in ocean circulation and may provide insight into the history of water mass circulation in the Southern Ocean. Early middle Eocene $\epsilon_{Nd}(T)$ values average -9.25 and display little variation compared to younger portions of the record, which illustrate long term oscillations beginning in the late middle Eocene. Starting at 40.8 Ma $\epsilon_{Nd}(T)$ values increase over a 6 Myr interval from -9.4 to -7.35 in a stepwise fashion. Although $\epsilon_{Nd}(T)$ values begin to rise during the late middle Eocene the period of most rapid change occurs in the late Eocene (after 37 Ma). $\epsilon_{Nd}(T)$ values begin to fall in the earliest Oligocene reaching -8.75 at 30 Ma, then rise to -7.75 during the late Oligocene, but fall again to -8.75 by the end of the Oligocene. A hiatus occurs from the latest Oligocene to early Miocene. Following that interval, late early Miocene values average -8.5. Throughout the record the most radiogenic Nd isotopic compositions (~ -7.5), are associated with high $\delta^{13}C$ values (1.2-1.4 ‰), while nonradiogenic Nd isotopic compositions are associated with lower $\delta^{13}C$ values (-2.4 ‰). The subsidence curve constructed for site 689 indicates a middle Eocene paleodepth of 1200-1500 m. A mean $\epsilon_{Nd}(T)$ value of -9.25 during the middle Eocene possibly reflects upward mixing of Warm Saline Deep Water (WSDW) from the Tethys Sea, which has been documented at a deeper site on the Maud Rise (690) on the basis of an oxygen isotopic inversion between the two

sites (Kennett and Stott, 1990). If this interpretation is correct, these data are the first to characterize the Nd isotopic signature of Paleogene WSDW in the Southern Ocean. The rapid shift toward radiogenic $\epsilon_{Nd}(T)$ values at 37 Ma in this time series is coeval with a change in climate-productivity-ventilation patterns at this site (Diester-Haass and Zahn, 1996) based on stable isotopes and benthic foraminiferal accumulation rates. We suggest that the early opening of the Drake Passage at 37 Ma created or strengthened the proto Antarctic Polar Front (pAAPF) south of site 689. Rapidly increasing $\epsilon_{Nd}(T)$ values at this time could represent the Cenozoic precursor to Antarctic Intermediate Water (AAIW) combined with the inflow of radiogenic Pacific Water through the Drake passage. This interpretation is consistent with increasing $\delta^{13}C$ values and the apparent position of the pAAPF based on microfossil assemblages in the Southern Ocean (Cooke et al., 2002). Oligocene oscillations of $\epsilon_{Nd}(T)$ values may be related to the appearance of cold, dense Antarctic Bottom Water (AABW) following first major Antarctic ice growth. The presence of AABW may have caused the depth of the mixing zone between WSDW and AAIW to shoal, resulting in lower $\epsilon_{Nd}(T)$ values at site 689. By the late Oligocene there is evidence that the Drake Passage was open to deep water flow (Scher and Martin, 2003) and it is likely that Circumpolar Deep Water (CPDW) became the bottom water mass at this site.

PP32C-02 1355h

The Paleocene-Eocene Thermal Maximum in the Southern Ocean: Middle Bathyal Constraints from ODP Sites 689 and 738

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The Paleocene-Eocene Thermal Maximum (PETM; 55 Ma) is marked by a 2-3‰_{oo} negative carbon-isotope excursion (CIE), increased temperatures, reduced ocean-atmosphere circulation, and intensified oceanic carbonate dissolution. The most parsimonious mechanism to drive these global patterns was a massive methane hydrate destabilization that released methane to the ocean-atmosphere and elevated pCO₂. PETM reconstructions of the Southern Ocean are based largely on the lower-bathyal ODP Site 690 (South Atlantic Sector; 1,900 m paleodepth). To improve our understanding of this climatically sensitive region, we determined cm-scale variations in bulk-carbonate stable-isotopes and wt% carbonate through the PETM at the lesser known middle-bathyal ODP Sites 689 (Atlantic Sector; 1.1 km paleodepth) and 738 (Indian Sector; 1.3 km paleodepth). Sites 689 and 738 both contain three stratigraphic intervals of relatively stable $\delta^{13}C$ values through the CIE onset; we view these intervals as coeval to similar intervals at Site 690, which Bains et al. (1999) interpret as pauses between distinct methane releases. This congruence suggests that Sites 689 and 738 are as stratigraphically complete as Site 690 through the CIE onset, although much of the subsequent CIE recovery interval is lost in a coring gap at Site 689. Through the CIE recovery interval, Site 738 $\delta^{13}C$ increases by 0.8‰_{oo} over an ~5-cm interval compared to an equivalent increase over a greater than 150-cm interval at Site 690. Rather than a hiatus, we hypothesize that this Site 738 pattern records ocean-atmosphere $\delta^{13}C$ changes at a relatively constant MAR, which is consistent with Farley and Eltgroth's (2003) Site 690 data indicating increased MARs through the CIE recovery interval. These findings imply that (1) the MAR increase was not circum-polar, and (2) carbon cycling/removal from the ocean-atmosphere reservoir was more rapid than previously estimated. Carbonate saturation is a critical parameter in carbon-cycle dynamics; wt% carbonate may provide a first-order estimate of carbonate saturation changes by assuming constant carbonate export production. Sites 689 and 738 wt% carbonate values drop markedly at the CIE onset as predicted by the methane hydrate hypothesis and documented at deeper pelagic PETM sections. Unlike deeper records, Site 689 and 738 wt% carbonate values then transiently increase, stabilize, and drop again at the third and final $\delta^{13}C$ step-decrease during the CIE. Following this second drop, wt% carbonate values at both middle-bathyal sites rapidly increase to pre-CIE values within the CIE minimum, while values at the lower-bathyal Site 690 gradually increase through the CIE recovery interval. We hypothesize that these patterns reflect carbonate saturation profile changes in response to pulsed pCO₂ increases from distinct methane releases. Specifically, given that wt% carbonate values remain suppressed at Site 690, we interpret the "double-dip" pattern at Sites 689 and 738

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as two distinct lysocline shoalings to at least middle-bathyal depths. If true, current PETM models may underestimate the magnitude of carbonate undersaturation, and thereby the methane volume released, during the PETM.

PP32C-03 1410h INVITED

Glacioeustatic Changes in the Early and Middle Eocene (51-42 Ma) Greenhouse World Based on Shallow-Water Stratigraphy from ODP Leg 189 Site 1171 and Oxygen Isotope Records

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Sequence boundary ages identified in shallow-water sediments obtained from ODP Leg 189 Site 1171 compare well with other stratigraphic records (New Jersey USA and Northwest Europe) and oxygen isotope increases, indicating that significant global sea-level changes (>10 m) occurred during the late early to middle Eocene (51-42 Ma). Six sequence boundaries were identified and dated using lithology, water-depth changes, age control (bio- and magnetostratigraphy), and CaCO₃ content and physical properties (e.g., photometricity). Benthic foraminiferal biofacies and planktonic/benthic foraminiferal ratios were used to estimate water-depth changes. Glauconitic clays and silts occur above the basal surface with increasing water depths indicated by foraminiferal studies (transgressive systems tracts). This is overlain by decreasing glauconite silt and maximum nanofossil percents, and an increase in CaCO₃ content (condensed section), which is followed by a decrease in CaCO₃ content as clays then silts increase up section as water depths decreased (highstand systems tracts). A comparison of sequence boundary ages from Site 1171 (50.9, 49.2, 48.5, 47.8, 47.1, 44.5 and 42.6 Ma) to oxygen isotope increases shows a good correlation. Additionally, sequence boundaries identified in Eocene studies from Leg 150X onshore boreholes (New Jersey, USA) and NW Europe compare well with the timing of sequence boundary development at Site 1171. The synchronous nature of sequence boundary development from globally distal sites and oxygen isotope increases indicates a global control. The only mechanism that can explain these large rapid changes is glacioeustasy. This is supported by modeling studies (Deconto and Pollard, 2003) and CO₂ estimates (Pearson and Palmer, 2000) showing that the first time CO₂ levels decreased below a threshold that would support the development of an ice sheet in Antarctica was at ~51 Ma. Estimates of sea-level amplitudes range from 20±7 m for the early Eocene (51-49 Ma) and ~25±8 m to ~45±14 m for the middle Eocene (48-42 Ma) using constraints established for the Oligocene oxygen isotope records.

PP32C-04 1425h

Productivity Patterns at the Eocene-Oligocene Transition: Beginning of the High Productivity Area in the Southern Ocean

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At the end of Eocene extensive plate tectonic events affected a reorganization of the southern world's oceans. The opening of the Tasman and Drake passages enabled a first establishment of an initial Antarctic Circumpolar Current (ACC) with a frontal system. Cooling and glaciation of the Antarctic was reflected in an

enhanced latitudinal temperature and density gradient, and a stronger mixing of the high latitude vertical water column. The beginning of the ACC enhanced an austral upwelling system. Several DSDP/ODP sites of the Southern Ocean and the lower latitudes have been investigated to recover long term productivity patterns from the middle Eocene to the late Oligocene. A multi-proxy approach including biological, sedimentological and geochemical proxies is chosen. The aim of the study is a reconstruction of the productivity in southern high latitudes in comparison to lower latitudes. Changes in paleoproductivity at the Eocene-Oligocene transition took mainly place in the southern high latitudes. Here we note a change to higher paleoproductivity starting in the latest Eocene or at the Eocene-Oligocene transition. In the Weddell Sea the benthic foraminifera fauna indicate an increase in seasonality. In equatorial oceans, we have no indications for a shift to higher paleoproductivity at the Eocene-Oligocene transition. On the contrary a few sites show a shift to lower productivity at or after the transition. Sites between 40 and 50 degrees paleolatitudes near Australia and New Zealand show changes to higher paleoproductivity, but changes at the northern site are not highly significant. Changes in paleoproductivity were forced by the reconstruction of ocean circulation. The stronger mixing of the water column, the beginning upwelling and the enhanced bottom water production effected an increase of southern high latitude productivity. Oceanographic changes in lower latitudes were less dramatic. Surface water temperatures were nearly constant while the bottom waters cooled. Vertical stability of the water column increased and therefore changes in paleoproductivity were either negligible, or negative. The boundary between the areas may be at 30-40 degrees S.

PP32C-05 1440h

Estimates of Middle Miocene Ice Volume and Temperature Change from Southern Ocean Benthic Foraminiferal Mg/Ca and $\delta^{18}O$

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The middle Miocene global climate transition (16.8 to 12 Ma) represents a critical step in Cenozoic climate evolution, separating warmer early from cooler late Neogene climates. Between 14.0 and 13.8 Ma, Earth's climate cooled abruptly, as manifested by the globally recognized $\sim 1^{\circ}/_{\infty}$ $\delta^{18}O$ increase. This increase is interpreted to reflect some combination of global cooling and increased Antarctic ice volume. Given limitations of $\delta^{18}O$ as a temperature proxy, debate exists as to the relative proportions of ice growth and temperature change encompassed in the middle Miocene $\delta^{18}O$ increase. Foraminiferal Mg/Ca ratios provide an independent geochemical temperature proxy that should assist with separating temperature and ice volume signals contained in middle Miocene $\delta^{18}O$ records. Such separation is fundamental to improved understanding of mechanisms forcing this major Cenozoic climate reorganization. Previous studies of benthic foraminiferal Mg/Ca at relatively low resolution across the middle Miocene $\delta^{18}O$ increase indicate that global deep waters cooled $\sim 2-3^{\circ}C$ and Antarctic ice volume increased by $\sim 30\%$. Thus, benthic foraminiferal Mg/Ca studies conducted at moderate to high resolution between 16.8 and 12 Ma may provide insight into feedbacks involved in Antarctic cryosphere expansion and global climate evolution. Studies conducted in the high Southern latitudes may also provide critical information concerning changes in meridional heat flux to the Southern Ocean. We have generated a benthic foraminiferal (*C. mundulus*) Mg/Ca record from the South Tasman Rise (STR) in the Pacific sector of the Southern Ocean (ODP Site 1171: paleolatitude-55°S, paleowater depth- 1600m) to assess the potential for using Mg-paleothermometry to reconstruct middle Miocene deep water temperatures. For the Mg/Ca temperature proxy to be successful on pre-Quaternary timescales, several factors are crucial: very well preserved foraminiferal CaCO₃ and the presence of fossil species for which there are modern analogues with Mg/Ca temperature calibrations. At Site 1171, down core variations in *C. mundulus* Mg/Ca are similar to those observed in the paired $\delta^{18}O$ record. Both benthic foraminiferal Mg/Ca and $\delta^{18}O$ records exhibit significant variability during the middle Miocene Climatic Optimum (MCO; 16.5-14.0 Ma) and less after the major $\delta^{18}O$ increase (13.7-12.5 Ma). We employ the *Cibicides* sp. Mg/Ca-temperature calibration of Martin et al (2002) to estimate STR bottom water temperatures ($\sim 1600m$) from the Mg/Ca record. Paleotemperatures suggest that bottom waters fluctuated between 5 and 8°C during the MCO. Across the middle Miocene $\delta^{18}O$ increase (1.2°/∞; 14.0-13.7 Ma) STR

bottom waters cooled $\sim 1.5^{\circ}C$, from 6.5 to 5°C. Calculations of seawater $\delta^{18}O$ ($\delta^{18}O_{sw}$) from *C. mundulus* $\delta^{18}O$ and Mg/Ca-derived temperatures suggest an average $\delta^{18}O_{sw}$ increase of $\sim 0.5^{\circ}/_{\infty}$ between 14 and 13.8 Ma. This preliminary estimate suggests a major expansion of the Antarctic cryosphere was encompassed in the middle Miocene $\delta^{18}O$ increase. While the exact phasing of ice volume and temperature change has yet to be determined, our results suggest that the reorganization of heat and moisture supply to the high southern latitudes played a major role in forcing the middle Miocene climate reorganization.

PP32C-06 1455h

Mid Miocene Paleocyanography at Western Subtropical Pacific Site 588: Results From Paired Mg/Ca and Oxygen Isotopes of Benthic Foraminifera

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The middle-Miocene expansion of the East Antarctic Ice Sheet (16-14 Ma) is well documented in records of foraminiferal $\delta^{18}O$ values. Here, this time interval is revisited with a study using Mg/Ca ratios paired with $\delta^{18}O$ values from benthic foraminifera from subtropical western Pacific Site 588A; this approach allows components of seawater $\delta^{18}O$ ($\delta^{18}O_{sw}$) fluctuation and deep water temperature change to be calculated allowing for more judicious assessment of $\delta^{18}O_{sw}$ values, and inferences about ice volume changes. During the interval of mid Miocene ice sheet expansion, our study reveals a longer-term trend of increasing Mg/Ca ratios between 16-14.5 Ma, followed by a rapid recession to minimum ratios between 14.5 and 14 Ma. After this relatively sharp decline, Mg/Ca ratios remain stable until 12 Ma, whereupon they begin to increase again. Our Mg/Ca data illuminate a $\sim 2^{\circ}C$ warming trend during the majority of the mid Miocene epoch of ice growth (16-14.5 Ma). The warming is followed by more rapid cooling by the same amount in the bottom water regime at this site. These temperature changes could not have been discerned from the $\delta^{18}O$ record alone, which is generally interpreted to reflect, in part, a bottom water cooling during this time (e.g., Flower and Kennett, 1993). The mid Miocene warming trend apparent in the Mg/Ca data implies that either the amount of ice growth on Antarctica has been underestimated or that there is a regional water-mass effect on the $\delta^{18}O_{sw}$ that is being masked in the benthic foraminiferal $\delta^{18}O$ record. Forthcoming work focusing on this particular interval of time will help to resolve regional versus global changes in the $\delta^{18}O_{sw}$; Site 588 may be sensitive to variations in regional intermediate water masses perhaps linked to changes in the subtropical front or intermediate water masses intruding from the Indian Ocean.

PP32C-07 1510h

Testing the Phosphorus Paleoproductivity Proxy Across a Productivity and Sedimentology Gradient in the Southern Ocean

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Because of its role in biological productivity and its tendency to be preserved in sediments, records of phosphorus (P) burial (reactive P concentrations and accumulation, P/Ti ratios) have been used as proxies of export production. Unlike organic C, P is redistributed into different sedimentary pools during diagenesis and much of the sedimentary P flux to the seafloor may actually be retained in sediments in certain depositional environments. At three sites in the southeastern Atlantic Ocean and one site off the coast of Tasmania, we have systematically compared detailed P geochemistry with P/Ti ratios from bulk sediment geochemistry. We have verified that in these settings P/Ti ratios reflect the reactive P component, which is indicative of P that was once bioactive. However, based on quantification

of opal intrinsic P, we have discovered that the commonly used SedEx reaction scheme does not liberate organic P found within opal. P/Ti ratios are a useful proxy because the ratios are resistant to the effects of dissolution and potentially sediment focusing, and they are not influenced by sediment type. Using down-core P/Ti ratios as a proxy for export production in the Southern Ocean is particularly useful because of the variability in sediment type and the paucity of carbonate at some sites. Surprisingly, maxima in P/Ti ratios over the last 1 Ma tend to occur at all sites at glacial terminations, regardless of position relative to important frontal zones. These findings are in contrast to other work suggesting that productivity north and south of the Antarctic Polar Front is opposite on glacial/interglacial time scales. We suggest that the increases in export production at terminations are related to changes in surface ocean circulation, nutrient delivery, and sea-ice interactions.

PP32C-08 1525h

A Comparison of West Antarctic and East Antarctic Response to High-Frequency Climate Change During the Holocene

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Based on results from Ocean Drilling Project Site 1098 in the Palmer Deep, we have a highly resolved record of West Antarctic Holocene climate evolution as traced by terrigenous provenance, terrigenous accumulation, nutrient utilization, and surface and export production. Biogenic opal, Corg, and P accumulation rates all increase ~2000 years B.P., reaching a maximum ~5500 to 7000 years B.P. Opal concentrations are less variable, yet indicate that biosiliceous production increased during the mid-Holocene. 13C/12C in bulk organic matter are high (with values similar to ice-edge bloom products) ~4500 to 7000 years B.P., signifying stronger diatom bloom events during the mid-Holocene. Prior to ~3000 years B.P., $\delta^{15}N$ was lower for ~2000 years, resulting from less complete utilization of photic zone nitrate. The Al/Ti ratio indicates a change in terrigenous composition ~3500 years B.P. indicating a change in source, weathering style, and/or intensity. To date, there are few comparable records from the East Antarctic Margin. Here, we present preliminary results from a 25-meter core recovered from the MacRobertson shelf of East Antarctica. These sediments are laminated diatomaceous muds comprising a two-component system of biogenic opal (20-50%) and terrigenous material, very similar in character to the Palmer Deep sediments. Our current age model is based on a total of 10 AMS C14 dates. Opal concentrations at this site do not vary considerably through the middle to late Holocene. However, during the early Holocene there appear to be large and frequent changes in opal. This interval is not as prolonged as that shown in the Palmer Deep, but it does indicate that opal concentrations in both East Antarctica and West Antarctica behaved somewhat concurrently during the early Holocene. Whether this is the result of a similar mechanism remains to be determined.

PP32D MCC: 3004 Wednesday 1600h

Evolution of the Antarctic Climate System: Modeling and Observation II (joint with A, OS, C, GC)

Presiding: A J Payne, University of Bristol; R DeConto, University of Massachusetts

PP32D-01 1600h INVITED

Modeling of the Early Cenozoic History of the Antarctic Ice Sheet

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Numerical modeling of the initial growth of the Antarctic Ice Sheet in the Paleogene using coupled climate-ice sheet-sediment components is reviewed. In this approach, a Global Climate Model (GCM) is asynchronously coupled to a dynamical 3-D Antarctic ice sheet-sediment model, to test the sensitivity of the coupled system to evolving Cenozoic boundary conditions, including paleogeography, atmospheric carbon dioxide, changing orbital parameters, and changes in ocean heat transport. The asynchronous coupling scheme enables long (millions of years) integrations, simulating ice sheet inception around the Eocene-Oligocene boundary, and subsequent ice sheet variability over orbital timescales. It is found that declining Cenozoic atmospheric carbon dioxide and relatively high frequency orbital forcing trigger ice-sheet height-mass balance feedbacks that produce a sudden transition, from relatively small land-based ice caps localized on high topography, to a single large East Antarctic ice sheet comparable to today, similar to observed events around the Eocene-Oligocene boundary. Changes in ocean heat transport, like those assumed to have occurred in response to the opening of Southern Ocean gateways (Tasmanian and Drake Passages) are shown to have a smaller effect than previously expected. The consequences of hysteresis due to the height-mass balance feedback, the relation to albedo feedback and the stability of the East Antarctic Ice Sheet are discussed. Predicted spatial and temporal patterns of coastal sediment discharge are compared with observed distributions and core records of offshore Cenozoic sedimentary deposits.

PP32D-02 1615h

A Different Look at Gateways - Australian/Antarctic and Drake Passage

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A deepwater passageway between Australia and East Antarctica is considered important to the development of the Cenozoic Antarctic ice sheet. Identification of magnetic anomalies formed at the Australia-Antarctic ridge makes relative motion of the two continental masses with respect to one another, easy to reconstruct. Unfortunately, exact knowledge of the extent of the true continental margin of East Antarctica is not known. An excellent match of the continental shelf break of East Antarctica with its conjugate section of the southern Australian margin from 124°E to 133°E produces an unacceptable overlap of the continental margin of the Coates coast region of Antarctica with the Kangaroo Island section of the southern Australian margin. If the unacceptable overlap is assumed to have originated as post-breakup deposition of glacially-derived sediments deposited on older ocean crust off the outflow region of the Wilkes Land Basin, then the time of the development of a deep seaway between Australia and East Antarctica pre-dates the Eocene-Oligocene boundary (33.5 Ma) by perhaps as much as 7 to 8 million years. Another seaway between Tasmania and the South Tasman Rise may be even older but would not necessarily have been initially the medium depth seaway that it is presently. The South Tasman Rise would have been over a fixed Balleny Islands hotspot during much of the Eocene, resulting in

uplift. It passed over the active hotspot and was no longer above it by about 35 Ma which may have resulted in the rapid subsidence seen in the ODP 189 holes at the Eocene-Oligocene boundary. Only if the assumed, continental margin off the Wilkes Land Basin is older than Oligocene and the South Tasman Saddle was above 1000 meters during the Eocene would the opening of a seaway between Australia and East Antarctica have been established as late as 33.5 Ma or at the Eocene-Oligocene boundary.

PP32D-03 1630h

Estimates of Oligocene Sea-Level Amplitudes and Ice-Volume Changes at Milankovitch Time Scales

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Sea-level amplitudes and ice-volume changes were determined for the Oligocene at the obliquity and eccentricity time scales (41 and ~400 ky) using high-resolution deep-sea oxygen isotope records and sea level to oxygen isotope calibrations established for Southern Ocean ODP Site 689, South Atlantic DSDP Site 522 and western tropical Atlantic ODP Site 929. Amplitudes of apparent sea-level (ASL, defined as eustasy plus the effects of water loading on the crust) for the upper Oligocene at the ~400 ky time scale range between 25 and 30 m, and at the obliquity time scale, between 10 and 20 m. High frequency ASL changes for the lower and "mid"-Oligocene are less certain because the resolution of the records from Sites 522 and 689 is lower. At the 400 ky time scale, available evidence at these sites suggests that ASL varied by as much as ~35 m. At the obliquity time scale, sufficient resolution is available only at Site 522, where ASL changes are estimated as between 15 and 20 m. Estimates of equivalent ice-volume changes in Antarctica at the million-year time scale suggest expansion to near the present-day volumes, collapsing in some cases to less than 15% of today's value. At the 400 ky time scale, ice volume varied by up to ~50% of the present-day figure. At the obliquity time scale, it ranged from ~25 to 35% of the contemporary volume. These estimates of ice volume and ASL changes were obtained by applying previously developed oxygen isotope to sea-level calibrations (Pekar et al., 2002) to the isotopic records. Correlation is good to excellent ($r^2 = 0.726-0.960$), suggesting that although benthic foraminiferal records are known to include a bottom-water temperature signal, temperature changes generally vary linearly with changes in ice volume. A minimum calibration for the Oligocene of $0.13\text{‰}/\text{‰}$ per 10 m ASL change ($r^2 = 0.726$) was determined from Site 689. This calibration may contain a small temperature signal, which would result in a calibration of $0.10\text{‰}/\text{‰}$ per 10 m ASL change. An oxygen isotope to ASL calibration of $0.32\text{‰}/\text{‰}$ per 10 m ASL was determined for oxygen isotope event M11 (23.8 Ma) at Site 929. A calibration of $0.22\text{‰}/\text{‰}$ per 10 m ASL ($r^2 = 0.960$) was obtained for the lower Oligocene at Site 522, spanning oxygen isotope events Oi1 (33.5 Ma), Oi1a (32.8 Ma), and Oi1b (31.7 Ma).

PP32D-04 1645h

Evolution of the Antarctic climate system: a synthesis of land and offshore records from southern Victoria Land

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We compare the results of geomorphological analysis of a 260-km sector of the Transantarctic Mountains in southern Victoria Land with offshore records of sedimentation in adjacent offshore cores (Cape Roberts and CIROS-1) and seismic results from wider areas of the Ross Sea shelf. Interpretation of the independent records shows good agreement and allows the following synthesis of the climatic evolution of this part of Antarctica. Denudation since rifting at ~55 Ma has