ANTARCTIC AND SOUTHERN OCEAN FUTURE DRILLING WORKSHOP
Portland (Oregon, USA) 13th and 14th of July 2012,

SUMMARY

Valuable insights into the future sensitivity of the Antarctic cryosphere to atmospheric and oceanic warming can be gained from long-term geologic records of how it changed during past warm periods. While paleoclimate records spanning hundreds of thousands of years have been obtained from Antarctic ice cores, continental outcrops and margin to deep ocean sediments cores provide records of contemporaneous changes in ice sheet extent and oceanographic conditions, that extend farther back in time, including periods with atmospheric CO_2 levels and temperatures similar to those that are likely to be reached in the next 100 to 200 years.

Based on the existing data and the current knowledge, successful projects with a multi-leg, multi-platform approach can be developed (e.g. transects involving a combination of ANDRILL, seabed drilling and *JOIDES Resolution* sites). The purpose of the workshop, held in Portland (Oregon, USA) on 13th and 14th of July 2012, was to stimulate new Antarctic and Southern Ocean drilling proposals and ensure coordination among existing ones, so that regional, scientific objectives are tackled through a unified approach. The workshop held before the SCAR Open Science Conference 2012, with the financial support of the SCAR/ACE program, was attended by 50 participants (annex 1) from all over the world, with a wide range of geoscience skills, technology expertise and project management experience. It offered an ideal opportunity to hold open discussions to guide and stimulate concerted international action to ensure a robust plan for Antarctic scientific drilling during the next phase of IODP.

The strategy followed that of the IODP Science Plan in addressing outstanding scientific questions by drilling several depth and latitudinal transects in different sectors of the East and West Antarctic margin, where the ice sheet is grounded below sea level and is considered to be unstable. These questions are also relevant to three of the IODP Science Themes (Theme 1 in particular):
1) Climate and Ocean Change: Reading the past informing the future.

- Challenge 1: How does Earth's climate system respond to elevated levels of atmospheric pCO_2?
- Challenge 2: How do ice sheets and sea level respond to a warming climate?
- Challenge 3: What controls regional patterns of precipitation, such as those associated with Monsoons or El Niño? (in areas where ultra-high resolution Holocene records exist – e.g., Wilkes Land, Prydz Bay, Antarctic Peninsula e.g. Palmer Deep, Maxwell Bay)

2) Earth Connections: Deep-processes and their impact on Earth's subsurface environment
3) Biosphere Frontiers: Deep life, biodiversity, and environmental forcing of ecosystems

Main questions underpinning future scientific drilling around Antarctica and in the Southern Ocean, and tied to the IODP Science themes, are:

1) *How will the Antarctic Ice Sheets respond to elevated temperatures and atmospheric pCO_2? What is the contribution of Antarctic ice to past and future sea level changes in terms of rate and magnitude?*
2) What did a "greenhouse world" look like in Antarctica? Can Antarctica sustain any ice sheets when the atmosphere is above 1000 ppm CO_2?
3) *What were the patterns, causes, and consequences of Gondwana breakup (recorded in large igneous provinces and continental fragments of the Southern Ocean)? What was the timing of rifting and subsidence controlling the opening of ocean gateways and the initiation of the circumpolar current system?*

The ANDRILL program has demonstrated the ability to recover >98% of the drilled sediments at continental shelf sites. In addition, despite the low recovery from drilling continental shelf sediments at some sites, drilling at others on DSDP 28, ODP 188 and the recent IODP Expedition 318 of the Wilkes Land margin has shown that ship-based riser-less drilling can achieve good recovery (60-100%) from glacially-influenced continental rise sediments. In order to maximize recovery it is essential that sufficient and good-quality site surveys are carried out, that the most appropriate drilling tools are used with regard to the expected sedimentary facies, that clear weather/ice contingencies and accurate drilling time are estimated, and that an adequate number of alternate sites are planned (i.e. operational flexibility and good site surveys). Technological advances, such as drilling from a stable platform (e.g. the ANDRILL deep drilling and the MeBo shallow drilling) and a riser system (employed by *Chikyu*, ANDRILL, and the petroleum industry), could allow greater improvements to the recovery from the continental shelf.

Improved paleonvironmental and dating methods have been developed through the ANDRILL project and by drilling more continuous sections from continental rise sediment drifts. In some cases the improved chronology allows insights into ice sheet dynamics at orbital scale through Miocene and Pliocene times. It is also important to recognize that there are still large time intervals and regions around Antarctica in which no data exist, and even 20-30% recovery from these can still significantly advance our understanding of ice sheet history

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RATIONALE FOR FUTURE ANTARCTIC AND SOUTHERN OCEAN DRILLING

The Antarctic cryosphere plays a key role in the global climate system through production of dense bottom waters that drive the global thermohaline circulation, its influence on wind patterns over the Southern Ocean that drive the Antarctic Circumpolar Current, and the albedo difference between ice and ocean. Furthermore, the Antarctic ice sheet has the potential to raise global mean sea level by 58 m if it completely melted. Therefore, even relatively small changes in the Antarctic cryosphere have significant impact on global climate dynamics and sea level with important societal consequences (e.g., changes in rainfall patterns, coastal inundation, etc.). Lack of understanding of how ice sheet dynamics might change in a warmer climate was identified in the IPCC Fourth Assessment as the largest uncertainty in predicting sea-level rise. In fact, so little is understood about the response of the Antarctic ice sheet to climate forcings, that it is often a fixed feature in many climate models.

Valuable insights into the future sensitivity of the Antarctic cryosphere to atmospheric and oceanic warming can be gained from the geologic record of past climatic warm intervals (e.g. the Pliocene). While paleoclimate records spanning hundreds of thousands of years have been obtained from Antarctic ice cores, continental outcrops and margin to deep ocean sediments cores provide records of contemporaneous changes in ice sheet extent and oceanographic conditions that extend farther back in time, including periods with atmospheric CO_2 levels and temperatures similar to those that are likely to be reached in the next 100 to 200 years (figure 1).

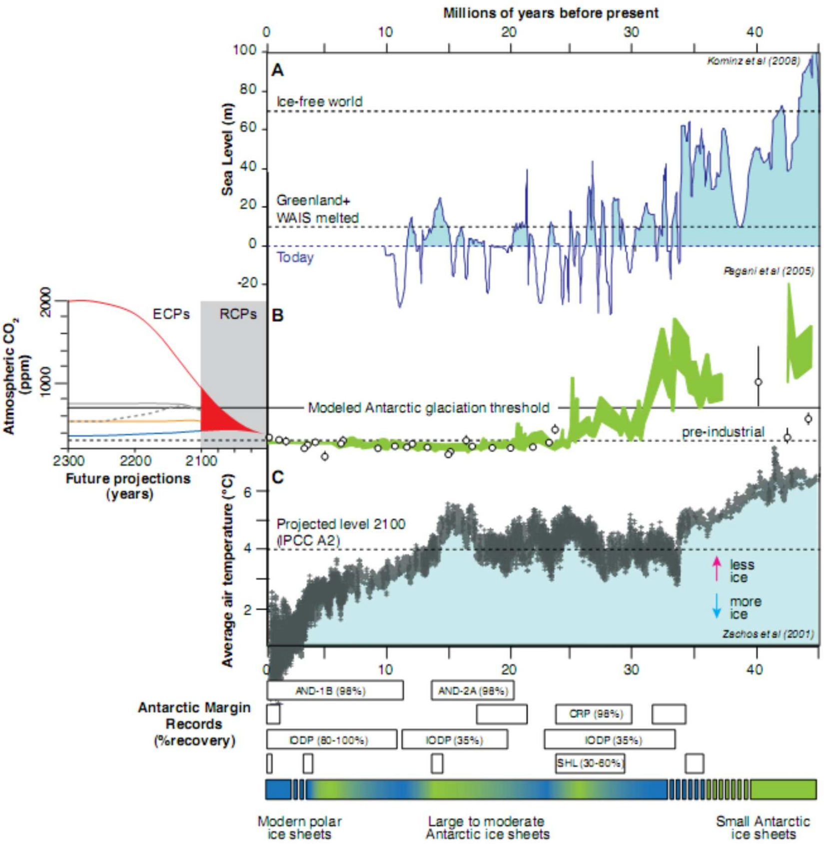

Figure 1. Earth's environmental evolution over the past 45 million years reconstructed from proxy data. From Shevenell and Bohaty, 2012.

(A) a sea level curve from the New Jersey margin (Kominz et al., 2008). Cramer et al (2011 JGR) scale the Miller/Kominz curve to fit within the 65m global ice volume inventory, acknowledging that there is no evidence for +100m sea-levels in the Eocene. WAIS = West Antarctic ice Sheet.

(B) alkenone δ^{13}C-based atmospheric CO2 reconstructions (green; Pagani et al., 2005) and boron isotope pH reconstructions (open circles; Pearson and Palmer, 2000). The solid black line indicates model-derived CO2 glaciation threshold for Antarctica (DeConto et al., 2008). The dashed line highlights pre-industrial CO2 levels. The red envelope includes atmospheric CO2 concentrations for the representative concentration pathways (RCPs) to 2100 (IPCC, 2007; Meinshausen et al., 2011) and the red, gray, dashed gray, yellow, and blue lines indicate extended concentration pathways (ECPs) to 2300 (Meinshausen et al., 2011). The ECPs are within the range reconstructed for the early Cenozoic, illustrating the importance of geologic drilling in providing long-term paleoclimatic context.

(C) Rise in average air temperature above the 1961-1990 baseline, assuming this follows the deep-sea benthic foraminifer oxygen isotope (δ^{18}O) compilation of Zachos et al. (2008), without adjustment for global ice volume. White bars indicate key Antarctic margin reference sections recovered by the Cape Roberts Project (CRP), ANDRILL (AND), integrated ocean drilling program (IODP), and SHALDRIL (SHL); core recovery is indicated in parentheses. The green and blue-banded bars reveal the evolution of Antarctica's ice sheets, as inferred from geologic data.

Atmosphere-ocean changes in the circum-Antarctic are thought to play a key role in past atmospheric CO_2 variability by controlling deep-water exposure rates (upwelling) sea-ice extent, upper ocean physical parameters and stratification, nutrient utilization and biological export, and high-low latitude exchange of nutrients and heat. Because the Southern Ocean is one of the primary regions of global deep and intermediate water mass formation, and a "junction box" where mixing occurs among major water masses from all large ocean basins, it is central for propagating climate change globally.

Despite the role that the Antarctic cryosphere/Southern Ocean system plays in driving Earth's climate, the circum-Antarctic region is currently undersampled with respect to scientific ocean drilling (see figure 2). For example, only one expedition was drilled south of the Antarctic Polar Front during the International Ocean Drilling Program (2003-2013).

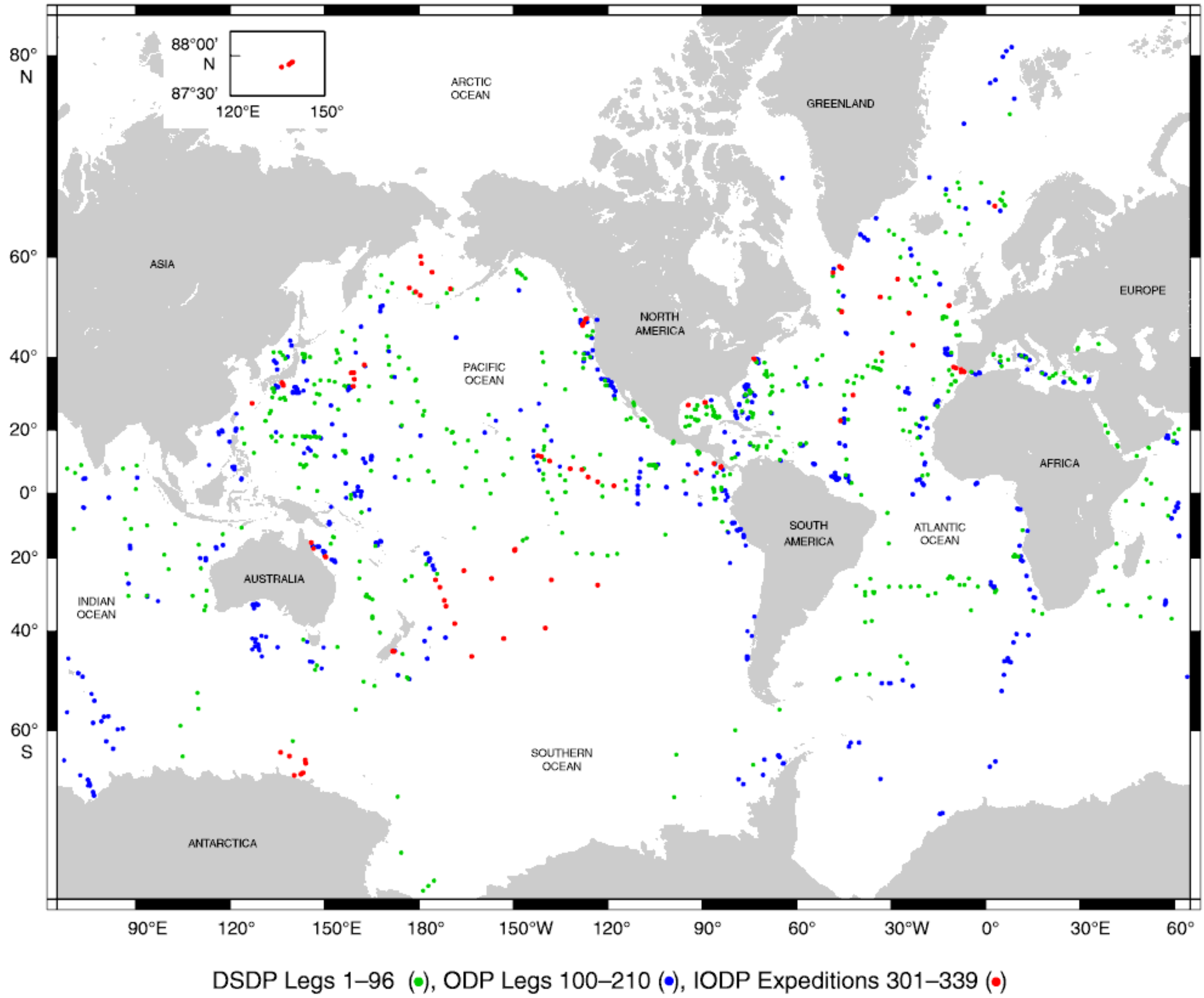

Figure 2. Map of the world oceans with completed DSDP, ODP and IODP legs

The variable response of the ice sheet to on-going climatic change mandates broad geographic drilling coverage, particularly in climatically sensitive regions with large upstream drainage basins (e.g. the Ross Sea, Amundsen Sea, Weddell Sea,Wilkes Land, offshore Totten Glacier and Prydz Bay, figure 3).

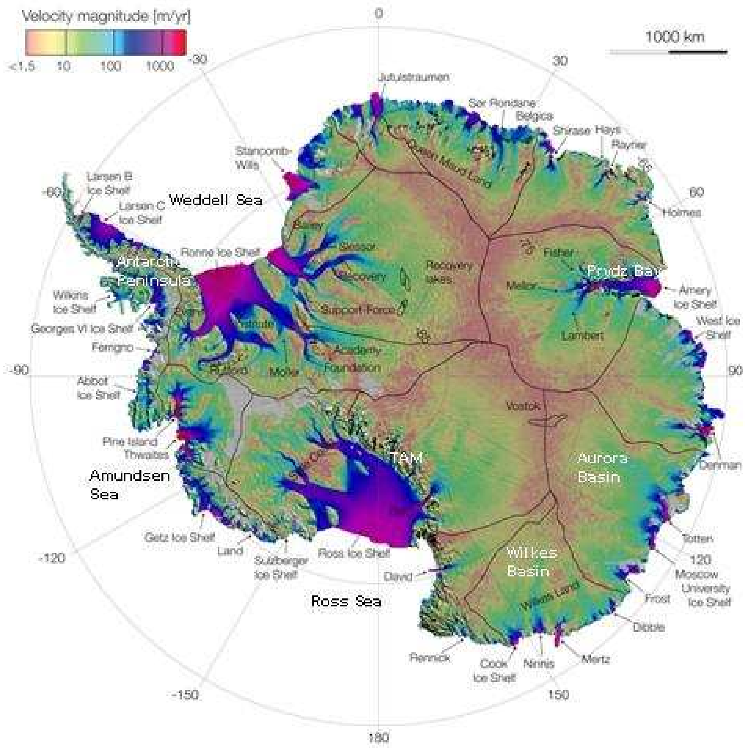

Figure 3. Antarctic Ice Sheet velocities, showing drainage basins (Rignot et al., 2011, modified).

To this end, the new SCAR program *Past Antarctic Ice Sheet dynamics* (PAIS) aims at obtaining sedimentary records from ice sheet - ice shelf - offshore transects within specific drainage sectors to advance the currently poor understanding of linkages between the ice sheet, ocean circulation, and deep/bottom water processes through time.

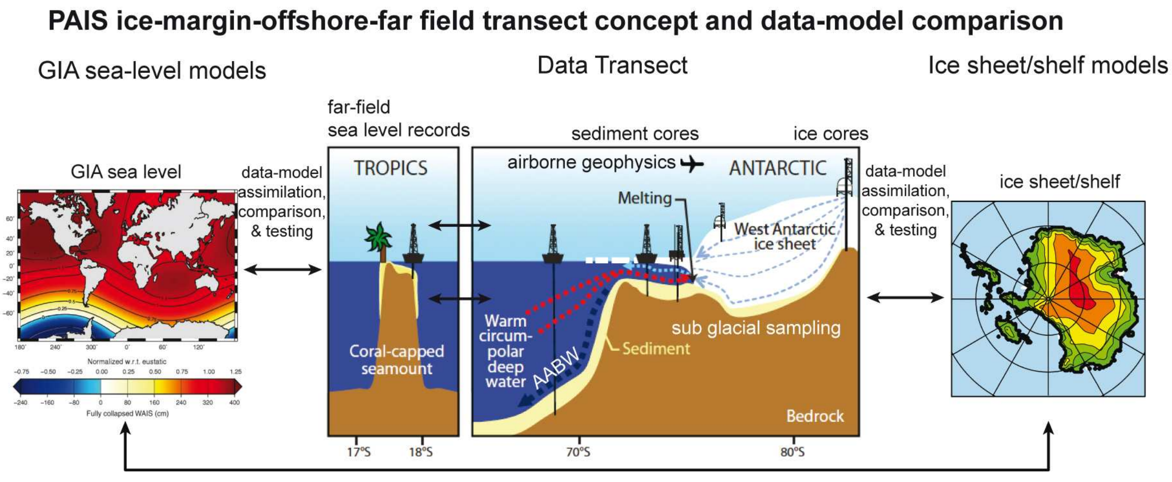

Figure 4 (from the PAIS proposal). A schematic representation of the PAIS "from subice-to-abyss" transect concept, extending from the ice sheet interior, along an ice flowline, and offshore to the tropics. The meridional transect links Antarctic ice sheet changes to both proximal and far field records of ice volume, ice sheet geometry, and sea level. The data-data and data-model concept links on-ice, proximal, and far-field records with the new generation of ice sheet models, including Glacial Isostatic Adjustment GIA earth models of time-evolving global sea level. In particular PAIS consider the further effects of these changes on the global gravity field and thus on regional sea level, which is the self-consistent gravitational effect. The GIA example (left) is from Bamber et al. (2009) representing the normalized sea level response to the loss of ice on West Antarctica. The schematic transect (middle) is after Schoof (2010) as depicted in the new 2013-2023 IODP Science Plan, and the continental ice sheet simulation of a past WAIS collapse (right) is from Pollard and DeConto (2009).

Early attempts to drill continental shelf sediments with the *JOIDES Resolution* were plagued by poor recovery. However, recovery rates during recent scientific ocean drilling expeditions, including ODP Legs

178 and 188 and IODP Expedition 318, indicate that it is technologically possible to adequately recover (60-100%) from glacially-influenced continental rise sediment sequences, with riserless drilling technology. These sequences, while still not recovered at rates equivalent to those at deep-sea sites, have been used to answer important questions related to Cenozoic climate and ice sheet evolution. Recent drilling legs have also had additional success due to improved site survey data, clear operational weather/ice contingencies, accurate drilling time estimates, and identification alternative drilling targets.

Recently, the ANDRILL program has achieved nearly 100% recovery of drilled sediments on the Ross Sea continental margin with the aid of a stable platform and riser drilling technology. Newer technologies, such as the MeBo drill rig that is deployed from a ship but operates from the sea floor, will further improve continental margin drilling around Antarctica. In addition to improved and emerging drilling technologies, substantial progress has been made in our ability to date recovered sediments and in the development and interpretation of paleoclimate/paleoenvironmental proxies in Antarctic margin sediments. These developments allow insights into past ice sheet dynamics that are possible even with partial recovery of margin sedimentary sequences (e.g. orbital scale variations in Antarctica's cryosphere during the Miocene and Pliocene (Naish et al., 2009)).

Fundamental hypothesis driven science can be accomplished by drilling depth transects from ice proximal to distal locations that will enable researchers to link past perturbations in the ice sheet with Southern Ocean and global climate dynamics. With current technology, projects developed using a multi-leg, multi-platform approach (e.g. latitudinal and/or depth transects involving a combination of land/ice shelf, seabed, and riserless drilling platforms) will likely make the most significant scientific advances. As each sector of the Antarctic has its own glacial and climatic history, transects from a variety of drainage basins are critical for constraining climate and ice sheet models. Key transect areas were identified at community workshops held in 2009 and 2012 (http://www.scar-ace.org), and a preliminary drilling strategy was presented at the IODP New Ventures in Exploring Scientific Targets meeting (INVEST; http://www.marum.de/iodp-invest.html), from which the IODP Science Plan for 2013-2023 *Illuminating Earth's Past, present, and Future beyond 2013* was developed. While legacy drilling material is an important component of this approach, these sequences are geographically limited, recovery is often poor, and records do not always target key climatic intervals.

STRATEGIES ON HOW TO APPROACH MAIN SCIENTIFIC OPEN QUESTIONS BY DRILLING

A number of palaeoclimate questions from critical times-slices in the evolution of the Antarctic cryosphere have been answered in limited locations. These range from determining environmental conditions from paratropical rainforest during the Early Eocene (Pross et al., 2012) to the onset of the Cenozoic glaciation of the continent ~34 million years ago (Kennett, 1977; Barrett, 1989; Hambrey et al., 1991; Wise et al. 1992; Exon et al., 2001; Anderson et al., 2011; Wellner et al., 2011), and to the more recent West Antarctic Ice Sheet (WAIS) retreat and re-advance events during the Pliocene and Pleistocene in various locations on the continental margin (e.g., Naish et al., 2009). While the potential for reconstructing past ice sheet history has been demonstrated through a careful integration of geological and geophysical, data with numerical ice sheet modelling (e.g., DeConto and Pollard, 2003; Naish et al., 2009; Pollard & DeConto, 2009; Weber et al., 2011), uncertainties remain high due to the sparse geographic distribution of the records and the variability in the ice sheet's response. To understand how the Antarctic ice sheet affects and is affected by climatic and oceanic processes, comprehensive records from ice proximal to deep-sea environments are needed at carefully chosen time intervals that provide the best analogues for predicting future climatic changes.

The West Antarctic and East Antarctic ice sheets differ in ice mass balance, size, maximum elevation, age of oldest ice and depth to subglacial bedrock. Geological records from the East and West Antarctic continental margins are required from areas where the ice sheet is grounded below sea level and where the bed becomes deeper towards the interior of the ice sheet to better understand the forcings and feedbacks involved with the onset and Cenozoic evolution of these ice sheets. This configuration is thought to be inherently unstable (Weertman, 1974; Schoof, 2007), particularly in regions where warm, relatively saline Circumpolar Deep Water inundates the continental shelf (Jacobs et al., 2011; Pritchard et al., 2012). Ice proximal to distal multi-platform drilling transects from West and East Antarctic drainage sectors into the Southern Ocean will provide an improved understanding of processes that control the stability/instability of the Antarctic cryosphere. Moreover, global sea-level reconstructions for the Last Interglacial Period (Kopp et al., 2009) and the mid-Pliocene (Miller et al., 2012) suggest very high sensitivity of the polar ice sheets to relatively small increase in global mean surface temperature and climate forcings. An improved understanding of the processes and feedbacks that affect Antarctic amplification, especially their influence on ocean circulation and marine ice sheet stability, is critically needed from strategically located transects of marine sediment cores on the most vulnerable margins.

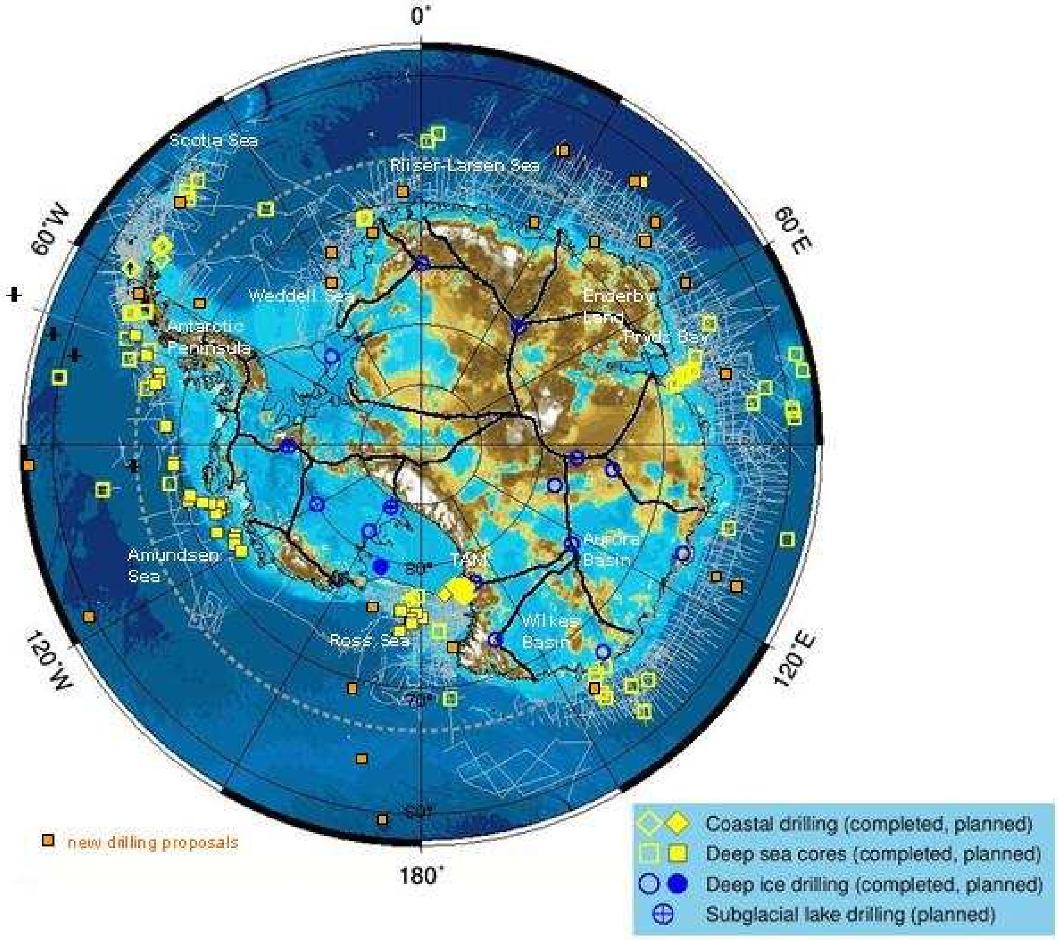

Figure 5 PAIS drilling strategy showing the ice sheet-ice shelf-offshore transects within specific drainage sectors of interest to reconstruct ice sheet dynamics and paleoclimate from vulnerable areas of the Antarctic margin and the Southern Ocean. These are indicated by bed elevation (i.e., marine-based ice sheet). Black lines delineate the main ice divides. Bed elevation and ice sheet velocity maps modified from Bedmap (Lythe et al., 2001) and Rignot et al., 2011a, respectively. Graphic: Dan Zwartz.
Yellow squares indicate existing and active IODP and ANDRILL proposals. Orange squares indicate new proposals (IODP, MeBo, ANDRILL)

Outstanding scientific questions to be addressed by ocean drilling in different sectors of the East and West Antarctic margin are relevant to three of the IODP Science Themes:

1) Climate and Ocean Change: Reading the past informing the future.

- Challenge 1: How does Earth's climate system respond to elevated levels of atmospheric CO_2?
- Challenge 2: How do ice sheets and sea level respond to a warming climate?
- Challenge 3: What controls regional patterns of precipitation, such as those associated with Monsoons or El Niño? (in areas where ultra-high resolution Holocene records exist – e.g., Wilkes Land, Prydz Bay, Antarctic Peninsula)

2) Earth Connections: Deep-processes and their impact on Earth's subsurface environment

3) Biosphere Frontiers: Deep life, biodiversity, and environmental forcing of ecosystems

HYPOTHESES UNDERPINNING FUTURE SCIENTIFIC DRILLING AROUND ANTARCTICA AND IN THE SOUTHERN OCEAN

Icehouse world, Oligocene to present: *What is the contribution of Antarctic ice to past and future sea level changes in terms of rate and magnitude? Can Antarctic ice volume/sea level records be reconciled with far-field deep ocean oxygen isotope and temperature proxy records?*

1. The size of the ice sheets, the extent of sea ice, and the latitude of the Polar Front are all linked. Models and the little data available suggest that when the ice sheets expand, sea ice extends farther north, and the atmospheric and the oceanic frontal systems also migrate northwards. The contrary occurs when the ice sheet retreats. This affects sea level, wind patterns, the Antarctic Circumpolar Current, ocean temperatures, the oxygen isotopic composition of sea water and ice, deep-water formation, oceanic productivity and CO_2 exchange with the atmosphere, each of global climate significance. New drilling proposals seek to characterize the Cenozoic evolution of the Antarctic cryosphere and Southern Ocean system, including long term trends, orbital cyclicity, and the magnitude and rates of change in different locations to test models and provide confident pictures of environmental condition occurring at past critical climate thresholds. Proposals include investigations of the timing and response of the Antarctic cryosphere and of Southern Ocean system to external and internal forcing mechanisms, past climate teleconnections and interhemispheric links, the development of the Ross and Weddell Gyres, past surface and deep-water circulation and relationships to global climate.
2. The ice sheet is most vulnerable at major ice streams and ice shelves where ice is grounded below sea level. Drilling proposals testing this hypothesis aim to characterize ice behavior in the major drainage sectors through the study of continental archives and their seaward counterparts on the continental shelf, slope, and rise.
3. Far-field Oligocene-Miocene deep ocean oxygen isotope records (e.g. Zachos et al., 2001; Pälike et al., 2006) imply significant ice volume fluctuations from the EAIS when atmospheric pCO2 levels were between 400-600ppm, yet available ice sheet models (e.g. DeConto and Pollard, 2003) imply significant hysteresis of EAIS requiring up 4x PAL CO2 to cause retreat of sufficient magnitude. The most noticeable example is the transition from warmth in the late Oligocene to the earliest glaciations (Mi-1) of Pliocene implying 80m ice volume equivalent sea-level fall. Understanding EAIS sensitivity to this range of pCO2 is of critical importance to future climate projections, and proximal geological records are required from the Antarctic margin.
4. Antarctic ice retreat can be caused by either surface or basal warming. Using the developing proxies for temperature, new techniques in geochemical provenance, and the latest ice sheet, GIA and ocean models, the past ice extent and ocean paleotemperatures can be more precisely determined. Antarctic sediments have recorded past climates that can provide analogues to better predict ice response to future warming (Hellmer et al., 2012).

Greenhouse world, Cretaceous to Eocene: *What did a "greenhouse world" look like in Antarctica? Can Antarctica sustain any ice sheets when the atmosphere is above 1000 ppm CO2?*

1. Antarctica is a key location to examine the Earth's greenhouse climate states, such as the early Eocene and the middle part of the Cretaceous. Remarkably warm climates are indicated at Antarctic sites where Eocene material has been recovered (Francis et al., 2009; Pross et al., 2012). This is crucial data that defines the low equator-to-pole temperature gradient and suggests drastic polar amplification of warming during greenhouse climates. Models suggest changes in climate sensitivity to CO_2 may be required to produce this low meridional temperature gradient. Thus it is vital to future climate predictions to place high-latitude constraints on temperatures and their variability. This can be accomplished by accessing Cretaceous to Eocene sediments from the Antarctic continental margin.
2. Eocene hyperthermals, including the Paleocene-Eocene thermal maximum, may result from rapid carbon release from Antarctic permafrost (DeConto et al., 2012). Evidence for this recently-proposed hypothesis would be most likely to be found in Paleogene sediments around Antarctica.
3. Mid- and late Eocene climate cooling led to the initiation of major glaciation at the Eocene/Oligocene boundary. Pre-cursor glacials may have existed during the late Eocene, and the details of the threshold conditions that led to full glaciation can be found. Direct evidence for such glaciations would be found in proximal Paleogene sediments around Antarctica.

Tectonics and climate:

1. The pattern and cause of Gondwana breakup is recorded in some large igneous provinces and continental fragments of the Southern Ocean. Drilling into hard rock of these features will provide valuable data to assess their role of both deep-earth geodynamics-magmatic processes and paleoenvironmental conditioning of the Cretaceous hothouse world.

2. The timing of rifting and subsidence control the opening of ocean gateways and the initiation of the circumpolar current system. Shelf and deep-water sediments hold the information that can date the timing and gauge the effects of gateway opening. They can also provide improved constraints for Antarctic paleotopography, which is an important factor in models of past ice sheets. Initial attempts to reconstruct paleotopgraphy at the Eocene/Oligocene boundary have recently been made (Wilson and Luyendyk, 2009; Wilson et al., 2012). Detailed paleotopography and paleobathymetry grids series of time periods relevant to major climate changes are some of the yet missing constraints for much improved paleoclimate models. The existing network of seismic profiles around the Antarctic margin provide vital strata information for such reconstructions but need to be validated and calibrated by chronology and facies analysis from drill samples.
3. The ice sheet covers 99.6% of Antarctic bedrock (Fox and cooper, 1994), and only a handful of ice coring sites have penetrated to the bed of the ice sheet. Even where sites have penetrated to the ice bed, penetration into the bed has been limited to only a few metres. However, glacial erosion products of bedrock material transported and deposited around the continental margin have started to reveal a pattern of the subglacial geology. This helps us to understand the major crustal blocks and the fundamental deep-earth structure of the Antarctic continent.

THE WEST ANTARCTIC MARGIN AND THE SOUTHERN PACIFIC OCEAN: ACTIVE AND NEW DRILLING PROPOSALS

Depth and latitudinal transects for future deep and shallow drilling projects are identified in 4 main regions of the **West Antarctic margin** and 3 regions of the **South Pacific Ocean** on the basis of their ice drainage systems and existing data (figure 5):

- Ross Sea (drainage area of WAIS Siple coast and Transantarctic Mountains glaciers): proposals IODP 751-Full and ANDRILL-CH and *new* IODP-MSP (*Mission Specififc Platform) and ANDRILL proposals*
- Amundsen Sea (drainage area of WAIS through Pine Island - Thwaites glaciers): proposal IODP 784-Full and MeBo shallow drilling proposal
- Antarctic Peninsula margin and Bellingshausen Sea (drainage areas of Antarctic Peninsula Ice Sheet and WAIS north of Ellsworth Land): proposal IODP 732-Full2
- Weddell Sea (drainage area of WAIS north of Ellsworth Land and EAIS Shackleton Range/Coats Land): *new IODP proposal (former IODP 503-Full)*
- Scotia Sea (integrative ice rafting record from all Antarctic ice sheets) with sites from the Chile margin and the northern Antarctic Peninsula. *New IODP proposal.*

- South-East Pacific Paleoceanography (SEPAP): new IODP proposal
- South-West Pacific Paleoceanography (SOWEPAP): new IODP proposal
- Paleogene South Pacific Latitude Transect (SPLAT): IODP 567-Full

The Ross Sea is a large embayment of the West Antarctic continental margin, bounded to the west by the Transantarctic Mountains (TAM) and to the south by the Ross Ice Shelf. The Ross Ice Shelf is the floating extension of the Siple coast ice streams (e.g. the Whillans Ice Stream) that represent the main drainage system of the WAIS toward the Southwest Pacific Ocean. The Ross Ice Shelf is also the seaward floating termination of outlet glaciers, draining the East Antarctic Ice Sheet thought the TAM (e.g. Byrd Glacier). The continental shelf is the widest in Antarctica and Cenozoic tectonic subsidence allowed the accumulation of a large thickness of glacial and interglacial sediments.
Exisiting proposals aim to drill the sea floor below the floating Ross Ice Shelf, both near its outer edge (e.g. the ANDRILL Coulman High project and new ANDRILL and MSP proposals in the Roosevelt sub-basin) and near the ice grounding line (e.g. the WISSARD project in the Whillans Glacier, and also in the outer continental shelf and rise (IODP 751-Full and a new MSP proposal along the North Victoria Land coast and Northern Basin) will provide the full range of information on the WAIS and EAIS dynamics and evolution from records deposited in the ice proximal and distal sectors. The correlation with existing records (DSDP Leg 28, DVDP, CIROS-1, MSSTS-1, CRP1,2,3, ANDRILL-MIS and SMS projects) and the good coverage of seismic data will allow a comprehensive reconstruction of the Cenozoic changes.

Amundsen Sea, Bellingshausen Sea and Pacific margin of Antarctic Peninsula
Drilling in this sector aims to retrieve sediment cores that record the dynamic behavior of the WAIS and APIS. Rapid retreat of the ice margin is currently occurring from the Amundsen Sea Embayment (ASE) to the

western Antarctic Peninsula. Negative ice mass balance in the ASE and off the western Bellingshausen Sea margin are the largest of any of the Antarctic regions, which makes these systems a main contributor to present sea level change. A network of seismic profiles has been acquired in these areas in the last 10 years, but as yet no drill cores exist to place recent observations in a long-term context and constrain models of paleo-ice sheet dynamics. Shallow drilling using the MeBo seabed drilling device will enable collection of samples from dipping sediment sequences on the inner to middle shelf that crop out at the seafloor or are covered by only a few meters of glacial till and were deposited in pre-glacial to early glacial periods. Other proposed sites for MeBo drilling will enable study of subglacial processes that operated during the last glacial period, e.g. drilling into grounding zone wedges and meltwater channel fills. IODP transect drilling (e.g. proposal IODP 784-Full) on the ASE continental shelf to rise will aim for longer and more continuous cores of strata from early glacial to Pliocene-Pleistocene periods to address WAIS dynamics of warm time intervals, past Circumpolar Deep Water incursions and the WAIS response to Marie Byrd Land uplift.
The main aim of IODP drilling (e.g. proposal IODP 732-Full) on sediment drifts on the continental rise in the Bellingshausen Sea and off the western Antarctic Peninsula will be to obtain continuous, high resolution Pliocene-Pleistocene records of WAIS and APIS changes, together with paleoceanographic records spanning the same period. Most sites are located on the shallowest parts of drift crests to maximize the likelihood of carbonate microfossils being preserved, and isotope records will be combined with relative paleomagnetic intensity dating to obtain chronologies with near-millenial scale resolution. Expanded Late Miocene and Paleocene records can also be targeted in this area.

The **Weddell Sea** is a large embayment of the Antarctic continental margin facing the Atlantic Ocean and partly covered by the Filchner-Ronne Ice Shelf. The ice shelf drains both the WAIS from the area north of Ellsworth Land (with Rutford Ice Stream, Institute Ice Stream and others) and the EAIS from Shackleton Range/Coats Land (with Slessor and Recovery Glaciers, and others) and further to the east other ice streams flow into smaller ice shelves (e.g. Veststraumen Ice Stream and Stancomb-Wills Ice Stream. The new IODP proposal aimed to drill the Weddell Sea will obtain high-resolution records from continental slope and rise contourite ridges (Weber et al., 2011). Variations in glacial/interglacial brine and bottom water formation, in CO_2 sequestration, alkalinity (Rickaby et al., 2010) and depth of the CCD, the onset and variability of the Weddell Gyre circulation, and the occurrence and variability of the Antarctic Gateway between the Ross and Weddell Sea without a blocking West Antarctic Ice Sheet are to be addressed. The Cenozoic cooling and glacial history will be determined from sedimentary sequences drilled on the Polarstern Plateau, Torge Plateau, and the slope off Atka Bay, with alternate sites on Maud Rise. In addition, the Mesozoic record will complement the one drilled by ODP Leg 113 and will provide clues about the opening history of the restricted Jurassic-Cretaceous Weddell Basin (Jokat et al., 2003; Leinweber and Jokat, 2012; Mutterlose and Wise, 1990) after the breakup of Gondwana, as well as insight into high-latitude processes in a warmer climate. Did the anoxic basin change steadily or stepwise in a greenhouse world? Can we determine Oceanic Anoxic Events? Are high-latitude Mesozoic faunas and floras adequately preserved?
Alternate and new sites in the **Scotia Sea** are located in a distal position to the Weddell Sea sites (Weber et al., 2012). It should provide crucial information on the timing and magnitude of Antarctic ice-sheet disintegration events, the opening of the Drake Passage and the influence on the Antarctic Circumpolar Current (ACC), The Scotia Sea surrounds the Drake Passage and connects the Atlantic with the Pacific Oceans as well as the Antarctic Peninsula with Patagonia. This region is crucial with respect to past changes in meridional overturning and the establishment and variability of various oceanic and atmospheric fronts along the ACC.

The **Southern Pacific Ocean** represents a major site of deep and intermediate water formation and it represents the prime location to improve understanding of past Antarctic cryosphere stability/instability, as it collects about 70 % of the West Antarctic Ice Sheet drainage. Presently, this sector is particularly sensitive to low to high latitude teleconnections, (e.g. El Niño-Southern Oscillation, SAM), suggesting that these teleconnections may have played an important role in past cryosphere development.
To date, our picture of Southern Ocean Cenozoic climate development at tectonic to orbital time-scales is primarily based on paleoceanographic studies from the Atlantic and Indian Ocean sectors of the Southern Ocean and very little information is available from the Pacific Sector (apart from DSDP leg 28, ODP leg 189), though it constitutes the largest portion of the Southern Ocean. IODP proposals in the west, central and east Pacific Ocean aim to test: 1) its response to the opening and closure of gateways and South Pacific basin shaping, and its implication for Antarctic continental ice sheet and ice shelf development; 2) to Evolution of surface water temperatures and the oxygen isotopic composition of seawater during the mid Miocene phase of Antarctic ice sheet expansion; 3) Timing and response of Pacific Southern Ocean paleoceanography to external forcing mechanisms and past climate teleconnections.

The West Antarctic margin and the Southern Pacific Ocean:

IODP 732-full2 Antarctic Peninsula (AP), IODP 784-full Amundsen Sea (ASE), IODP 751-full Eastern Ross Sea (ERS), IODP 567-full Southern Pacific Ocean (SPLAT) and in the Southwestern Pacific Ocean (SOWEPAP) are scientifically linked because all of them will detect the signal of WAIS dynamics in different sectors of West Antarctica and the influence on the sedimentation of past circulation changes (warm current intrusions onto the continental shelf, Antarctic bottom water formation, shifts of the Polar Front).

The Antarctic Slope Current and Coastal Current coming from the narrow shelf between the Amundsen and the Ross Seas shows nearly freezing temperature and low salinity content. This water masses enter the Ross Sea continental shelf from Cape Colbeck and reach the Ross Ice Shelf via the Little America Trough. An array of moorings is monitoring the subsurface temperature, salinity and current of these water masses, near the outer and mid sector of the Little America Trough. The measurements reveal active ocean-ice interactions, with meltwater outflow in early winter, preceded by relatively warm subsurface influences throughout the summer (Orsi, 2012, SCAR OSC abstract)

Observations from repeated hydrography program (NSF/CLIVAR project) in the Ross Sea show evidence of decadal scale changes of the water mass properties, circulation patterns and transports (Orsi, 2012 SCAR-OSC abstract). The densest Ross Sea outflow is no longer distinguishable by its high salt content from other sources. It became lighter primarily due to lower salinities of the source waters. The Ross Sea densest outflow water is presently substituted by warmer but far-reaching, as documented by progressive and widespread warming of the abyssal ocean. The bulk of deep northern source waters entering the subpolar gyres has also warmed. The observed evolution of the southern Pacific points to the relatively rapid Antarctic response to global change.

During the last two decades warm deep water floods the troughs of the Amundsen Sea continental shelf, thinning the floating ice and accelerating its glaciers (Jacobs et al., 2012). Records are still too sparse to understand the impact of local versus more regional changes on the global sea level rise. The upper deep ocean water is warming (Levitus et al. 2009), the modeled continental shelf circulation is sensitive to sea ice production (Hellmer et al., 2012), and the response of deep-draft ice to ocean temperature may not be linear (Rignot and Jacobs, 2002; Holland et al., 2008).

The time correlation of similar events recorded in both the ASE and Eastern Ross Sea ERS sectors with the Southern Pacific Ocean record will provide insights into the influence of warm water masses on the stability of the grounding WAIS in the past and will strengthen models simulating the effects of ocean forcing on ice grounded below sea level and on timing and response of Pacific Southern Ocean paleoceanography to external forcing mechanisms, past climate teleconnections and interhemispheric links
The AP, ASE and ERS transects across the West Antarctic margin aim to target a similar sedimentary architecture with the most recent (Plio-Pleistocene) seismic sequence made of aggrading topset beds bound by landward deepening surfaces along glacial troughs in the continental shelf. The continental rise is characterised by giant sediment mounds formed during the phase of maximum margin build-up and shaped by the action of bottom currents. In many cases, seismic reflectors can be correlated from the continental shelf to the rise, which enables the reconstruction of consistent records from ice-proximal to ice-distal processes.

The scientific hypotheses that can be tested by comparing latitudinal and depth drilling transects of AP, ASE and ERS and the Southern Pacific Ocean are: *Did the WAIS collapse in the most recent (Plio-Pleistocene) warmest interglacials? How fast? Which were the mechanisms (rates and modes) that caused the WAIS instability during the Cenozoic?*

The results obtained in AP, ASE, ERS and the Southern Pacific Ocean will be tied with the inner shelf ANDRILL-SMS and MIS results and with existing and future ice cores (e.g. at Byrd, WAIS divide, Fletcher Promontory and Siple Dome) results in order to obtain a full range of information along depth and latitudinal transects of the WAIS.

Major periods of IRD flux, are identified in deep sea records of the Scotia Sea, indicative for enhanced iceberg routing through “Iceberg Alley” at major climatic tipping points. Since Iceberg Alley provides an integrated and representative distal record of ice sheet disintegration, most proposals conducting research on Antarctic ice-sheet dynamics are linked. As the southern extension of the Atlantic Ocean, the Weddell Sea is another key area for Earth’s climate variability because it influences global thermohaline circulation as the major source of AABW formation. Strategically located sediment sites from the continental slope and rise of the Weddell Sea and Scotia Sea provide unique deepwater archives to trace past ice sheet dynamics of

WAIS and EAIS, at high resolution, since the Pliocene and to reconstruct the thermohaline circulation changes and the long-term glaciation history at moderate CO_2 levels.
The proposed coring program stretches over 4 degrees of latitude and includes sites from the continental slope and rise. Studying the crucial Weddell Sea part of the Antarctic ice sheets will complement existing and planned proposals on the continent regarding the West Antarctic Ice Sheet in the Ross Sea counterpart and the East Antarctic Ice Sheet in Mac Robertson Land. It also constitutes a transect from the Weddell Sea to Patagonia, together with the planned IODP proposal for the Scotia Sea.

The East Antarctic margin: active and new drilling proposals

Depth and latitudinal transects for future deep and shallow drilling projects are identified in 4 key regions of the **East Antarctic margin and of the Southern Indian Ocean**, on the basis of their drainage systems and existing data (Figures 5 and 6):

1. Enderby Land, Cosmonaut and Riiser-Larsen Sea, Conrad Rise, Del Caño Rise, South Indian Ocean (drainage area of eastern Dronning Maud Land glaciers and Enderby Land glaciers)
2. Bruce Bank - Kerguelen Plateau (drainage area of Wilhelm II Land and Queen Mary Land)
3. Totten Margin-Budd Coast (drainage area of the Moscow University glacier and the Totten glacier)
4. Adelie-George V Land continental shelf (drainage area of Mertz and Ninnis glaciers)

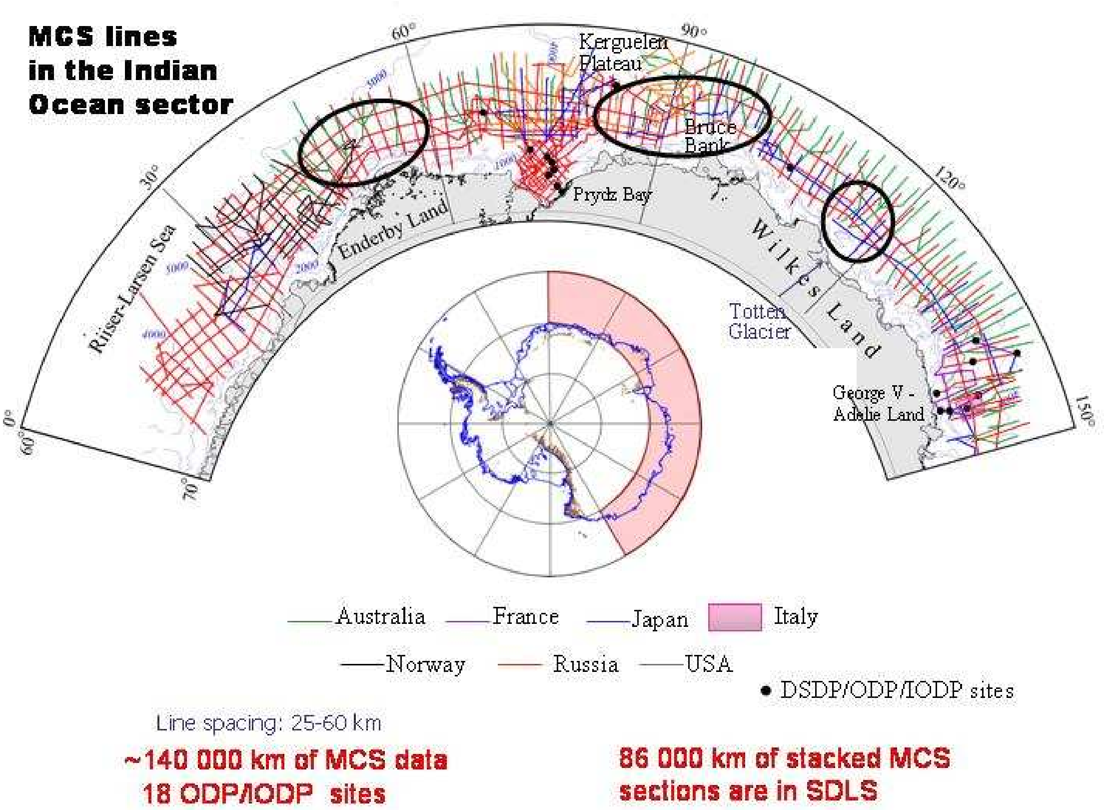

Figure 6. Existing seismic data coverage in key transects across the East Antarctic margin.

The continental shelf of the **Enderby Land margin** is 50-70 km wide and hardly accessible due to its perennial ice coverage. Overdeepened troughs cross the shelf being the result of erosion by glacial advances. The continental rise is characterised, like in the other sectors of the Antarctic margin, by submarine (turbidity) channels and levees. Fields of sediment waves developed on the channel levees, due to overspill and flow stripping from submarine channels and possibly reflecting downslope flow of AABW. Contourite drifts have been observed in the Conrad Rise (Oiwane H. et al., 2012), aligned along the axis of the modern ACC (Durgadoo et al., 2008).
Enderby Land margin was never drilled, despite dense seismic data coverage (e.g. Kuvaas et al., 2005). Up to 6 km of sediments were deposited on the Enderby Land continental margin after rifting between India and Antarctica. The age of the seismic sequences is inferred from the underlying dated oceanic crust and from

indirect correlation with existing ODP and IODP sites from the “nearest” Prydz Bay margin.
Eocene/Oligocene boundary and late Eocene strata can be recovered with shallow and/or deep drilling in water depths of about 3500-4500 m, along the flanks of submarine channels and from the continental shelf where seaward dipping glacial and preglacial strata are proposed to be close to the sea floor. Contourite drifts developed along the lower continental rise of the Enderby Land margin have continuous Early Miocene sections, potentially preserving an archive of Antarctic margin paleoceanography and history of the East Antarctic Ice Sheet.
Drilling the sediment mounds on the Conrad Rise will provide high-resolution data for paleoceanography and paleoclimate studies of the Cenozoic sequence, as demonstrated by the investigations made on Holocene short sediment cores, into which millennial- to centennial-scale variability in winter sea-ice coverage and in the position of the polar front has been observed (Katsuki et al., 2012). A pre-proposal was recently submitted by Ikehara et al. to IODP aimed to drill the Riiser-Larsen Sea and the Conrad Rise. PEP rejected the pre-proposal, but highlighted that the proposal has the potential to make a significant contribution to understanding the Cenozoic evolution of the Antarctic cryosphere and the ACC in the Atlantic/Indian Ocean sector of the Southern Ocean. PEP also provided useful suggestions and encouraged the proponents to resubmit a new pre-proposal. During the Portland workshop and in a following workshop (that was held in Japan in November 2012) some potential co-proponents addressed PEP advices and discussed the integration of all data set available in the proximal and distal areas. to use the latitudinal transect approach, by integrating also results obtained by ODP leg 177 in the Southern Ocean (Gersonde et al., 1999; Hodell et al., 2002). A new pre-proposal to IODP is in preparation and will be submitted after further data processing and proposal editing.
The Queen Maud Land glaciers and Enderby Land glaciers are not recognized to be very dynamic at the moment (see figure 3), although the overdeepened troughs crossing the shelf and the large channel-levees suggest highly dynamic ice flowing during past glacial maximum. The Enderby Land margin, the Riiser-Larsen Sea, the Conrad Rise, the Del Caño Rise and the South Indian Ocean represent a depth and latitudinal transect that will be crucial to reconstruct the evolution of the Antarctic Bottom Water, the polar front shift during past glacial and interglacial cycles.
The Conrad Rise is also a key area to understand the nature (continental or oceanic) of the crust underlying the sediment strata. Gravity anomaly of the western part of the Conrad Rise suggests the volcanism of Ob seamount occurred on the continental crust. However this hypothesis needs to be tested as there are controversial evidence from dredged ancient continental rocks (Coffin pers. communication). The continental crust around Ob seamounts possibly indicate continental fragments left behind in the middle of the Indian Ocean during Gondwana breakup process between India and Antarctica. One of the hypothesis that can be tested by drilling the Conrad Rise is that it is a continental fragment, that was left in the middle Indian Ocean after the separation of India and Antarctica during the breakup of Gondwana.

The **Bruce Bank - Kerguelen Plateau** are located seaward of the drainage area of Wilhelm II Land and Queen Mary Land, although there are no data in the continental shelf to make a depth and latitudinal transect from the Antarctic interior to the Indian Ocean. The Kerguelen Plateau was previously drilled by legs 119-120 and 183 (Barron, J., Larsen, B., et al.,1991; Wise, S.W., r., Schlich, R., et al.,1992; Coffin, M.F., Frey, F.A., Wallace, P.J., et al., 2000) that provided a unique clues into mafic large igneous provinces. The new IODP proposal for drilling Bruce Bank - Kerguelen Plateau is going to investigate “Flood basalts, continental breakup and hotspot tracks. Geodynamic processes and environmental changes associated with the Kerguelen large igneous province (LIP) and hotspot since ~130 Ma” . The volcanic rocks at Bruce Bank are the earliest manifestation of Kerguelen hotspot. Geophysical seismic data reveal also the presence at Bruce Bank of well-stratified predominantly Oligocene-Early Miocene section within the isolated plateau and a section into which greenhouse-icehouse transition and Late Cretaceous-Eocene sediments can be recovered, as well as Early Cretaceous (Hauterivian ?) volcanics.
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The Budd coast - Totten glacier margin is one of the least known, but most important sectors of the East Antarctic margin. It lies seaward of the Totten Glacier that is recognised as potentially the largest drainage system in East Antarctica most sensitive to climate change (e.g. Pritchard et al., 2009). It is the downstream end of a vast subglacial basin, the Aurora Basin, that contains the thickest ice in Antarctica and most of which is below sea level (Roberts et al., 2011, Young et al., 2011). The Totten Glacier drainage basin is the largest within the Wikes and Aurora subglacial basins and it is currently losing mass in most satellite based reconstructions. The subglacial topography suggests that rapid retreat of the Totten grounding line into the Aurora Basin could cause rapid draw down of ice with a sea level effect equivalent to or larger than the West Antarctic Ice Sheet.
Very few data have been collected on the Budd coast, therefore little is known about the ongoing processes in the ice proximal area. It has been proposed that the Totten Glacier is melting because of intrusion of warm Circumpolar Deep Water onto the continental shelf, as is happening in Pine Island Bay.

The existing seismic data, from the slope and rise show that the post-rift and syn-glacial sedimentary units are compared to the whole Wilkes Land margin (more than 4 km and up to 2 km thick, respectively; Close et al., 2007; Leitchenkov et al., 2007) and it is characterised by the largest gravity flow deposits. Inferred sedimentary rates between 39 and 9 Ma were very high and ranging from 160 to 200m/ky (O'Brien et al., 2006; Close et al, 2007). This would imply that the Totten Glacier drainage system has been one of the main provenance areas of sediment erosion and transport along the Wilkes Land margin. Drilling the continental shelf strata and the sediment mounds in the continental rise will be crucial to understand the past Antarctic ice sheet dynamics with respect to the ocean and past climate changes.
US (a site survey cruise to Totten in 2014 on the Palmer is on the USAP/NSF schedule) and Australian (a proposal was submitted in 2012 to use the R/V Investigator and is now under evaluation) coordinated projects are aimed to collect new sediment and seismic data from the Totten Glacier margin at different resolution to be integrated with existing Australian data Russian data and to provide the basis for future drilling proposals, aimed to acquire long palaoeclimate records that will elucidate the development of the Totten Glacier and the Aurora Basin over millions of years.

The peculiarity of the **George V and Adelie Land** continental margin, is located seaward of the Wilkes subglacial basin. It has a narrow shelf and little thickness of post rift sediment, comparing to the Bud Coast margin and but it is that it is the third source area in terms of production of AABW and that a good coverage of geophysical and geology data (e.g. leg IODP 318, Escutia et al., 2010), combined with long series of oceanography and biology measurements, provide excellent basis for identifying key areas to extract paleoclimate and paleoceanography records.
Along the Wilkes Land shelf of Antarctica, shallowly-buried strata represent Antarctica’s climate and ice history from the lush forests of the Eocene greenhouse to the dynamic ice sheets of the Miocene and Pliocene. Yet there are currently very few records of Antarctic climate and ice conditions from close to the continent. On the Wilkes Land Shelf, existing short cores (Domack, 1980) and dredges (Schrum et al., 2004) uncovered Cretaceous, Eocene, and Oligocene-Pliocene sediment close under the sea floor. A network of seismic lines show these gently dipping strata outcropping at the sea floor and easy to be drilled with transects of shallow (~50m) holes (De Santis et al., 2010). A new IODP-MSP is targeting these strata with the aim to provide information on Antarctica’s role in the greenhouse and icehouse climates, and the transitions between the two. Moreover shallow drill sites into deformed strata, onlapping the continental basement, near the coast,, will provide information to date the tectonic phases (De Santis et al., 2010), affecting this sector of the margin, likely related to the Australia-Antarctica rifting and the opening of the Tasman Gateways

The East Antarctic margin: Link among drilling proposals

The drill sites of the four East Antarctic proposals form key parts of latitudinal transects from continent to Southern Ocean. The landward end of the transects are formed by the ice drainage basins of Antarctica. They also provide a longitudinal sampling of different ice drainage sectors of the Antarctic continent.

The Southern Ocean sites of the latitudinal transects will core bathymetric highs on the continental rise, to find past latitudinal migration of the polar fronts, sea ice extent, and perhaps the strength of the ACC (Enderby Land, Bruce Bank). Sites on the continental shelf and slope record ice advances as glacial erosion surfaces, and are the only direct way of determining the ice extent through warm-cold cycles, and can be set in the context of migrations of the Southern Ocean fronts (George V Land, Budd Coast), of the Antarctic Coastal Current and of the Weddell Sea Gyre (Enderby Land margin and the Cosmonaut and Riiser-Larsen Sea). Southward movement of the fronts sets the scene for warmer water incursions onto the shelf, and faster retreat of the main outlet ice streams, as is currently occurring in the Pine Island glacier of West Antarctica. Variability of coastal polynyas and wind strength have influenced the AABW formation in past times (e.g. in the George V-Adelie Land margin, Harris et al., 2001).

The four proposals contrast with each other in terms of ice flow and potential ice loss from the neighbouring continent, from the mountainous hinterland of Enderby Land to the Wilkes and Aurora subglacial basins (George V Land, Budd Coast) where ice is grounded well below sea level on slope that deepens towards the continental interior, an unstable configuration under warming conditions. These differences are reflected in the thicknesses of glacially-eroded sediment that accumulates offshore: the Totten (Budd Coast) and Lambert glacier produce the most, indicating focusing of glacial erosion in these areas, probably as the result of ice advance and retreat.

All time scales are represented, from Holocene fluctuations and the last deglacial (Budd Coast), to the Pleistocene 100 kyr cycles (Enderby Land, Bruce Bank), to the superinterglacials of the Pliocene, to the mid Miocene climate optimum, and the Eocene-Oligocene inception of major Antarctic ice sheets (George V Land, Enderby Land, Bruce Bank).

The proposals also link with existing and proposed drilling campaigns to form latitudinal transects. For example, the George V Land shelf proposal links the Wilkes subglacial basin, the rise sites of IODP Exp. 318, and the ODP Exp. 189 sites at the Australian side of the Southern Ocean. The Enderby Land proposal forms a transect of the Riiser-Larsen slope, Conrad Rise, and Del Caño Rise and links to the southern end of the ODP Leg 177 South Atlantic latitude transect. Latitudinal comparisons are important for specific time intervals, for example the Eocene of George V Land and Coulman High (ANDRILL) are separated by 10°of latitude.

This set of proposals will also investigate: the break-up of Gondwana and the rifting of Africa, India and Australia north from Antarctica; the timing of the opening of the southern ocean gateways; the role of large igneous provinces in this breakup (and also their possible influence on ocean chemistry and climate) (Enderby Land, Bruce Bank, George V Land). The targeted bathymetric highs, as well as providing sediment records of southern ocean paleoceanographic change, may also be identified as continental fragments that were isolated during rifting (e.g. Conrad Rise).

Status of site survey
About 350.000 km of multichannel seismic data have been collected so far from the Antarctic margin south of 60°S, by several nations (figure 5). The SCAR A NTARCTIC Seismic Data Library System (SDLS) http://sdls.ogs.trieste.it/ provides open access to all the multichannel seismic-reflection data. The digital data are distributed on DVD to library branches worldwide, but have also been made available from the SDLS website for free download. These data represent the basis for identifying the location of drill sites.

Sediment cores and seismic data are available for most of the proposals aimed to drill the West Antarctic margin (Amundsen Sea-Bellingshausen Sea, Antarctic Peninsula, Ross Sea) and South Pacific Ocean although in some cases additional crossing seismic profiles will be required.

The seismic data coverage in the East Antarctic margin is good in some areas, targeted by specific, new proposals (e.g. the George V Land margin, Prydz Bay) to be tied and to complement existing data (Leg IODP 318, ODP 188, ODP 119). However the seismic grid is generally still too sparse to aim for regional depth and latitude drilling transects (e.g. in the Budd Coast, Totten Glacier margin). Some areas of the continental shelf are almost completely unexplored. However the existing data are used to identify best regions to conduct further surveys, from where we can extract large sediment records to address the scientific questions outline above.

Conclusions

Most of the Antarctic drilling proposals are located in the areas that are potentially most vulnerable today and also in the past to changing climate and glacial conditions, with the aim of detecting morphologic, sedimentological and bio-geo-chemical signals of patterns, causes, rates and consequences of previous ice sheet retreat and collapse. This information will be crucial to validate current models of modern ice-sheet stability and achieve better constraints for projections of future instability.
To test globally relevant scientific hypothesis by extracting information from past sedimentary records in the polar regions, we need to understand the meaning of the stratigraphic record that is sometimes difficult to decipher. Therefore we need to advance our understanding of processes involved in forming natural sedimentary archives. For this we will cross-correlate and compare sedimentary sequences deposited in different environmental settings, during the same time. These data are crucially needed to build realistic modeling of past ice-sheet dynamics, also considering glacial isostatic adjustment, subglacial morphology, ice melting by a warming ocean and impact on the stability of grounded ice and floating ice shelves.

The coordinated action plan for Antarctic drilling presented here prioritizes depth transects from sub-ice areas to the oceanic abyss, in different key sectors of the East and West Antarctic margins in order to detect the modes and rates of ice-sheet volume versus oceanic frontal changes in past warmer times.
Considering the present status of proposals (on the basis of the IODP PEP Proposal Evaluation Panel evaluation and the available site survey data) and the planned location of the Joides Resolution (JR) at the onset of the next phase of IODP, we conclude that there are several deep sea drilling proposals, requesting

the use of the JR in the South Pacific Ocean sector, that are enough mature (one is in the OTF status and one has PEP highest ranking), to be eventually considered for drilling. There are some other proposals, (like for example the ones to drill in the Weddelle Sea, the Scotia Sea, the Totten margin, the Conrad Rise), that are in an initial stage and will need a longer time to develop full mature proposals. In some cases more site survey data is needed (like in the East Antarctic continental shelf, that is still almost unexplored), and more work on data processing and integrating is planned before editing drilling proposals to test outstanding scientific hypothesis,.

There are some highly relevant locations both in the EAIS and in the WAIS sectors that can be drilled by IODP-MSPs (e.g. shallow drilling), considering the good existing site survey and their high scientific importance (i.e., Wilkes Land continental shelf in the pre-proposal stage). The coordinated set of IODP-MSP proposals already submitted and to be submitted, are endorsed by PAIS and supported by a large international scientific community. These IODP proposals are also coordinated through PAIS with continental (i.e., Lake Ellsworth) and nearshore-coastal drilling programs (i.e., ANDRILL portfolio proposals).

The current (3/12/2012) state of planning and development for Antarctic drilling projects

Active Proposals	**Name of PI**	**status**	**Region**
IODP 751-Full	Bart Phil (USA)	To be re-submitted to PEP on April 1st 2013	Ross Sea, Eastern, outer shelf, slope and rise
ANDRILL –CH	Luyendyk Bruce (USA)	Ongoing scientific review. First drilling is planned for 2014-2016	Ross Ice Shelf / Coulman High
784-Full	Gohl Karsten (Germany)	Re-submitted with corrections to PEP on October 1st 2012	Amundsen Sea Embayment shelf and rise
732-Full	Channell Jim (USA)	PEP highest ranking	West Antarctic Peninsula & Bellingshausen Sea sediment drift
New pre-proposal	Wise Woody (USA)	Submitted to PEP on Oct. 1st, 2012	Weddell Sea and Scotia Sea
New pre-proposal	Williams Trevor (USA)	Submitted as a Mission Specific Platform (MSP) pre-proposal on October 1st 2012	Adelie-George V Land margin (East Antarctica)
567-Full	Thomas Debbie (USA)	OTF. Waiting for scheduling.	South Pacific
625-Full	Gersonde Reiner and Lamy Frank (Germany)	To be submitted as a full proposal revised (including only the South east Pacific sites) On April 1st 2013	South East Pacific

Future proposals	**Name of PIs**	**Status**	**Region**
IODP-MSP	Busetti, De Santis, Sauli, Levy, Lyendyk, Bart et al. (Italy-USA)	Pre-proposal to be submitted on April 1st 2013	Ross Sea, North Victoria Land coast and Northern Basin
IODP-MSP	Luyendyk, Wilson et al (USA)	Pre-proposal (ex SHALDRILL) will be submitted after ANDRILL-Coulman High drilling	Ross Sea, Eastern inner shelf, Roosvelt Is.
ANDRILL	Naish Tim (NZ)	Pre-proposal will be submitted after seismic survey	Ross Ice Shelf: Kamb Ice Stream, Siple coast
ANDRILL	Harwood David (USA)	Pre-proposal will be submitted after seismic survey	Ross Ice Shelf, TAM Byrd Glacier, Discovery Deep
ANDRILL	Pekar Steve (USA)	Pre-proposal will be submitted after ANDRILL Coulman High drilling	Ross Sea, Southwestern coast, off Shore New Harbor
IODP	Weber, Lamy, Domack et al. (Germany, USA)	Pre-proposal to be submitted Apr. 1st, 2013	Scotia Sea, Chile margin, Antarctic Peninsula
IODP	Lamy Frank (Germany)	To be submitted as a pre-prop. On April 1st 2013	South West Pacific
IODP	Ikehara, Leitchenkov, Kuhn, Naish, Dunbar, Crosta, et al. (Japan, Russia, Germany, NZ,	Former pre-proposal 804. To be re-submitted as a pre-prop. On April 1st 2013 A workshop was held in Nov. 2012	Enderby Land, Riiser-Larsen Sea, Conrad Rise, Del Caño Rise, South Indian Ocean

	USA, France)	in Japan	
IODP	Coffin, Leitchenkov et al (AUS, Russia)	Pre-proposal submitted by Apr. 2013	Kerguelen Plateau, Princess Elizabeth Trough; Bruce Bank
IODP	O'Brien, Leitchenkov et al. (AUS, Russia, USA, Italy, Germany)	Waiting for a better site survey (pending NSF and AUS proposals for site survey)	Totten Glacier margin - Budd Coast

Reference list

Anderson, J.B., S. Warny, R.A. Askin, J.S. Wellner, S. Bohaty, A.E. Kirshner, D.N. Livsey, A.R. Simms, T.R. Smith, W. Ehrmann, W. Majewski, D.L. Barbeau, Jr. 2011. Progressive Cenozoic cooling and the demise of Antarctica's last refugium. Proceedings of the National Academy of Sciences of the United States of America 108:11,256–11,360, http://dx.doi.org/10.1073/pnas.1014885108.

Bamber, J.L., R.E. Riva, B.L.A. Vermeersen, and A.M. LeBrocq. 2009. Reassessment of the potential sea-level rise from a collapse of the West Antarctic Ice Sheet, Science, 324(5929), 901-903.

Barrett P.J.,1989. Antarctic Cenozoic history fro the CIROS-1 drillhole, McMurdo Sound, Bull. 245, 254 pp., Dep. of Sci. and Ind. Res., Wellington, New Zealand.

Barron J., B. Larsen, et al., 1991. Proc. ODP, Sci. Results, 119: College Station, TX (Ocean Drilling Program). doi:10.2973/odp.proc.sr.119.1991.

Close D.I., H.M.J. Stagg, and P.E. O'Brien. 2007. Seismic stratigraphy and sediment distribution on the Wilkes Land and Terra Adelie margins, East Antarctica. Marine Geology, 239, 33-57.

Coffin, M.F., F.A. Frey, P.J. Wallace, et al. 2000. *Proc. ODP, Init. Repts.,* 183: College Station, TX (Ocean Drilling Program). doi:10.2973/odp.proc.ir.183.2000

Cramer B.S., Miller K.G. Barrett P.J., Wright J.D. 2011. Late Cretaceous-Neogene trends in deep ocean temperature and continental ice volume: Reconciling records of benthic foraminiferal geochemistry ($\partial^{18}O$ and Mg/Ca) with sea level history. Journal of Geophysical Research, vol. 116, C12023.

DeConto, R.M., D. Pollard. 2003. Rapid Cenozoic glaciation of Antarctica induced by declining atmospheric CO2. Nature 421, 245–249.

DeConto, R., D. Pollard, P. Wilson, H. Pälike, C. Lear, and M. Pagani. 2008. Thresholds of Cenozoic bipolar glaciation. Nature 455:652–658, http://dx.doi.org/10.1038/nature07337.

DeConto, R.M., S. Galeotti, M. Pagani, D. Tracy, K. Schaefer, T.J. Zhang, D. Pollard, and D.J. Beerling. 2012. Past extreme warming events linked to massive carbon release from thawing permafrost, Nature, 484(7392), 87-91.

De Santis, L., G. Brancolini, F. Donda, and P. O'Brien. 2010. Cenozoic deformation in the George V Land continental margin (East Antarctica), Marine Geology, 269(1-2), 1-17.

Domack, E. W., W. W. Fairchild, and J. B. Anderson.1980. Lower Cretaceous sediment from the East Antarctic continental shelf, Nature, 287(5783), 625-626.

Domack, E., Duran, D., Leventer, A., Ishman, S., Doane, S., McCallum, S., Amblas, D., Ring, J., Gilbert, R., and Prentice, M., 2005, Stability of the Larsen B ice shelf on the Antarctic Peninsula during the Holocene epoch, Nature, 436, 681-685.

Donda F., P.E. O'Brien, L. De Santis, M. Rebesco, and G. Brancolini. 2008. Mass wasting processes in the Western Wilkes Land margin: implications for the East Antarctic glacial history. Paleogeography, Paleoclimatology, Palaecology, 260, 77-91.

Durgadoo, J.V., R E. Lutjeharms, A. Biastoch, and I. J. Ansorge. 2008. The Conrad Rise as an obstruction to the Antarctic Circumpolar Current. Geophysical Research Letters 35, L20606, doi:10.1029/2008GL035382.

Escutia, C., H. Brinkhuis, A. Klaus, and the Expedition 318 Scientists. 2011. Proc. IODP, 318: Tokyo (Integrated Ocean Drilling Program Management International, Inc.).

Escutia, C., Florindo, F., Bentley, M., and DeConto, R. (Editors). 2012. Cenozoic Evolution of Antarctic Climates, Oceans and Ice Sheets, Palaeogeography, Palaeoclimatology, Palaeoecology, in press.

Francis, J.E. , S. Marenssi, R. Levy, M. Hambrey, V.C. Thorn, B. Mohr, H. Brinkhuis, J. Warnaar, J. Zachos, S. Bohaty and R. DeConto. 2009. From Greenhouse to Icehouse – The Eocene/Oligocene in Antarctica. In Developments in Earth & Environmental Sciences, 8. Elsevier Publ. F. Florindo and M. Siegert (Editors), p. 311-372, DOI 10.1016/S1571-9197(08)00001-3.

Frey, F.A., Coffin, M.F., Wallace, P.J., and Quilty, P.G. (Eds.), 2003. Proc. ODP, Sci. Results, 183: College Station, TX (Ocean Drilling Program): College Station, TX (Ocean Drilling Program).

Gersonde, R., Hodell, D.A., Blum, P., et al., 1999. *Proc. ODP, Init. Repts.,* 177 [Online]. Available from World Wide Web: <http://www-odp.tamu.edu/publications/177_IR/177TOC.HTM>.

Hambrey M.J., B. Larsen and W.U. Ehrmann. 1991. The glacial record from the Prydz Bay continental shelf, east Antarctica. Proc. Ocean Drill.Program Sci. Results, 119, 77-132.

Harris, P.T., Brancolini, G., Armand, L., Busetti, M., Beaman,R.J., Giorgetti, G., Presti, M., Trincardi, F., 2001. Continental shelf drift deposit indicates non-steady state Antarctic bottomwater production in the Holocene. Marine Geology 179, 1–8.

Hellmer, H.H., F. Kauker, R. Timmermann, J. Determann, and J. Rae. 2012. Twenty-first-century warming of a large Antarctic ice-shelf cavity by a redirected coastal current. Nature, v. 485, p. 225-228, doi:10.1038/nature11064.

Hodell, D.A., Gersonde, R., and Blum, P., 2002. Leg 177 synthesis: insights into Southern Ocean paleoceanography on tectonic to millennial timescales. *In* Gersonde, R., Hodell, D.A., and Blum, P. (Eds.), *Proc. ODP, Sci. Results,* 177 [Online]. Available from World Wide Web: <http://www-odp.tamu.edu/publications/177_SR/synth/synth.htm>.

Holland D.M., Thomas R.H., De Young B., Ribergaard M.H., Lyberth B. 2008. Acceleration of Jakobshavn Isbræ triggered by warm subsurface ocean waters. Nature geoscience VOL 1, 659-664.

IPCC (Intergovernmental Panel on Climate Change). 2007. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. S. Solomon, D. Qin, M.Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller, eds, Cambridge University Press, Cambridge, UK, and New York, 996 pp.

S. Jacobs, A. Jenkins, H. Hellmer, C. Giulivi, F. Nitsche, B. Huber, and R. Guerrero. 2012. The Amundsen Sea and the Antarctic Ice Sheet. *Oceanography* 25(3):154–163, http://dx.doi.org/10.5670/oceanog.2012.90.

Jacobs, S.S., A. Jenkins, C.F. Giulivi, and P. Dutrieux. 2011. Stronger ocean circulation and increased melting under Pine Island Glacier ice shelf. *Nature Geoscience* 4:519–523.

Jenkins, A., Dutrieux, P., Jacobs, S.S., McPhail, S.D., Perrett, J.R., Webb, A.T. and White, D. 2010. Observations beneath Pine Island Glacier in West Antarctica and implications for its retreat. Nature Geoscience, 3, 468-472.

Jokat, W., Boebel, T., König, M. and Meyer, U., 2003. Timing and geometry of early Gondwana breakup. Journal of Geophysical Research 108, 2438. doi:10.1029/2002JB001802

Katsuki, K.,M. Ikehara, Y. Yokoyama, M. Yamane, B.-K. Khim, 2012. Holocene migration of oceanic front systems over the Conrad Rise in the Indian Sector of the Southern Ocean. Joiurnal of Quaternary Science 27, 203-210.

Kennett, J.P. 1977. Cenozoic evolution of Antarctic glaciation, the circum-Antarctic Ocean, and their impact on global paleoceanography. Journal of Geophysical Research 82:3,843–3,860, http://dx.doi.org/10.1029/JC082i027p03843.

Kominz, M.A., J.V. Browning, K.G. Miller, P.J. Sugarman, S. Mizintseva, and C.R. Scotese. 2008. Late Cretaceous to Miocene sea level estimates from the New Jersey and Delaware coastal plain coreholes: An error analysis. Basin Research 20:211–226.

Kopp, R. E. *et al.* 2009*.* Probabilistic assessment of sea level during the last interglacial stage. Nature 462, 863-867.

Kuvaas, B., Kristoffersen, Y., Guseva, J., Leitchenkov, G., Gandjukhin, V., Løvås, O., Sand, M., Brekke, H., 2005. Interplay of turbidite and contourite deposition along the Cosmonaut Sea/Enderby Land margin, East Antarctica. Marine Geology 217:143–159.

Leinweber, V. and Jokat, W., 2012. The Jurassic history of the Africa-Antarctica Corridor - new constraints from magnetic data on the conjugate continental margins. Tectonophysics 530: 87-101 .

Leitchenkov, G. L., V. V. Gandyukhin, Y. B. Guseva, and A. Y. Kazankov. 2007. Crustal structure and evolution of the Mawson Sea, western Wilkes Land margin, East Antarctica. In Antarctica: A Keystone in a Changing World—Online Proceedings for the Tenth International Symposium on Antarctic Earth Sciences, eds. Cooper, A. K., C. R. Raymond et al., USGS Open-File Report 2007-1047, Short Research Paper 028, doi:10.3133/of2007-1047.srp028.

Levitus S., Antonov J.I., Boyer T.P., Locarini R. A., Garcia H.E., Mishonov A.V. 2009. Global ocean heat content 1955–2008 in light of recently revealed instrumentation problems. GEOPHYSICAL RESEARCH LETTERS, VOL. 36, L07608, doi:10.1029/2008GL037155, 2009

Levy R., R. Cody, J. Crampton, C. Fielding, N. Golledge, D. Harwood, S. Henrys, R. McKay, T. Naish, C. Ohneiser, G. Wilson, T. Wilson, and D. Winter. 2012. Late Neogene climate and glacial history of the Southern Victoria Land coast from integrated drill core, seismic and outcrop data. Global and Planetary Change 80-8, 61–84.

Lewis, A.R., et al., 2008. Mid–Miocene cooling and the extinction of tundra in continental Antarctica. Proceedings of the National Academy of Sciences 105 (31), 10676–10680.

Lythe, M.B., D.G. Vaughn, and the DEDMAP Consortium, 2001, BEDMAP- A newicethicknessandsubglacialtopographic model of Antarctica. Journal of Geophysical Research, v. 106, n. B6, p. 11,335-11,351.

Massé, G., Belt, S.T., Crosta, X., Schmidt, S., Snape, I., Thomas, D.N. and Rowland, S.J. 2011. Highly branched isoprenoids as proxies for variable sea ice conditions in the Southern Ocean. Antarctic Science 23, 487-498.

Meinshausen, M., S.J. Smith, K. Calvin, J.S. Daniel. M.L.T. Kainuma, J.-F. Lamarque, K. Matsumoto, S.A. Montzka, S.C.B. Raper, K. Riahi, and others. 2011. The RCP greenhouse gas concentrations and their extensions from 1765 to 2300. Climatic Change 109:213–241, http://dx.doi.org/10.1007/s10584-011-0156-z.

Miller, K.G., Wright, J.D., Fairbanks, R.G., 1991. Unlocking the Ice House: Oligocene–Miocene oxygen isotopes, eustasy, and margin erosion. Journal of Geophysical Research 96: 6829–6848.

Miller, K. G., Wright, J. D., Browning, J. V., Kulpecz, A., Kominz, M., Naish, T. R., Cramer, B. S., Rosenthal, Y., Peltier, R., and Sosdian, S.: High tide of the warm Pliocene: implications of global sea level for Antarctic deglaciation, Geology, 40, 407–410, doi:10.1130/G32869.1.

Müller, J., A. Wagner, K. Fahl, R.Stein, M. Prange, and G. Lohmann. 2011. Towards quantitative sea ice reconstructions in the northern North Atlantic: A combined biomarker and numerical modelling approach. Earth and Planetary Science Letters 306, 137–148.

Mutterlose, J.; Wise, S. W.,1990.: Lower Cretaceous nannofossil biostratigraphy of ODP Leg 113 Holes 692B and 693A, continental slope off East Antarctica, Weddell Sea. In: Barker, PF, Kennett, JP; et al. (eds.), Proceedings of the Ocean Drilling Program, Scientific Results, College Station, TX (Ocean Drilling Program), 113, 325-351.

Naish, T., R. Powell, R. Levy, L. Krissek, F. Niessen,M. Pompilio, R. Scherer, F. Talarico, G. Wilson, T. Wilson, P. Barrett, G. Browne, L. Carter, R. Cody, E. Cowan, J. Crampton, R. DeConto, G. Dunbar, N. Dunbar, F. Florindo, C. Gebhardt, I. Graham, M. Hannah, D. Harwood, D. Hansaraj, S. Henrys, D. Helling, G. Kuhn, P. Kyle, A. Läufer, P. Maffioli, D. Magens, K. Mandernack, W. McIntosh, R. McKay, C. Millan, R. Morin, C. Ohneiser, T. Paulsen, D. Persico, D. Pollard, J. Reed, J. Ross., I. Raine, D. Schmitt, L. Sagnotti, C. Sjunneskog, P. Strong, M. Taviani, S. Vogel, T. Wilch, T. Williams, and D. Winter. 2009. Obliquity-paced Pliocene West Antarctic Ice Sheet Oscillations. Nature 458, 322-328, doi:10.1038/nature07867.

O'Brien P.E., I. Goodwin, C-F. Forseberg, A.K. Cooper, and J. Whitehead. 2007. Late Neogene ice drainage changes in Prydz Bay, East Antarctica and the interaction of Antarctic ice sheet and climate. Palaeogeography, Palaeoclimatology, Palaeoecology, 245, 390-410.

Oiwane H., Minoru I., Suganuma Y., Miura H., Nakamura Y., Sato T., Nogi Y. 2012. Antarctic Circumpolar Current Fluctuation in the Late Neogene: constraint from sediment wave Antarctic Circumpolar Current Fluctuation in the Late Neogene: constraint from sediment wave. NIPR - National Institute of Polar Research Symposium on Polar Science 26-30 nov. 2012. Abstract.

Orsi A., 2012. Ocean-Ice Shelf interactions in the Ross Sea and the changing modes of deep Ocean ventilation. Natural and Anthropogenic Forcing on the Antarctic and Southern Ocean Climate System Session SCAR Open Science conference Portland (USA) 2012. Abstract.

Pagani, M., J.C. Zachos, K.H. Freeman, B. Tipple, and S. Bohaty. 2005. Marked decline in atmospheric carbon dioxide concentrations during the Paleogene. Science 309:600–603, http://dx.doi.org/10.1126/science.1110063.

Pälike, H., Norris, R. D., Herrle, J. O., Wilson, P. A., Coxall, H. K., Lear, C. H., Shackleton, N. J., Tripati, A. K., Wade, B. S. 2006. The Heartbeat of the Oligocene Climate System, *Science* 314 (5807), 1894-1898. doi:10.1126/science.1133822

Pearson, P.N., and M.R. Palmer. 2000. Atmospheric carbon dioxide concentrations over the past 60 million years. Nature 406:695–699, http://dx.doi.org/10.1038/35021000.

Pollard D., and R.M. DeConto. 2009. Modelling West Antarctic Ice Sheet growth and collapse through the past five million years. Nature 458, 329-33, doi:10.1038/nature07809.

Post, A.L., P.E. O'Brien, R.J. Beaman, M.J. Riddle, and L. De Santis. 2010. Physical controls on deep water coral communities on the George V Land slope, East Antarctica. Antarctic Science 22: 371-378.

Pritchard, H.D., R.J. Arthern, D.G. Vaughn, and L.A. Edwards. 2009. Extensive dynamic thinning on teh margins of the Greenland and Antarctic Ice Sheets. Nature, v. 461, p. 971-975.

Pritchard, H.D, S.R.M. Ligtenberg, H.A. Fricker, D.G. Vaughan, M.R. van den Broeke and L. Padman. 2012. Antarctic ice-sheet loss driven by basal melting of ice shelves. Nature 484: 502-505.

Pross, J., Contreras, L., Bijl, P.K., Greenwood, D.R., Bohaty, S.M., Schouten, S., Bendle, J.A., Röhl, U, Tauxe, L., Raine, J.I., Huck, C.E., van de Flierdt, T., Jamieson, S.S.R., Stickley, C.E., van de Schootbrugge, B., Escutia, C., Brinkhuis, H. and Integrated Ocean Drilling Program Expedition 318 Scientists, 2012. Persistent near-tropical warmth on the Antarctic continent during the early Eocene epoch, Nature 488:73–77.

Rickaby, R.E.M., H. Elderield, N. Roberts, C.D. Hillenbrand, and A. Mackensen. 2010. Evidence for elevated alkalinity in the glacial Southern Ocean. PALEOCEANOGRAPHY, VOL. 25, PA1209, doi:10.1029/2009PA001762, 2010.

Rignot, E., and S.S. Jacobs. 2002. Rapid bottom melting widespread near Antarctic ice sheet grounding lines. Science 296:2,020–2,023, http://dx.doi.org/10.1126/science.1070942.

Rignot, E., I. Velicogna, M.R. van den Broeke, A. Monaghan, and J. Lenaerts. 2011. Acceleration of the contribution of the Greenland and Antarctic ice sheets to sea level rise. Geophysical Research Letters Vol. 38, L05503, doi:10.1029/2011GL046583.

Rintoul, S.R. 1998. On the origin and influence of Adélie Land Bottom Water, in Ocean, Ice, and Atmosphere: Interactions at the Antarctic Continental Margin, Antarct. Res. Ser., vol. 75, edited by S. Jacobs and R. Weiss, pp., 151–171, AGU, Washington.

Roberts, J.L., R. C. Warner, D. Young, A. Wright, T. D. van Ommen, D. D. Blankenship, M. Siegert, N. W. Young, I. E. Tabacco, A. Forieri, A. Passerini, A. Zirizzotti, & M. Frezzotti 2011. Refined broad-scale sub-glacial morphology of Aurora Subglacial Basin, East Antarctica derived by an ice-dynamics-based interpolation scheme. The Cryosphere, 5, 551-560.

Roy, M., van de Flierdt, T., Hemming. S.R, Goldstein, S.L. et al., 2007. $^{40}Ar/^{39}Ar$ ages of hornblende grains and bulk Sm/Nd isotopes of circum-Antarctic glacio-marine sediments: Implications for sediment provenance in the southern ocean. Chemical Geology, 244: 507–519.

Scher H.D., Bohaty S.M., Zachos J.C., Delaney M.L., 2011, Two-stepping into the icehouse: East Antarctic weathering during progressive ice-sheet expansion at the Eocene−Oligocene transition: Geology, v. 39, p. 383–386.

Schoof C. 2007. Ice sheet grounding line dynamics: Steady states, stability, and hysteresis. Journal of Geophysical Research, Vol. 112, F03S28,

Schoof, C. 2010. Beneath a floating ice shelf. Nature Geoscience 3:450–451.

Schouten, S., E.C. Hopmans, E. Schefuß, and J.S.S. Damsté. 2002. Distributional variations in marine crenarchaeotal membrane lipids: A new tool for reconstructing ancient sea water temperatures? Earth and Planetary Science Letters 204, 265–274.

Schrum, H., Domack, E., De Santis, L., Leventer, A., McMullen, K., Escutia, C. 2004. A Glimpse at Late Mesozoic to Early Tertiary Offshore Stratigraphy from Wilkes Land, East Antarctica: Results of Strategic Dredging of the Mertz-Ninnis Trough. American Geophysical Union, Fall Meeting 2004, abstract #PP51E-1359

Shevenell, A.E., J.P. Kennett, and D.W. Lea. 2004. Middle Miocene Southern Ocean cooling and Antarctic cryosphere expansion. Science 305:1,766–1,770, http://dx.doi.org/ 10.1126/science.1100061.

Shevenell, A.E., and S.M. Bohaty. 2012. Southern exposure: New paleoclimate insights from Southern Ocean and Antarctic margin sediments. Oceanography 25(3):106–117, http://dx.doi.org/10.5670/oceanog.2012.82.

van de Flierdt T, 2011, Continental weathering through the onset of Antarctic glaciation, Geology 39, 415-416

Villinski, J. C., J. M. Hayes, S. C. Brassell, V. L. Riggert, and R. B. Dunbar, 2008, Sedimentary sterols as biogeochemical indicators in the Southern Ocean, Org. Geochem., 39, 567–588.

Warny, S., R.A. Askin, M.J. Hannah, B.A.R. Mohr, J.I. Raine, D.M. Harwood, F. Florindo, and the SMS Science Team. 2009. Palynomorphs from a sediment core reveal a sudden remarkably warm Antarctica during the middle Miocene. Geology 37:955–958, http://dx.doi.org/10.1130/G30139A.1.

Weber, M.E., P.U. Clark, W. Ricken, J.X. Mitrovica, S.W. Hostetler, and G. Kuhn. 2011. Interhemispheric ice-sheet synchronicity during the Last Glacial Maximum. Science, 334, 1265-1269, doi: 10.1126:science.1209299.

Weber, M.E., G. Kuhn, D. Sprenk, C. Rolf, C. Ohlwein, and W. Ricken. 2012. Dust transport from Patagonia to Antarctica – a new stratigraphic approach from the Scotia Sea and its implications for the last glacial cycle. Quaternary Science Reviews, 36, 177-188, doi: 10.1016/j.quascirev.2012.01.016.

Weertman J., 1974. Stability of the junction of an ice sheet and an ice shelf. Journal of Glaciology, vol. 13, n. 67, 3-11.

Wellner, J.S., J.B. Anderson, W. Ehrmann, F.M. Weaver, A. Kirshner, D. Livsey, and A. Simms, 2011. Sedimentologic record of the evolving ice sheet as recorded in SHALDRIL cores from the Northwestern Weddell Sea, Antarctica, in Anderson, J.B., and Wellner, J.S., eds., Tectonic, Climatic and Cryospheric Evolution of the Antarctic Peninsula, American Geophysical Union Special Volume, p. 131-151.

Williams, G.D., N.L. Bindoff, S.J. Marsland, and S.R. Rintoul. 2008. Formation and export of dense shelf water from the Adelie Depression, East Antarctica. Journal of Geophysical Research, 113, 4010.1029/ 2007JC004346.

Willmott, V., Rampen, S.W., Domack, E., Canals, M., Sinninghe Damsté, J.S. and Schouten, S., 2009. Holocene changes in *Proboscia* diatom productivity in shelf waters of the northwestern Antarctic Peninsula. Antarctic Science 22: 3–10

Wilson, D.S., and B.P. Luyendyk. 2009, West Antarctic paleotopography estimated at the Eocene-Oligocene climate transition: Geophysical Research Letters, v. 36, p. 1-4.

Wilson, D.S., S.S.R. Jamieson, P.J. Barrett, G. Leitchenkov, K. Gohl, and R.D. Larter. 2012. Antarctic topography at the Eocene–Oligocene boundary. Palaeogeography, Palaeoclimatology, Palaeoecology, v. 335-336, p. 24-34. doi:10.1016/j.palaeo.2011.05.028.

Wise, S.W., Jr., R. Schlich, et al. 1992. *Proc. ODP, Sci. Results,* 120: College Station, TX (Ocean Drilling Program).
Williams, T., T. van de Flierdt, S.R. Hemming, E. Chung, M. Roy, and S.L. Goldstein. 2010. Evidence for iceberg armadas from East Antarctica in the Southern Ocean during the late Miocene and early Pliocene. Earth and Planetary Science Letters 290:351–361, http://dx.doi.org/ 10.1016/j.epsl.2009.12.031.
Young , D.A., A.P. Wright, J.L. Roberts, R.C. Warner, N.W. Young, J.S. Greenbaum, D.M. Schroeder, J.W. Holt, D.E. Sugden, D.D. Blankenship, T.D. Van Ommen, and M.J. Seigert. 2011. A dynamic early East Antarctic Ice Sheet suggested by ice covered fjord landscapes. Nature, 474, 72-75.
Zachos, J., M. Pagani, L. Sloan, E. Thomas, and K. Billups. 2001. Trends, rhythms, and aberrations in global climate 65 Ma to present. Science 292:686–693, http://dx.doi.org/10.1126/science.1059412.
Zachos, J.C., Breza, J., & Wise, S.W., 1992. Early Oligocene ice sheet expansion on Antarctica, sedimentological and isotopic evidence from the Kergulen Plateau. Geology, 20: 569–573.

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