Simultaneously, heat was building up in the tropics as less heat was distributed northward. As soon as the THC recovered in the North Atlantic, the heat that was built up in the tropics during H1, could be advected northward, leading to a series of rapid warmings in a flickering fashion in the North Atlantic region. Simultaneously with the warming at high latitudes, the tropics and the Southern Hemisphere experienced a cooling (Antarctic Cold Reversal-ACR) due to the heat gained in the Southern Hemisphere during the H1 is distributed northward. All known forcing mechanisms should at this point drive the climate globally into an interglacial mode. However, several times the climate at high northern latitude is punctuated by several cold periods, like the Younger Dryas cold period.

PP11B-0316 0830h POSTER

The 19-ka Meltwater Pulse

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Sea level records from Bonaparte Gulf suggest that the start of the deglacial sea-level rise began with an abrupt 10-15 m sea-level rise occurring over less than 500 years. We present evidence from the Irish Sea coast that seems to corroborate this event. We suggest that warming that began 21 ka led to the abrupt collapse of a part of the Northern Hemisphere ice sheet system at 19 ka, perhaps through destabilizing ice shelves. A large increase in atmospheric radiocarbon, the start of Oldest Dryas cooling in the GISP2 record, and responses in the Cariaco Basin and Lake Malawi, Africa, are consistent with this freshwater pulse being released into the North Atlantic at this time (19 ka), disrupting North Atlantic deep water formation. Subsequent cooling and reduced Atlantic thermohaline circulation throughout the Oldest Dryas was sustained by Heinrich event 1 at 17.7 ka. During this interval, global sea level rise slowed to an imperceptible rate, which could be explained by the widespread Northern Hemisphere cooling. The large reduction in NADW, combined with an increase in atmospheric greenhouse gases, caused warming in parts of the Southern Hemisphere, including regions of Antarctica. We suggest that the next major increase in sea level rise, MWP-1A, which originated largely from Antarctica, may be the result of the prolonged warming around Antarctica that destabilized fringing ice shelves. We also suggest that MWP-1A freshwater forcing caused a major reduction in Antarctic deep water formation, which in turn caused a major increase in the Atlantic THC and associated warming of the Bolling. Subsequent sea level rise continued through the remainder of the deglaciation as Northern Hemisphere ice sheets retreated in response to the warming.

PP11B-0317 0830h POSTER

Termination II Climate Records From Santa Barbara Basin, California Support Solar Forcing Mechanism and Milankovitch Theory

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Several climate records of the penultimate deglaciation exhibit change well before orbitally-related insolation variations thought to pace the Pleistocene ice ages. A few authors have attributed these changes to the glacial termination and suggest that this evidence of early deglaciation poses a challenge to Milankovitch theory. Additionally, millennial- to centennial-scale and glacial-interglacial climate oscillations have recently been linked to proxies of solar luminosity suggesting that solar forcing may be an important driver of climate change on both of these time scales.

High-resolution (50 yr) planktonic and benthic foraminiferal oxygen and carbon isotope records from Santa Barbara Basin reveal pronounced millennial- and centennial-scale climate variability during MIS 6 and Termination II. This includes greater variability during MIS 6 than during MIS 2, a stadial-interstadial millennial-scale climate oscillation immediately preceding Termination II, and a Younger Dryas-like climate oscillation during the penultimate deglaciation. The suite of millennial and centennial periodicities found in the Santa Barbara Basin climate records are similar to those found in cosmogenic nuclide production rates, North Atlantic drift ice, and many other climate records during the Holocene. Similarities in structure and timing of the Santa Barbara Basin and Vostok deglacial climate records are present.

The remarkable correspondence between the different Santa Barbara Basin climate records on millennial time scales suggests a tight coupling of climate system components as occurred during MIS 3. The rapid shifts in the California Current system were probably related to fluctuations in the atmospheric tele-connections of the California margin region to other areas of the Earth rather than a regional response to gradual changes in Laurentide ice sheet size. The specific centennial and millennial-scale periodicities and the greater climate variability during MIS 6 than during MIS 2 suggest that a solar forcing mechanism may have been important on both time scales. The records of early deglaciation during Termination II can be explained by the major interstadial and other centennial- to millennial-scale variability that immediately preceded the deglaciation and therefore do not pose a threat to Milankovitch theory. Finally, the similarities in the Santa Barbara Basin and Vostok deglacial climate records provide evidence for globally synchronous or near synchronous millennial-scale climate change during this time interval.

PP11B-0318 0830h POSTER

Timing and Pattern of the Abrupt Development of the Subarctic North Pacific Stratification During the Late Pliocene: Implications for Atmospheric CO_2 and the Onset of Major Northern Hemisphere Glaciation.

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The surface waters of the modern Pacific are isolated form the nutrient-rich waters below by a steep vertical gradient of salinity (halocline), a feature that is a dominant control on upper-ocean stratification in polar environments. The stratification of polar surface waters influences the exchange of CO_2 between ocean and atmosphere. Here we report high-resolution (3 cm sample spacing) biogenic opal accumulation rates and nitrogen-isotope data from sediments from ODP sites 882 (NW Pacific) and 887 (NE Pacific), which indicate that the subarctic halocline developed in less than 10 ka over the entire North Pacific Ocean. The density contrast would have prevented large-scale upwelling of nutrient-rich intermediate water masses. The photic zone was therefore partially isolated from its nutrient reservoir. This would have reduced biological productivity and subsequent organic matter export as suggested by a dramatic drop in biogenic opal accumulation rate. However, increased nutrient utilization indicated by a 2.5 $^{o}/_{oo}$ positive shift in δ^{15}N values would have led to an increased efficiency of the biological pump. After 2.73 Ma, this more complete utilization of the major nutrients across the North Pacific removed or significantly reduced one important subpolar oceanic leak of CO_2 back into the atmosphere, thereby lowering pCO_2. We infer that this coupled mechanism acted as a positive feedback on the gradual cooling trend between 3.2 and 2.73 Ma by decreasing atmospheric CO_2 concentration and it may have provided a critical threshold to keep the climate system cooler since 2.73 Ma, when major glaciation in the Northern Hemisphere commenced.

PP11C MCC: 130 Monday 0830h

Southern Ocean Climatic Evolution: The Marine Geologic Record I *(joint with A, GP, OS, GC)*

Presiding: **N Exon,** Geoscience Australia**; G Filippelli,** Indiana University/Purdue University, Indianapolis

PP11C-01 0830h

Paleogene tectonics and the sediments deposited as Australia and Antarctica separated: ODP Leg 189

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The break-up of Gondwana led to major changes in global climate that were addressed by ODP Leg 189 by drilling on foundered continental blocks off Tasmania. The leg cored marine sediments spanning the entire Cenozoic, and detailed sedimentological changes as Australia moved north from Antarctica. Despite general similarities, the sedimentary history at each site differs in detail, depending on tectonic history and depositional setting. Maastrichtian (70 Ma) to Eocene cores were dated by dinocysts and siliceous microplankton, and younger sequences by calcareous microplankton. Earlier DSDP cores had indicated that the final separation in the early Oligocene contributed to global Cenozoic climate cooling, with the developing Antarctic Circumpolar Current (ACC) isolating Antarctica from warm surface currents and helping to form an Antarctic ice sheet. The Drake Passage between South America and Antarctica also played a key role in the development of the ACC, and recent studies suggest similar early Oligocene deepwater flow there.

Breakup between Australia and Antarctica started in the early Campanian (83 Ma), Tasmania and eastern South Tasman Rise (T-STR) slid slowly northward past Wilkes Land along a transform fault, and the ocean entered the eastern Australo-Antarctic Gulf (AAG) from the west. Simultaneously, Lord Howe Rise moved away eastward from T-STR. STR was stretched and subsided, but formed an imperfect land bridge to Antarctica. Leg 189 cores show that rapidly deposited deltaic mudstones kept up with subsidence in Cretaceous to Eocene rifts, during both slow separation (70-43 Ma) and fast spreading (43-37 Ma). Winnowed late Eocene glauconitic siltstones record condensed sedimentation and subsidence in shallow seaways during the final separation of the two continents (37-33.5 Ma). Thereafter, Oligocene and younger pelagic carbonates were deposited slowly on rapidly subsiding blocks as Australia moved northward. The sediments show that the narrow AAG was relatively warm and poorly oxygenated into the late Eocene, as compared to the cooler proto-Pacific Ocean east of the land bridge.

The greatest changes occurred over the Eocene-Oligocene transition. Older sediments are shallow marine, organic-rich, dark gray, brown or green mudstones and siltstones, and were deposited largely in poorly ventilated marine deltas in relatively warm conditions. The younger sediments are pale gray or white pelagic carbonates deposited in deepening water as the continental blocks subsided in an open and cool ocean.

PP11C-02 0845h

Was Antarctica kept warm by subtropical waters in the Eocene? Part 1: Evidence from biotic endemism

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The opening of the Tasmanian Gateway (TG) during the Eocene/Oligocene transition has long been invoked as the causal mechanism for the global climate shift from the Hothouse world of the early Cenozoic to the Icehouse world of the past 35 Ma. ODP Leg 189 was designed to test the hypothesis that Antarctic cryospheric evolution resulted from the isolation of Antarctica by the opening of the TG and the consequent development of the Antarctic Circumpolar Current (ACC). Five sites (1168-1172) were drilled to document paleoceanographic and paleoclimatic changes associated with the opening of the TG as Australia moved northward from Antarctica during the early Cenozoic. In all, 4539m of sediments were cored that contain a wealth of microfossil assemblages that record shallow marine conditions from the Late Cretaceous (Maastrichtian) to Late Eocene and deep marine conditions thereafter. Demonstrating that this climatic transformation occurred synchronously with the opening of the TG is one of the major results of ODP Leg 189. To elucidate pre-TG paleo-ocean circulation in this critical region, Eocene phytoplankton records from Leg 189 and other published biotic records from the circum-Antarctic are here examined for biogeographic patterns. Results are incompatible with previous paleoceanographic reconstructions, particularly the assertion of a warm, poleward penetrating East Australian Current in the Middle and Late Eocene. Comparison with surface current directions as predicted from fully coupled climate model simulations and consequences are discussed in Part 2 (Huber et al., this session).

PP11C-03 0900h

Was Antarctica kept warm by subtropical waters in the Eocene? Part 2: Climate Model results

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Opening of the Tasmanian Gateway (TG) during the Eocene/Oligocene transition has long been invoked as the causal mechanism for the global climate shift from the "Hothouse" world of the early Cenozoic to the "Icehouse" world of the past 35 million years. ODP Leg 189 was designed to test the hypothesis that Antarctic cryospheric evolution resulted from the thermal isolation of Antarctica, caused by the opening of the TG. The proposed mechanism specifically being investigated was the cessation of poleward penetration of the heat-transporting, warm East Australian Current as the cause of the climate cooling. Five sites (1168-1172) were drilled to document paleoceanographic and paleoclimatic changes associated with the opening of the TG as Australia moved northward from Antarctica during the early Cenozoic.

Demonstrating that this climatic transformation occurred synchronously with the rapid opening of TG is one of the major results of ODP Leg 189. To test the TG hypothesis we compare model fully coupled (ocean-atmosphere-sea ice-land) climate model results for Late Eocene conditions with proxy data and isotopic climate reconstructions. In this part, we demonstrate that (1) the East Australia Current (EAC) never extended far poleward, bending eastward around the northern edge of New Zealand instead, (2) even if this current had extended to Antarctica it is unlikely that turning the current off would have initiated glaciation, (3) that the proxy data agree with the paleocurrent predictions of the model, and (4) that the geologic record is not consistent with changes in the EAC as being the control on Antarctic glaciation. One alternative hypothesis –that the climate changes were driven by changes in greenhouse gas concentrations–is explored and appears consistent with the proxy data record. The model-predicted climate sensitivity and the proxy record of climate change allow us to estimate the most likely concentrations of carbon dioxide (or its radiative equivalent) through the Paleogene. The model is most consistent with values of pCO2 greater than 1120ppm in the early Eocene, values ~1120ppm in the middle Eocene, values ~560ppm in the late Eocene, and near modern values in the Oligocene.

PP11C-04 0915h

Salinity Variation in the Eocene Australo-Antarctic Seaway: A Record of the Waxing and Waning of Antarctic Ice?

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A primary goal of ODP Leg 189 to the Tasmanian Seaway was to test the hypothesis that the initiation of the Antarctic Circumpolar Current (ACC) led to the development of the Antarctic cryosphere. Early cruise results indicate that the ACC was established some time very close to the Eocene-Oligocene (E-O) boundary, therefore evidence for extensive Antarctic glaciation should be confined to post E-O strata. At least two sedimentary geochemical proxies suggest that salinity conditions varied throughout the Eocene history of the Australo-Antarctic Seaway. First, C/S generated during shipboard analyses of sediments (verified by extensive post-cruise analyses) from Sites 1168, 1170, 1171 and 1172 indicate pore and bottom water salinities fluctuated between brackish and marine. C/S variations are observable at all of the sites, in some cases correlatable between sites, and most pronounced in the shallow confined portions of the seaway. Second, stable oxygen isotopic records obtained from calcite, siderite and francolite in carbonate concretions at Sites 1168 and 1171 require either untenably large temperature fluctuations (up to 20 to 35°C change), or more reasonable variations in pore and bottom water oxygen isotopic compositions of $\leq$5 per mil. In general, depleted oxygen isotopic values from the concretions either exist with, or immediately underlie C/S peaks or relative "freshenings". We explore conceptual models accounting for variations in runoff from the surrounding continental land masses (Australia and Antarctica) attributable to the presence of ice sheets or variations in precipitation. We conclude that the waxing and waning of continental-scale ice sheets in Eocene Antarctica cannot be discounted as a cause for the observed relative "freshenings".

PP11C-05 0930h

High-Southern Latitude Climatic and Biotic Events across the Oligocene-Miocene Boundary (Australo-Antarctic Gateway, Ocean Drilling Program Site 1168A)

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Early Miocene foraminiferal stable-isotope records indicate multiple transient glaciations within an otherwise moderately warm global climate. The first and largest of these glaciations, "Mi-1" of Miller et al. (1991), occurs at the Oligocene-Miocene boundary (~23 Ma), and coincides with relative minima in both eccentricity values (400 kyr) and obliquity variance (41 kyr) (Zachos et al., 2001). This orbital configuration would have minimized seasonality, and likely fostered glacial expansion through cooler summer seasons.

We investigated the climatic expression and biological impact of the Mi-1 event at high southern latitudes at ODP Site 1168A, a bathyal record of predominately nannofossil clay sedimentation (~4.5 cm/kyr) off the southwestern margin of Tasmania (~55° paleolatitude). Benthic foraminiferal stable-isotope stratigraphy indicates that the Mi-1 event is well-represented at Site 1168A: Peak Mi-1 δ^{18}O values of 3 $^{o}/_{oo}$ indicate greater cooling than observed in Atlantic ODP sites (608, 704, 926), while a post-Mi-1 values of 1.5 $^{o}/_{oo}$ are more consistent with Atlantic ODP sites. Peak Mi-1 δ^{13}C values of 2.25 $^{o}/_{oo}$ are 1 $^{o}/_{oo}$ heavier than observed in Atlantic ODP sites, whereas post-event values of 0.25 $^{o}/_{oo}$ are 0.5 $^{o}/_{oo}$ lighter than observed in Atlantic ODP sites.

Regional changes in the terrestrial and marine realm are associated with the Mi-1 event. Clay mineralogy data supports increasing seasonality in precipitation through the late Oligocene and Mi-1 event (i.e., 20% long-term increase in smectite), followed by an abrupt intensification in year-round precipitation and run-off (i.e., 20% rapid increase in kaolinite). Palynological analysis indicates significant fluctuations in runoff and alternating dominances of dinoflagellate cyst species. Immediately following the Mi-1 event is a massive influx of skolochorate acritarchs (possibly prasinophytes), which predominate the palynological record for at least a million years following Mi-1. Weight percent bulk carbonate increases across Mi-1 from 25% to 40%, and appears to represent an increase in carbonate export production and/or preservation. Bottom-water currents and oxygenation also appear to have increased across the Mi-1 event based on sortable-silt indices, ostracode valve articulation, and bulk-sediment pyrite content.

PP11C-06 0945h INVITED

Evidence for Water-Mass Changes on the Tasmanian Slope during the Early Miocene (19-16.5 Ma): Stable Isotope and Mg/Ca Records from ODP Leg 189 Site 1168

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High-resolution stable isotope (4-10 k.y. resolution) and moderately low-resolution Mg/Ca ratio records were constructed for the late early Miocene (19-16.5 Ma) from ODP Leg 189 Site 1168, located on the southwest slope of Tasmania. These records evaluated paleoceanographic changes that took place during isotopic excursions Mi1b (18.2-17.8 Ma) and Mi2 (16.5 Ma), and the First Climatic Optimum (17.7-16.7 Ma), a time of increased global warmth. Evidence exists that supports the idea for the development of warm saline deep waters (WSDW) originating from the eastern end of the Tethys Sea during the early Miocene. However, questions remain regarding the extent and strength of the WSDW and the possible role it played in the warming that took place during the First Climatic Optimum. Site 1168 is ideally located on the lower slope (estimates place it in lower bathyal waters during the early Miocene) to evaluate the potential penetration of WSDW and into the Southern Ocean.

Large fluctuations in the isotope and Mg/Ca ratio records from Site 1168 suggest changes in the water masses that bathed the Tasmanian slope during the early Miocene. Temperature estimates based on Mg/Ca ratios contain a surprisingly high range, from 4° to 10° C. Low temperatures (4°-6° C) are associated with high carbon isotope values ($>1.4^{o}/_{oo}$) and are interpreted represent Southern Component Waters (SCW). The high carbon isotope values also suggest a proximal source for SCW. High water temperatures (7°-10° C) indicate a warm-water mass and are interpreted to be due to the penetration of WSDW into

this area, replacing SCW at various times. Large high-frequency isotopic excursions (low oxygen and carbon isotope values) occurred between 18.7 and 18.4 Ma and were originally thought to be due to either localized effects (e.g., disassociation of hydrates) or possible diagensis. However, a recently published high-resolution isotopic record from the Southern Ocean (Site 1090) also contains large isotopic excursions (e.g., $>1^{o}/_{oo}$ decrease in oxygen isotope values) at this time, suggesting that these events may not due to diagensis but may be transient global events. We interpret that the changes observed in the isotopic and Mg/Ca ratio records are the result of both changes in the cryosphere and water-mass changes in the vicinity of Tasmania, the latter being due to the penetration of WSDW into the Southern Ocean.

PP11C-07 1000h

De-convolving Middle Miocene Antarctic Ice Sheet Expansion from Temperature Change: Mg/Ca and δ^{18}O records from the Southern Ocean

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Geologic records indicate that significant global atmospheric/oceanic cooling coincided with Antarctic cryosphere expansion in the mid-Miocene (16-12 Ma). Globally distributed stable isotope records exhibit a significant δ^{18}O increase at 14 Ma that is interpreted to reflect a combination of decreased global temperatures and increased Antarctic ice volume. Given the limitations of δ^{18}O as a temperature proxy, fundamental questions exist concerning the magnitude, phasing, and processes driving mid-Miocene ice volume and temperature change.

Recently developed independent geochemical temperature proxies (e.g. Mg/Ca and alkenone unsaturation ratios) should assist with de-convolving temperature and ice volume signals contained in mid-Miocene δ^{18}O records. The appeal of Mg/Ca as a paleotemperature proxy is that it is useful in sediments with low organic carbon content and can be measured on the same foraminifer $CaCO_3$ as δ^{18}O, making it possible to separate temperature and ice-volume signals. For the Mg/Ca temperature proxy to be successful on pre-Quaternary timescales, several factors are crucial: very well preserved foraminiferal $CaCO_3$ and the presence of fossil species for which there are modern analogues with Mg/Ca temperature calibrations.

We have generated both benthic (*C. mundulus*) and planktonic (*G. bulloides*) foraminiferal Mg/Ca records from the Southwestern Pacific sector of the Southern Ocean (ODP Site 1171: paleolatitude- 55°S, paleowater depth- 1600 m) to assess the potential for using Mg-paleothermometry to reconstruct middle Miocene deep- and surface-water temperatures. Our results suggest that Southern Ocean waters were 4-4.5°C warmer in the Middle Miocene Climatic Optimum (16-14 Ma) than after the mid-Miocene δ^{18}O shift. *C. mundulus* Mg/Ca paleotemperatures suggest that bottom waters cooled initially at 14.8 Ma and then warmed at 14.4 Ma. An interval of significant deepwater cooling (9.5°C to 5°C) coincided with the δ^{18}O shift (14.4-14 Ma). Warming occurred again at 13.6 Ma. *G. bulloides* Mg/Ca paleotemperatures suggest that regional surface-waters exhibited a similar pattern, cooling from 18°C to 13.5°C between 14.4 to 14.0 Ma. *G. bulloides* Mg/Ca temperature estimates are well within the present regional sea surface temperature (SST) range. This observation suggests that warm sub-tropical SSTs extended farther south (55°S) in the mid-Miocene. Comparison of benthic and planktonic foraminifer Mg/Ca paleotemperatures with δ^{18}O records suggests that deep water cooling lead the mid-Miocene δ^{18}O shift by 200 ky. Both benthic and planktonic temperature fluctuations exhibit 400-ky cyclicity.

Calculations of $\delta^{18}O_{sw}$ from both benthic and planktonic foraminifer δ^{18}O and Mg/Ca paleotemperatures indicate significant $\delta^{18}O_{sw}$ variability across the middle Miocene δ^{18}O shift with an apparent 400-ky cyclicity. In both records, $\delta^{18}O_{sw}$ increased before both deep water cooling and the middle Miocene δ^{18}O shift. A stepwise $\delta^{18}O_{sw}$ increase occurred concurrently with the δ^{18}O shift. While exact phasing of ice volume and temperature change has not yet be determined, our results suggest that the reorganization of heat and moisture supply to the high southern latitudes may have played a major roll in forcing the mid-Miocene climate reorganization.

PP11C-08 1015h

Accumulation of Siliciclastic and Biogenic Sediments at the Antarctic Continental Rise During the Late Miocene and Early Pliocene: A Comparison of ODP Sites 1095 and 1165

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Drift sediments drilled at ODP Sites 1165 (Leg 188, Prydz Bay) and 1095 (Leg 178, Antarctic Peninsula) offer the possibility to compare the climate evolution of East and West Antarctic continental margins during the late Miocene and early Pliocene (3 -8 Ma). Our investigations at these sites are based on biogenic silica measurements and coarse fraction grain size analyses as well as on non destructive core logging data. The long-term age models are derived from good bio- and magnetostraphic control. For selected intervals the chronology was refined using astronomical tuning based on a dominating 41 kyr obliquity signal detected in the high resolution physical (color, bulk density) and chemical (Fe, Ti) core logging records.

In order to estimate percent biogenic opal at a high resolution (5 cm interval) the core logging records were combined with biogenic silica measurements on discrete samples. These estimations (standard error $< 3\%$) based on a multi-regression approach allowed the calculation of mass accumulation rates of biogenic and terrigenous components on orbital time scales. A regression describing the relationship between opal preservation and sedimentation rate was used to extract the signal of primary opal deposition. Short term changes in opal deposition show variations in concert with orbital obliquity. During times of high tilt in earth axis maxima in biogenic productivity occur. This pattern is likely due to reduced sea ice cover over the East and West Antarctic continental rise.

The long-term comparison between East and West Antarctica reveals a remarkable similarity between bulk-, terrigenous-, and opal accumulation rates at both locations. 75 to 95% of the bulk sediment is contributed by terrigenous flux indicating that the sedimentary systems are largely controlled by the current transported fine siliciclastic component. Accumulation rates at Site 1095 are up to 4 times higher than at Site 1165 possibly due to a higher degree of downslope transport at Site 1095. There is a general trend to lower siliciclastic accumulation from the late Miocene to early Pliocene pointing to a transition from severe late Miocene glaciations to an early Pliocene climate that was likely warmer than today. A warming is also in agreement with decreasing amounts of iceberg transported material as indicated by grain size analyses. Step-like reductions in accumulation rates at 6.6 and the Miocene/Pliocene boundary (5 Ma) appear to be synchronous at both margins likely indicating global climate events.

PP11C-09 1050h

Surface Water Reservoir Ages and Paleoventilation During the Last Glacial Maximum in the Southwest Pacific and Southern Ocean

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The difference between the ^{14}C age of the atmospheric and marine carbon reservoirs varies spatially in the ocean because it is dependent on local and global ocean circulation. The ages of these reservoirs reflect a balance between equilibration with the atmosphere, radioactive decay of ^{14}C, the aging of isolated deep water masses through thermohaline circulation, and the subsequent cycling of those deep waters back to the mixed layer of the ocean. Large scale changes in thermohaline circulation associated with colder, glacial-type climate conditions are known to have changed ocean ^{14}C during the last glaciation. Nonetheless, although reservoir ages are known to have changed in the past, in practice they are assumed to have been constant through time. A recent study using New Zealand tephras as isochronous marine-terrestrial markers produced the first independent estimates of past reservoir ages in the last glaciation. Deep water ages were 3000-5000 years, three to five times more than previously indicated by work on surface-deep water age differences. These large reservoir ages must have been caused by climate related changes in ocean circulation which control global ^{14}C distributions. Additionally, the glacial age-depth profile put oldest water at deepest, rather than intermediate depths [*Sikes et al.*, 2000]. We extend the coverage of that study with 14C dates from the Kawakawa ash (22,590 ^{14}C yr BP) from additional water depths underlying both subtropical and subpolar waters. Results will determine the extent that changes in global thermohaline circulation and CO_2 cycling affected the deep marine carbon pools when climate was significantly different from today.

PP11C-10 1105h

Holocene Records of Antarctic Shelf Bottom Currents - A Key to Understanding Global Ocean Circulation in a Warmer Earth?

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Recent coupled ocean-atmospheric modelling carried out at the Antarctic CRC predicts that the formation rate of ocean bottom water and global thermohaline circulation will slow down due elevated CO2 and global warming. Palaeoenvironmental studies on sediment cores collected from the Antarctic continental shelf indicate that this same situation may have occurred previously during the mid-Holocene climate optimum, between 3,000-5,000 years before present (BP). The George Vth basin on the East Antarctic margin has been identified by oceanographers as an important source of Antarctic bottom water, hence the Holocene history of bottom current activity here is relevant to variations in bottom water export. Seismic and sediment core data collected during a joint Italian/Australian expedition to this area indicates that the Holocene history of sedimentation on the shelf occurred in response to changes in bottom current regime. Weaker currents during the mid-Holocene correspond to a phase of rapid sediment accumulation of biosiliceous ooze, whereas stronger bottom currents over the past 2,000 years coincides with lower sediment accumulation rates and deposition of a winnowed, muddy sand. Hence our sediment core records indicate that the slowdown in thermohaline circulation persisted for 2,000 years in response to the mid-Holocene climate event. This observation is consistent with the prediction of the climate model, that the deep ocean convection will not recover from the present, anthropogenic global warming for thousands of years.

PP11C-11 1120h

History of the Deep Western Boundary Current at Rekohu Sediment Drift, Southwest Pacific (ODP Site 1124)

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ODP Site 1124, located 600 km east of the North Island of New Zealand, records post-middle Oligocene variations in the Pacific Deep Western Boundary Current (DWBC) and/or New Zealand climatic and tectonic evolution. Sediment parameters, such as terrigenous grain size, flux, magnetic fabric, and noted non-depositional events, have been used to interpret DWBC intensity and Antarctic climate. Results indicate that the Antarctic Circumpolar Current reached modern intensities at approximately 23 Ma. Periods of more intense circulation are indicated by the presence of hiatuses at 22.5-17.6, 16.5-15, and 14-11 Ma. The oldest interval of high current intensity occurs within a climatically warm period, however, the intensity of thermohaline circulation around Antarctica increased because of the recent opening of circum-Antarctic gateways. The younger hiatuses represent glacial periods on

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Antarctica and major fluctuations in the East Antarctic Ice Sheet, while the intervals around the hiatuses represent times of relative warmth, but with continued current activity. The period between 11 to 9 Ma is characterized by conditions surrounding the formation and stabilization of the West Antarctic Ice Sheet causing a high velocity DWBC, yet the increased terrigenous input may result from either changing Antarctic conditions or more direct sediment transport from New Zealand.

The Pacific DWBC did not exert a major influence the sediment at Site 1124 from 9 Ma to the present; the late Miocene to Pleistocene sequence is more influenced by the climatic and tectonic history of New Zealand. Despite the apparent potential for increased sediment supply to this site resulting from changes in sediment channeling, increasing rates of mountain uplift, and volcanic activity, terrigenous fluxes remain low and fairly constant throughout this younger period.

PP11C-12 1135h INVITED

The Late Pleistocene Ross Ice Sheet and Eustatic Sea Level Rise

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Radiocarbon dates obtained from central Ross Sea foraminifera indicate that glacial ice reached its maximum position in the Ross Embayment after 13.8 ^{14}C ka, suggesting that deglaciation of this major sector of the Antarctic ice sheet lagged the onset of Late Pleistocene eustatic sea level rise by 4-5 ky. The 13.8 ^{14}C date is the youngest of 18 ^{14}C dates from Ross Sea glacial till and provides a maximum constraint on the age of ice advance. Assuming that grounding line retreat was broadly synchronous across the western and central Ross Sea, ice sheet retreat was very likely in progress during the time of melt-water pulse (mwp)-IA (ca. 12 ^{14}C ka). However, the total contribution to mwp-IA from the various ice sheets remains poorly constrained.

A numerical model simulation shows that the maximum volume of grounded ice in the Ross Embayment during the last glacial maximum was 2.4 x 10^6 km^3 greater than the present-day ice sheet, which translates to ~6.75 m eustatic sea level rise. If stepwise retreat occurred from the maximum ice position back to Ross Island during mwp-IA, the ice sheet volume in the Ross Sea sector would have been reduced by ~20%, yielding a eustatic rise of <1.4 m. Given this conservative estimate of the contribution of expanded ice in the Ross Sea sector, it is highly unlikely that Antarctica was the sole, or even dominant source of mwp-IA (with a minimum eustatic rise of 13.5 m as described by Blanchon and Shaw, 1995, Geology v.23, p.4-8). Grounded ice in the Ross Embayment was still retreating at the time of mwp-IB (ca. 9.5 ^{14}C ka) and was likely a contributor to sea level rise at that time, but by similar logic, was most likely not the dominant source.

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PP11C-13 1150h

The Oxygen Isotopic Composition and Temperature of Southern Ocean Bottom Waters During the Last Glacial Maximum

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We use oxygen isotopic measurements of pore waters recovered from ODP Sites 1168 and 1170 in the Indian Ocean sector of the Southern Ocean and a numerical model to obtain the oxygen isotopic composition of bottom waters during the last glacial maximum (LGM). At these sites, the pore water oxygen isotopic values increase by ~0.30 $^o/_{oo}$ in the upper 30-40 m below seafloor. Previous work has shown this maximum to be the diffusionally attenuated record of the glacial-interglacial (G-I) shift in oxygen isotopic composition of the ocean. Site 1168 is located in middle bathyal water depths (2463 m) on the slope of the western margin of Tasmania (42° 36.58' S, 144° 24.76'E) north of the present-day Subtropical Front (STF). Site 1170 is located 400 km south of Tasmania on the western South Tasman Rise (47° 9.04'S, 144° 2.98'E, 2705 m water depth) ~150 km south of the STF and well north of the Subantarctic Front. Currently, both sites are bathed by Circumpolar Deep Water (CDW). We applied a diffusion-advection model using a finite difference, central differencing scheme to solve for magnitude of the oxygen isotopic change in overlying seawater since the LGM. The model results produce similar values for the two sites: 1.0 $\pm 0.15^o/_{oo}$ at 1168 and 1.05 $\pm 0.15^o/_{oo}$ at 1170. Previously published values for this technique come from Atlantic sites, and resulted in a consistent G-I change of $0.8^o/_{oo}$. One exception is Site 1093, which is located in the Southern Ocean (Atlantic sector) and produced a calculated change ($1.1^o/_{oo}$) close to that of Sites 1168 and 1170. Likewise, the bottom waters at Site 1093 are probably CDW. We will also use the pore water results above with the G-I difference in the isotopic values of benthic foraminifers to calculate the temperature of bottom water during the LGM at Sites 1168 and 1170.

PP12A MCC: Hall D Monday 1330h

Southern Ocean Climatic Evolution: The Marine Geologic Record II
Posters *(joint with A, GP, OS, GC)*

Presiding: **D A Warnke,** California State University, Hayward**; P E OBrien,** Geoscience Australia

PP12A-0319 1330h POSTER

A 450 000 kyr Surface Hydrography History From the Subantarctic Atlantic Ocean (ODP Site 1089)

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We established a palaeo sea surface temperature (SST) record, by using a radiolarian-based transfer function, for the northern subantarctic Atlantic Ocean (ODP Site 1089, 40^0 56 S; 9^0 54 E), in order to reconstruct its surface hydrography and interocean heat exchange history during the last five climate cycles (ca. 450 ka). The produced record has a centennial scale time resolution, which makes it unique (in length and resolution) for the subantarctic zone. At this location, close to the subtropical front, ocean/atmosphere interactions, interoceanic exchange processes, and mesoscale eddy mixing play an important role in shaping the characteristics of sea water eventually advected to the North Atlantic. The centennial resolution allows to recognize millennial scale climatic events, similar to the Dansgaard-Oeschger cycles (originally described from Greenland ice cores), both during Marine Isotopic Stage (MIS) 3 and 6. Similar to observations from Termination I (Antarctic Cold Reversal), rapid cooling rebounds were encountered at Terminations II to V, and are not therefore limited either to the circum-Atlantic area or to last Termination. A comparison of SST and ice volume proxies suggests a lead of a few kyrs between SST and the minimum extent of global ice volume, indicating that temperatures rose substantially at subantarctic latitudes before any considerable northern hemisphere continental ice volume change was recorded. The climatic history of ODP Site 1089 displays good correlation to other records (e.g. Vostok) with the exception of MIS 10, where a warm SST anomaly was recognized. This anomaly is also present in oceanic records along the thermohaline circulation belt path, but absent in both Polar Zone and Vostok climatic records. The implications of our record for interhemispheric climate connecting mechanisms and the role played by the Southern Ocean in steering global climatic change will be discussed.

PP12A-0320 1330h POSTER

Plio-Pleistocene Biogenic Opal Deposition in the Southern Ocean

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About 2/3 of the annual supply of silicic acid to the World Ocean is buried in the Southern Ocean as biogenic silica (BSi), formed by diatoms and radiolaria in surface waters and exported to the seafloor. Main BSi accumulation occurs in an area between the sea ice edge and the Polar Front Zone and seems to be steered by a complex interaction of biological and physical parameters governing the modern Southern Ocean ecosystem. Sediment cores recovered during Ocean Drilling Program Leg 177 and expeditions with RV POLARSTERN reveal the history of the opal deposition in the Atlantic and Pacific sector of the Southern Ocean during the Pliocene and the Pleistocene. This period is characterized by distinct changes and variability in global climate and ocean circulation that can be related to the spatial-temporal distribution of BSi deposition on long and short time scales. Changes in ocean circulation, water mass structure, sea ice and climatic variability that impact the distribution of silicic acid and the development of coarsly silicified diatoms (e.g. Actinocyclus ingens, Thalassiosira antarctica, Fragilariopsis kerguelensis), presenting the major carriers of biogenic opal, control past BSi deposition in the Southern Ocean. Major deposition in the area of the modern Southern Ocean opal belt starts at the Plio/Pleistocene transition. Such strong export of BSi and related organic carbon might have reinforced the trend of global cooling observed since the Mid-Pliocene climate optimum.

PP12A-0321 1330h INVITED POSTER

Late Neogene sedimentation at ODP Site 1171 (Leg 189), South Tasman Rise: history of paleoproductivity and ice rafting.

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The late Neogene (11.3-1 Ma) sediments at Site 1171 reflect changing paleoproductivity, radiolarian opal preservation as well as coarse glauconite and clastic material input as shown by an analysis of the coarse fraction and stable isotopes. A hiatus spans the 8.7-5.23 Ma interval. Accumulation rates fluctuate between 0.5 and 4.5 cm/ky. The following results have been obtained:

1. A coarsening of the sand (increase in >250 μm sized fraction and related reduction in fine sand) since 5.23 Ma is not due to winnowing after the time of non-deposition, but to improved carbonate preservation.

2. Up to 1000 μm sized glauconite, quartz grains and rock debris present in nearly all samples are attributed to delivery from melting icebergs (IRD). Major periods of IRD delivery are at 10.5-10.7, 9.2-10.2 and 3.2 Ma.

3. Two measures of paleoproductivity, which were thought to be interdependent so far, proved to be independent. Whereas the paleoproductivity data in gC/cm^2*ky derived from benthic foraminiferal numbers as well as Uvigerina numbers, fish debris concentration and carbonate dissolution show a coherent picture with higher productivity prior to 9 Ma (paleo-export- productivity values of 25-75 gC/cm^2*ky) than after the hiatus (values of 8-45 gC/cm^2*ky), the data derived from radiolarian and sponge skeletons show minima during times of highest paleoproductivity as derived from benthic foraminifers. Abundance of radiolarian skeletons is interpreted in terms of preservation conditions related mainly to production, location of the site relative to the polar front and water temperature. The observed anticorrelation of radiolaria and IRD leads to the assumption that radiolaria are better preserved during cool periods, whereas during warmer intervals radiolarian opal is more or less completely dissolved and IRD supply is enhanced perhaps because of more rapidly moving glaciers or preferential melting over Site 1171 or less sea-ice that impedes iceberg dispersal or increased strength of the warm East Australian Current.

4. We tentatively correlate the depressions in $CaCO_3$ content at 9.6-10 Ma and 10.6-11.2 Ma and related high productivity and dissolution spikes to the "carbonate crash events" and the strong dissolution, higher Uvigerina numbers and slightly increased paleoproductivity at 4.5-5.23 Ma to the declining late Miocene "biogenic bloom" event. These two major paleoceanographic events during the late Neogene have so far been known only from equatorial and subtropical upwelling areas.