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 downcore 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., δ15N 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 icesheet. 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 $0.13^o/_{oo}$ 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 $0.10\ ^o/_{oo}$ per 10 m ASL change. An oxygen isotope to ASL calibration of $0.32^o/_{oo}$ per 10 m ASL was determined for oxygen isotope event Mi1 (23.8 Ma) at Site 929. A calibration of $0.22^o/_{oo}$ 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

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removed a wedge of rock 4-7 km thick at the coast, declining inland to ∼ 1 km. Most denudation occurred in the Eocene under temperate climatic conditions from fluvial planation of the mountains and incision of river valleys near the coast, with sedimentation occurring offshore. A subsequent pulse of denudation, most rapid at 34-31 Ma, and declining until ∼17 Ma, coincided with further crustal extension and a change from cool temperate to polar climate. During this interval, local warm-based glaciers first built up on mountain massifs and experienced cyclic periods of expansion and retreat. Glacier temperatures, meltwater, vegetation and chemical weathering progressively decreased and there was a cold polar climate before inundation by a full Antarctic ice sheet. This latter event occurred between 14.8 and 13.6 Ma and the ice sheet was sufficiently thick to override the Transantarctic Mountains and extend to the edge of the continental shelf. Following retreat offshore and thinning of the maximum ice sheet, the last ∼ 13.6 Ma have seen little landscape or climatic change under a hyperarid polar climate. Glacier fluctuations in the last ∼ 13 Ma owe their variability to internal glacier dynamics or changes in relative sea level.

PP32D-05 1700h

Pliocene Warming, Contribution of Atmosphere, Oceans and Cryosphere

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The relative role of the atmosphere, oceans and cryosphere in contributing towards middle Pliocene warmth (ca. 3 Ma BP) is investigated using the HadCM3 coupled ocean-atmosphere general circulation model (GCM). The model was initialised with boundary conditions from the USGS PRISM2 data set and a Pliocene atmospheric CO_2 level of 400 ppmv and run for 300 simulated years. The simulation resulted in a global surface temperature warming of 3°C compared to present-day. In contrast to earlier modelling experiments for the Pliocene, surface temperatures warmed in most areas including the tropics (1 to 5°C). Compared with present-day, the model predicts a general pattern of ocean warming (1 to 5°C) in both hemispheres to a depth of 2000 m, after which no significant differences are noted. Sea ice coverage is massively reduced (up to 90%). The flow of the Gulf Stream/North Atlantic Drift is up to 100 mms^{-1} greater in the Pliocene case. Analysis of the model-predicted meridional stream function suggests a global pattern of reduced outflow of Antarctic bottom water (AABW; up to 5 Sv), a shallower depth for North Atlantic Deep Water formation and weaker thermohaline circulation (3 Sv). The decrease in AABW occurs mainly in the Pacific rather than Atlantic Ocean. Model diagnostics for heat transports indicate that neither the oceans nor the atmosphere are transporting significantly more heat in the Pliocene scenario. Rather, these results indicate that the major contributing mechanism to global Pliocene warmth was the reduced extent of high latitude terrestrial ice sheets (50% reduction on Greenland, 33% reduction on Antarctica) and sea ice cover resulting in a strong ice-albedo feedback. These results highlight the need for further studies designed to improve our knowledge regarding Pliocene terrestrial ice configurations before further coupled ocean-atmosphere modelling experiments are conducted.

PP32D-06 1715h INVITED

Internal ice sheet layer distortions in interior West Antarctica

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Upstream of Ice Stream D in West Antarctica, ice penetrating radio-echo sounding (RES) data reveal a major and distinctive englacial structure, where internal layers are located at an ice depth up to 1 km deeper than their surrounding elevations. The linear englacial fold' that is formed by the layer pattern can be traced well across 10 km, and less well for much longer. The long-axis of the structure is located at a 30 degree angle to the current ice flow direction. We examine a number of ways in which this layer pattern may have formed and show that it is more easily explained if the ice flow direction were along the line of the fold's axis than under the current glaciological setting. Using ice flow modelling, we interpret the englacial feature to have been caused by ice-sheet downdraw and/or basal melting at a time when the ice flow direction was different to today. Current ice dynamics may account for subsequent deformation of the internal layer patterns in the last few thousand years.

PP32D-07 1730h INVITED

Calving Bay Reentrants During the Late Pleistocene to Holocene Retreat of the Antarctic Ice Sheet: Sedimentologic and Geomorphologic Evidence

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Swath bathymetric surveys of major paleoice stream troughs from both the West and East Antarctic continental shelf are coupled with Jumbo Piston and ODP (Sites 1098 & 1099) sediment cores to develop a temporal and spatial model for deglaciation. Deglaciation is demonstrated to have post dated MWP-1a by at least 1000 years for several ice stream systems including those off the Antarctic Peninsula. The nature of sediment lithofacies at the transition from grounded ice to glacial marine conditions demonstrates a process of sediment focusing where by marine varves are deposited in front of calving ice fronts for several hundred years following deglaciation. The marine varves are characterized by alternating couplets of diatom ooze and siliciclastic silty, sandy clays. Sediment core sites that demonstrate this ubiquitous lithofacies are located within inner shelf basins (troughs) that mark the landward juncture of major ice drainage off the continent and initiation of ice streaming out across the continental shelves. Seven such systems are detailed within this study including the Palmer Deep, Mertz Trough, Mertz-Ninnis Trough, Svenner Channel, Nielsen Basin, and Iceberg Alley. Swath bathymetry indicates that ice receded via backstepping of grounding lines within the main axis of the ice stream troughs (i.e. Mertz Trough). This configuration of grounding lines must have led to calving bay reentrants that extended several tens to hundreds of kilometers into the interior of surrounding ice sheets. The focusing of sedimentation within the inner portions of these reentrants is explained by the concentration of iceberg rafting and the restriction of estuarine circulation and associated productivity within the calving bays. The existence of such embayed drainage for several hundred years implies that significant drawdown of ice sheet elevations could have been accommodated by the streaming and calving of glacial ice at the heads of these embayments. The timing of the recessional events is constrained by over 200 radiocarbon dates that fix recession to around 11 ka BP, a thousand years after MWP-1a but roughly coincident with the well known Younger Dryas event.

PP32D-08 1745h

Recent History of the NW Corner of the Ross Ice Shelf, Antarctica, from Sediment Cores

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Cores of sea floor sediments beneath the Ross Ice Shelf behind Ross Island contain a record of sub-ice shelf sedimentation over the last 20,000 years. The sediments have been accumulating in a 900-m-deep depression resulting from the loading of Erebus volcano, and are being deposited from relatively slow (5-10 cm/sec) currents whose average flow direction is eastward (from McMurdo Sound toward the central Ross Sea). Cores from the two sites were both 60 cm long, but significantly different in character. The core from site 1 was taken about 5 km east of the shelf edge where the ice is 70 m thick. It is an unconsolidated pebbly sandy mud from 62 to 34 cm below the sea floor, where it changes over a cm to a soft fine sandy mud that dominates the rest of the core. Samples yielded uncorrected AMS bulk organic carbon ages of 24,550 years at 34 cm, 18,080 years at 21 cm and 4343 years at 1 cm, indicating an average sedimentation rate of 0.03 mm/year. The changes in sedimentary facies are taken to record a shift of the grounding line landward followed by establishment of the present open circulation that continued to the present day. The low shear strength throughout the core shows that the ice shelf was not grounded, even at the height of the Last Glacial Maximum. The core from site 2, which lies 12 km east of the shelf edge beneath 140 m of ice, is entirely a soft terrigenous sandy mud with a higher diatom content than the upper part of site 1, but similar in other respects. It yielded ages from 12,797 years at 59 cm, 6562 years at 29 cm and 2701 years at 2 cm, indicating a higher sedimentation rate (0.06 mm/year), and records relatively constant conditions throughout that time. The facies and chronology suggest that the Ross Ice Shelf front has not retreated significantly from its present position during the Holocene. The cores also indicate the potential value for recovering a history for the Ross Ice Shelf back to Pliocene times through the proposed coring of Windless Bight by the ANDRILL consortium to 1000 m below the sea floor.

URL: http://andrill-server.unl.edu/

PP41A MCC: 3004 Thursday 0800h

Rapid Climate Change During the Holocene and Last Glacial I *(joint with A, OS, C, GC)*

Presiding: **C Morrill,** National Center for Atmospheric Research**; J Chiang,** University of California, Berkeley

PP41A-01 0800h

A high-resolution 25 ka sea-surface temperature record from the NW Atlantic Ocean: foraminiferal Mg/Ca compared to δ^{18}O and sediment parameters.

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We have measured the Mg/Ca ratio in planktonic foraminifera *Neogloboquadrina pachyderma*(sinistral), *Globigerina bulloides* and *Globigerina ruber* (white variety) in two North Atlantic cores. A modified version of the Boyle and Keigwin (1985/6) cleaning technique was employed (removing cemented clays, metal oxides and organic matter). Mg/Ca ratios within the Heinrich layers in the Labrador Sea (Hu90013-29; 58.2361°N, 56.4576°W; 2918m) vary from 0.30 to 1.25 mmol/mol measured mainly in the *N. pachyderma* (s.). In core CHN82-20PC (43.3°N, 29.5°W; 3020 m) in the open North Atlantic Mg/Ca ranges from 0.67 to 1.20