



WP 14

Agenda Item: 4.3.5

Person Responsible: C. Escutia

**XXXIII SCAR Delegates Meeting**

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# **Past Antarctic Ice Sheet Dynamics (PAIS)**



## Executive Summary

**Title:** Past Antarctic Ice Sheet Dynamics (PAIS)

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### **Introduction/ Background:**

The overarching goal of PAIS is to improve confidence in predictions of ice sheet and sea level response to future climate change and ocean warming. For this, PAIS aims to improve understanding of the sensitivity of East, West, and Antarctic Peninsula Ice Sheets to a broad range of climatic and oceanic conditions. Study intervals span a range of timescales, including past “greenhouse” climates warmer than today, and times of more recent warming and ice sheet retreat during glacial terminations. The PAIS research philosophy is based on data-data and data-model integration and intercomparison, and the development of “ice-to-abys” data transects, extending from the ice sheet interior to the deep sea. The data-transect concept will link ice core, ice sheet-proximal, offshore, and far-field records of past ice sheet behaviour and sea level, yielding an unprecedented view of past changes in ice sheet geometry, volume, and ice sheet-ocean interactions. These integrated data sets will enable robust testing of a new generation of coupled Glacial Isostatic Adjustment-Ice Sheet-Atmosphere-Ocean models that include new reconstructions of past and present ice bed topography and bathymetry. PAIS will accomplish its objectives by: 1) facilitating the planning of new data-acquisition missions using emerging technologies; 2) encouraging data sharing and integration of spatially targeted transect data with modelling studies; and 3) initiating/expanding cross linkages among Antarctic research communities.

### **Important Issues or Factors:**

PAIS continent-to-abys transects build on ongoing and planned projects and therefore guarantee continuous deliverables.

### **Recommendations/Actions and Justification:**

Support for PAIS plans for the remaining life of the Programme and input from EXCOM on PAIS plans based on the SCAR Strategic Plan and the Horizon Scan outcomes.

### **Expected Benefits/Outcomes:**

Publications and science relevant to large international programmes/initiatives and policy makers, enhancement of SCAR profile.

### **Partners:**

ANDRILL, IODP, ICDP, AntECO, APECS, IGBP-PAGES, IPICS, ISMASS, SCADM, SCERCE, SHALDRIL and other SCAR Expert and Action Groups.

### **Budget Implications:**

Request for confirmation of SCAR science programme funding at current level until the internal progress review.

# Past Antarctic Ice Sheet Dynamics (PAIS)

## 1. Rationale for the Programme

The Antarctic cryosphere and surrounding seas play a fundamental role in the global ocean/climate system, affecting global sea level, ocean circulation and heat transport, planetary albedo, air-sea gas exchange, and marine productivity. Obtaining a history of Antarctica's role in these global processes is therefore crucial for understanding past and future ice-ocean-atmospheric and tectonic feedbacks within Earth's climate system. Despite the critical role of Antarctica and the Southern Ocean in the global system, key geological and geophysical data from this region are lacking. In part, this is because Antarctica's massive ice sheets hide most of the Cenozoic geological record. Terrestrial records from rock exposures around the Antarctic margin provide snapshots of regional climate, but these records are geographically sparse and difficult to date. Coastal and open marine records provide a better-dated and more complete window into Antarctic ice sheet behaviour. However, these records are also sparse in their local coverage (i.e., representing coastal or offshore conditions, but not both) and there are many areas of the Antarctic margin without any records recovered.

To understand Cenozoic Antarctic cryosphere evolution in the context of the Earth's climate system, PAIS coordinates palaeoenvironmental and tectonic studies along transects from the interior of the continent to abyssal plains. These studies preferably extend from specific drainage sectors, because different regions of the ice sheet undoubtedly will have different histories. These records, integrated with state-of-the-art coupled GIA-ice sheet-ocean-climate models have the potential to substantially advance our understanding of forcings, magnitudes and rates of response, and feedbacks at the ocean-ice interface, thus improving ice sheet model parameterizations. PAIS aims to constrain past ice sheet dynamics that are relevant to future scenarios of ice sheet behaviour and sea level change as a response to elevated CO<sub>2</sub> and temperatures during this century (IPCC, 2013). To achieve this aim, PAIS focuses on temporal targets that span the last deglaciation to the early Cenozoic greenhouse world, with the main focus on periods of rapid warming and climatic conditions warmer than present. These intervals include: a) the transition from the Last Glacial Maximum (LGM) to early Holocene warmth; b) Pleistocene "super-interglacials" (e.g., MIS5, MIS11, MIS 31), long suspected as being times of significant WAIS retreat; and c) times of elevated global temperatures and CO<sub>2</sub> levels that are close to what is forecasted for our near future (IPCC, 2013), such as the Pliocene PRISM interval from ~3-3.3Ma and the extended period of maximum warmth during the early Pliocene (4.2 to 3.7 Ma). Other periods of prolonged warmth include the Miocene Climate Optimum (17-14 Ma), and the persistent elevated temperatures and pCO<sub>2</sub> levels exceeding 1000 ppmv prior to the formation of continental Antarctic ice sheets 34 million years ago. This greenhouse world includes temperature spikes (hyperthermals) lasting ~100,000 years, somewhat analogous to the conditions projected for a continued "Business As Usual" carbon emissions scenario.

## 2. Important Issues or Factors

### i) Five Scientific Highlights

i.1) GREENHOUSE WORLD (>1000 ppm CO<sub>2</sub>): *Bijl, P.K., Bendle, J.A., Bohaty, S.M., Pross, J., Schouten, S., Tauxe, L., Stickle, C.E., Röhl, U., Sluijs, A., Olney, M., Brinkhuis, H., Escutia, C., and Expedition 318 Scientists. Onset of Eocene Antarctic cooling linked to early opening of the Tasmanian Gateway. Proceedings of the National Academy of Sciences of the United States of America, Vol. 110, Issue 24: 9645-9650.*

Based on dinoflagellate biogeography and sea surface paleothermometry from sediment cores obtained from each side of the Tasman Gateway (TG) and the Australian-Antarctic Gulf, Bijl et al (2013) present insights into the earliest throughflow of a westbound Antarctic Counter Current at 49–50 Ma through a southern opening of the TG. This early opening occurs in conjunction with the simultaneous onset of regional surface water and continental cooling (2–3 °C), evidenced by biomarker- and pollen-based

paleothermometry. The paper shows that the westbound flowing current across the TG resulted in cooling of Antarctic surface waters and coasts, which was conveyed to global intermediate waters through invigorated deep convection in southern high latitudes. Although atmospheric CO<sub>2</sub> forcing alone would provide a more uniform middle Eocene cooling, the opening of the TG better explains Southern Ocean surface water and global deep ocean cooling in the apparent absence of (sub-) equatorial cooling.

i.2) GREENHOUSE-ICEHOUSE TRANSITION: *Stocchi, P., Escutia, C., Houben, A.J.P., Bijl, P.K., Brinkhuis, H., DeConto, R., Galeotti S, Vermeersen, B.L.A., and Expedition 318 Scientists. Relative sea level rise around East Antarctica during Oligocene glaciation. Nature Geosciences, Vol 6: 380-384.*

The stepwise expansion of ice on Antarctica during the Eocene-Oligocene Transition (EOT, 34 million years ago), induced crustal deformation and gravitational perturbations around the continent. The result is that close to the ice sheet, sea level rose despite an overall reduction in the mass of the ocean caused by the transfer of water to the ice sheet. Consequently, the coasts experienced a progressive relative sea-level rise. Sediment cores from around Antarctica (i.e., Wilkes Land, Ross Sea and Prydz Bay) and at the vicinity of the Antarctic ice sheet are in agreement with the spatial patterns of relative sea-level change indicated by models. These results are consistent with the suggestion that near-field processes such as local sea-level change influence the equilibrium state obtained by an ice sheet grounding line.

i.3) EARLY ICEHOUSE ECOSYSTEMS: *Houben, A.J.P., Bijl, P.K., Pross, J., Bohaty, S.M., Stckley, C.E., Passchier, S., Roel, U., Sugisaki, S., Tauxe, L., van de Flierdt, T., Olney, M., Sangiorgi, F., Sluijs, A., Escutia, C., Brinkhuis, H., and the Expedition 318 Scientists. Modern Southern Ocean plankton ecosystems arose at the onset of Antarctic glaciation. Science, Vol 340 no 6130 pp. 341-344*

On the basis of fossil marine dinoflagellate cyst records from the Wilkes Land and other sites around the Antarctic margin the paper shows that a major restructuring of the Southern Ocean plankton ecosystem occurred abruptly and concomitant with the first major Antarctic glaciation in the earliest Oligocene (~33.6 million years ago). This turnover marks a regime shift in zooplankton-phytoplankton interactions and community structure, which indicates the appearance of eutrophic and seasonally productive environments on the Antarctic margin.

i.4) PLIOCENE WARMTH (365-415 ppm CO<sub>2</sub>): *Cook C.P., van de Flierdt T., Williams T. J., Hemming S. R., Iwai M., Kobayashi M., Jimenez-Espejo F.J., Escutia C, González J.J., McKay R., Passchier S., Bohaty S.M., Tauxe L., Sugisaki S., Lopez Galindo A., Patterson M.O., Riesselman C, Sangiorgi F., Pierce E. L., Brinkhuis H., and IODP Expedition 318 Scientists. Dynamic Behaviour of the East Antarctic Ice Sheet during Pliocene Warmth. Nature Geosciences, Vol 6, Issue 9: 765-769*

The paper reports on strontium and neodymium isotopic ratios from detrital material indicating erosion of two distinctly different source bodies, now mostly under the ice sheet. The data is interpreted as evidence for retreat of the ice sheet margin several hundreds of kilometers inland during the warm intervals of the early Pliocene (5.3 and 3.3 million years ago). These results suggest a dynamic behaviour of the East Antarctic ice sheet (EAIS) in the vicinity of the low-lying Wilkes Subglacial Basin during times of past climatic warmth with increases in Southern Ocean surface water productivity associated with elevated circum-Antarctic temperatures. Estimates for global sea level high-stands during these times imply possible retreat of the East Antarctic ice sheet, but until now ice-proximal evidence from the Antarctic margin was scarce.

i.5) THE LAST DEGLACIATION: *Mike Bentley, Colm O'Cofaigh and John Anderson (Eds.). Special Issue of Quaternary Science Reviews, September 2014: Antarctic deglacial history from glacial geology Ice Sheet Extent and Deglaciation (RAISED).*

The volume consists of six papers, each on a sector of Antarctica but with the common time-slice approach. A seventh paper, authored by the 78 members of the RAISED Consortium brings all the sectors together into a continent-wide synthesis of ice sheet history since the Last Glacial Maximum. All the articles are open-access (paid for by Durham University, BAS, and with a contribution from PAIS) and so will be fully available to the wider community.

In addition to these articles, the paper by *Weber, M.E., Clark., P.U., Kuhn, G., Timmermann, A., Spreng, D., Gladstone, R., Zhang, X., Lohmann, G., Menviel, L., Chikamoto, M.O., Friedrich, T., Ohlwein, C.*

2014. *Millennial-scale variability in Antarctic ice sheet discharge during the last deglaciation. Nature 510: 134-138*, shows evidence for episodic mass loss of the Antarctic ice sheet between 20 and 9 kyr. Older events are related to the deglaciation of the Antarctic Peninsula Ice Sheet and the East Antarctic ice sheet in the SE Weddell Sea, with the onset of the Antarctic-wide deglacial warming marked by an IRD peak at around 17 kyr when the Northern Hemisphere was cold during Heinrich event 1.

## ii) Progress against prior work plan, including metrics of performance.

Since the last report, we have made substantial progress in programmes that cover some of the original objectives for PAIS (Table 1 of the Implementation Plan in appendix 1).

### *Progress related to Current Programmes listed in our Implementation Plan:*

- Work continues in the nearly 2000 m of sediment core collected during the IODP Expedition 318 drilled the Wilkes Land margin (*Escutia et al., 2011*). Until now the focus has been on greenhouse paleoenvironments (*Pross et al., Nature, 2012; Bjil et al, PNAS, 2013*), the greenhouse-icehouse transition (*Stocchi et al., Nat. Geos. 2013*), the early icehouse paleoenvironments (*Houben et al., Science, 2013*) and the early Pliocene warmth (*Cook et al., 2013*). The focus is changing now to the Oligocene, the late Oligocene-Miocene climate transition leading to the Mi-1 event, the Pleistocene and the last deglaciation. A synthesis paper of the results to date (*Escutia et al., 2014*) has been submitted to *Developments in Marine Geology Series: Earth and life processes discovered from subseafloor environment, vol. 7*. In addition, this Expedition has already resulted in 5 PhD theses.
- The Antarctic Geological Drilling programme (ANDRILL) continues to develop results from its SMS and MIS Projects. These projects have resulted to date in more than 100 publications in peer-reviewed journals, including *Nature*, and in 17 theses and dissertations. The next planned ANDRILL project, the Coulman High Project is at present undergoing review by the US National Science Foundation, the IODP Science panel and ICDP.
- Whillans Ice Stream Subglacial Access Research Drilling (WISSARD) project had its first successful borehole operation in the 2012-13 field season. The target was clean-access entry and sampling of Subglacial Lake Whillans. All goals were achieved including high-definition video imaging of lake sediment; *In situ* measurements were made of the lake water; and water and sediment samples were recovered (*Fricke et al., 2012; Tulaczyk et al., 2013*). Many aspects of the data are still being worked-up, but a paper on the unique subglacial lake ecosystem has been accepted and is soon to be published by *Nature* (*Christner et al., in press*). Prior to the subglacial sampling several key papers from surface geophysical surveys of radar and active source seismic reflection were published as outcomes of the site surveying. These papers included new insights into Lake Whillans geometry and dynamics, and also new inferences on grounding-line geometries and processes. The up-coming 2014-15 austral field season involves subglacial access from the ice plain over the grounding zone of Whillans Ice Stream. The aim is to provide the first direct observations and measurements at an ice sheet-ice shelf transition. *In situ* data will also be used to constrain or modify hypotheses put forward from the geophysical data, as well as to enable assessment of the continuum of subglacial environmental processes and biology from the subglacial lake downstream to the grounding zone.

### *Progress related to Approved Programmes listed in our Implementation Plan:*

- Shallow drilling on the Amundsen Sea Embayment shelf and in Pine Island Bay with MeBo is scheduled to take place in February to March 2015 on RV *Polarstern* cruise PS90 (*Gohl et al.*).
- A site survey cruise, funded by the Natural Environment Research Council UK-IODP programme, is scheduled to take place west of the Antarctic Peninsula in January to February 2015 on RRS *James Clark Ross* cruise JR298, with the aim of augmenting the site survey data available for IODP proposal 732-Full2 (*Larter et al.*).
- IODP 813 'Greenhouse to Icehouse Antarctic paleoclimate and ice history from George V Land and Adélie Land shelf sediments' (*Williams et al.*) with seabed-drilling (RockDrill-II or MeBo) was highly rated by the SEP and is scheduled by the ECORD Facility Board for early 2016, if a research vessel can be made available (possibly the NB *Palmer*).

- Work continues in preparations for the implementation of the Tottem Glacier (Armand et al.) seismic and coring cruise in 2015-2016.

***Progress related to Proposed Programmes listed in our Implementation Plan:***

- IODP proposal 567 ‘Paleogene South Pacific APC transect: heat transport and water column structure during an extreme warm climate (SW Pacific)’ (Thomas et al.) is at the JR Facility Board for possible scheduling.
- IODP proposal 732 ‘Sediment Drifts off the Antarctic Peninsula and West Antarctica’ (Channel et al.) was highly ranked by the former PEP and is at the JR Facility Board for possible scheduling.
- IODP proposal 839 ‘Development and sensitivity of the West Antarctic Ice Sheet tested from drill records of the Amundsen Sea Embayment’ (Gohl et al.) was highly rated by the SEP and is now at the JR Facility Board for possible scheduling.
- IODP proposal 751 ‘Ocean-ice sheet interactions and West Antarctic Ice Sheet vulnerability: clues from the Neogene and Quaternary record of the outer Ross Sea continental margin’ (McKay et al.) is currently in the holding-bin at the SEP but will likely be forwarded to the JR Facility Board for possible scheduling if issues with site survey data are solved.
- IODP proposal 847 ‘Plio-Pleistocene reconstruction of ice-sheet, atmosphere, and ocean dynamics in Iceberg Alley (Scotia Sea)’ (Weber et al.) was submitted as full proposal. SEP asked for a revision.
- IODP proposal 848 ‘Late Neogene ice-sheet and sea-level history of the Weddell Sea, Antarctica’ (Weber et al.) is still at pre-proposal stage. SEP asked for a full proposal.
- IODP proposal 861-Pre ‘Cenozoic formation of the Antarctic glacial landscape investigated by low-temperature thermochronometry (W Antarctic Peninsula)’ (Balco et al.) was submitted as pre-proposal stage. SEP asked for a full proposal.
- ANDRILL Coulman High (Luyendyk, Levy et al.) proposal is still under review by NSF, IODP Science Evaluation Panel and the International Continental Drilling Program (ICDP).

### **3. Outputs/Deliverables**

#### **i) Selected publications (impact factor >9: Nature, Science, Nature Geoscience & PNAS)**

- Christner, B.C., J.C. Prisco, A. M. Achberger, C. Barbante, S.P. Carter, K. Christianson, A.B. Michaud, J.A. Mikucki, A.C. Mitchell, M.L. Skidmore, T.J. Vick-Majors, and the WISSARD Science Team. 2014. A microbial ecosystem beneath the West Antarctic Ice Sheet. *Nature* (accepted).
- Weber, M.E., Clark, P.U., Kuhn, G., Timmermann, A., Sprenk, D., Gladstone, R., Zhang, X., Lohmann, G., Menviel, L., Chikamoto, M.O., Friedrich, T., Ohlwein, C.. 2014. Millennial-scale variability in Antarctic ice sheet discharge during the last deglaciation. *Nature* 510: 134-138.
- Williams, T., *Climate Science: How Antarctic ice retreats. Nature* 510, 39-40
- Johnson, J.S, Bentley, M.J., Smith, J.A., Finkel, R.C., Rood, D.H., Gohl, K., Balco, G., Larter, R.D. & Schaefer, J.M. 2014. Rapid thinning of Pine Island Glacier in the early Holocene. *Science*, 343, 999-1001.
- Stocchi, P., Escutia, C., Houben, A.J.P., Bijl, P.K., Brinkhuis, H., DeConto, R., Galeotti, S., Vermeersen, B.L.A., and Expedition 318 Scientists. Relative sea level rise around East Antarctica during Oligocene glaciation. *Nature Geosciences, Vol 6: 380-384, 2013.*
- Houben, A.J.P., Bijl, P.K., Pross, J., Bohaty, S.M., Stckley, C.E., Passchier, S., Roel, U., Sugisaki, S., Tauxe, L., van de Fliedert, T., Olney, M., Sangiorgi, F., Sluijs, A., Escutia, C., Brinkhuis, H., and the Expedition 318 Scientists. Modern Southern Ocean plankton ecosystems arose at the onset of Antarctic glaciation. *Science, Vol 340 no 6130 pp. 341-344, 2013.*

- Cook, C.P., van de Flierdt, T., Williams, T. J., Hemming, S. R., Iwai, M., Kobayashi, M., Jimenez-Espejo, F.J., Escutia, C, González, J.J., McKay, R., Passchier, S., Bohaty, S.M., Tauxe, L., Sugisaki, S., Lopez Galindo, A., Patterson, M.O., Riesselman, C, Sangiorgi, F., Pierce, E. L., Brinkhuis, H., and IODP Expedition 318 Scientists. Dynamic Behaviour of the East Antarctic Ice Sheet during Pliocene Warmth. *Nature Geosciences*, Vol 6, Issue 9: 765-769, 2013.
- Bijl, P.K., Bendle, J.A., Bohaty, S.M., Pross, J., Schouten, S., Tauxe, L., Stickley, C.E., Röhl, U., Sluijs, A., Olney, M., Brinkhuis, H., Escutia, C., and Expedition 318 Scientists. Onset of Eocene Antarctic cooling linked to early opening of the Tasmanian Gateway. *PNAS*, Vol. 110, Issue 24: 9645-9650, 2013.

In addition, two special volumes are planned for 2014:

- Special issue "Deglacial history of the Antarctic Ice Sheet", edited by Bentley, M., O'Cofaigh, C. and Anderson, J. *Quaternary Science Reviews*, September 2014, which includes the following contributions:
  - i. Michael J. Bentley, Colm Ó Cofaigh, John B. Anderson, Howard Conway, Bethan Davies, Alastair G.C. Graham, Claus-Dieter Hillenbrand, Dominic A. Hodgson, Stewart S.R. Jamieson, Robert D. Larter, Andrew Mackintosh, James A. Smith, Elie Verleyen, Robert P. Ackert, Philip J. Bart, Sonja Berg, Daniel Brunstein, Miquel Canals, Eric A. Colhoun, Xavier Crosta, et al. (78 co-authors). 2014. A community-based geological reconstruction of Antarctic Ice Sheet deglaciation since the Last Glacial Maximum. *Quaternary Science Reviews* (2014), <http://dx.doi.org/10.1016/j.quascirev.2014.06.025>
  - ii. Andrew N. Mackintosh, Elie Verleyen, Philip E. O'Brien, Duanne A. White, R. Selwyn Jones, Robert McKay, Robert Dunbar, Damian B. Gore, David Fink, Alexandra L. Post, Hideki Miura, Amy Leventer, Ian Goodwin, Dominic A. Hodgson, Katherine Lilly, Xavier Crosta, Nicholas R. Golledge, Bernd Wagner, Sonja Berg, Tas van Ommen, Dan Zwartz, Stephen J. Roberts, Wim Vyverman, Guillaume Masse. Retreat history of the East Antarctic Ice Sheet since the Last Glacial Maximum. *Quaternary Science Reviews* (2013), <http://dx.doi.org/10.1016/j.quascirev.2013.07.024>
  - iii. John B. Anderson, Howard Conway, Philip J. Bart, Alexandra E. Witus, Sarah L. Greenwood, Robert M. McKay, Brenda L. Hall, Robert P. Ackert, Kathy Licht, Martin Jakobsson, John O. Stone. Ross Sea Paleo-Ice Sheet Drainage and Deglacial History During and Since the LGM. *Quaternary Science Reviews* (2013), <http://dx.doi.org/10.1016/j.quascirev.2013.08.020>
  - iv. Robert D. Larter, John B. Anderson, Alastair G.C. Graham, Karsten Gohl, Claus-Dieter Hillenbrand, Martin Jakobsson, Joanne S. Johnson, Gerhard Kuhn, Frank O. Nitsche, James A. Smith, Alexandra E. Witus, Michael J. Bentley, Julian A. Dowdeswell, Werner Ehrmann, Johann P. Klages, Julia Lindow, Colm Ó Cofaigh, Cornelia Spiegel. Reconstruction of changes in the Amundsen Sea and Bellingshausen Sea sector of the West Antarctic Ice Sheet since the Last Glacial Maximum. *Quaternary Science Reviews* (2013), <http://dx.doi.org/10.1016/j.quascirev.2013.10.016>
  - v. O'Cofaigh et al - Reconstruction of ice-sheet changes in the Antarctic Peninsula since the Last Glacial Maximum.
  - vi. Claus-Dieter Hillenbrand, Michael J. Bentley, Travis D. Stollendorf, Andrew S. Hein, Gerhard Kuhn, Alastair G.C. Graham, Christopher J. Fogwill, Yngve Kristoffersen, James. A. Smith, John B. Anderson, Robert D. Larter, Martin Melles, Dominic A. Hodgson, Robert Mulvaney, David E. Sugden. Reconstruction of changes in the Weddell Sea sector of the Antarctic Ice Sheet since the Last Glacial Maximum. *Quaternary Science Reviews* (2013), <http://dx.doi.org/10.1016/j.quascirev.2013.07.020>
  - vii. Dominic A. Hodgson, Alastair G.C. Graham, Stephen J. Roberts, Michael J. Bentley, Colm Ó Cofaigh, Elie Verleyen, Wim Vyverman, Vincent Jomelli, Vincent Favier, Daniel Brunstein, Deborah Verfaillie, Eric A. Colhoun, Krystyna M. Saunders, Patricia M. Selkirk, Andrew Mackintosh, David W. Hedding, Werner Nel, Kevin Hall, Matt S. McGlone, Nathalie Van der



Putten, William A. Dickens, James A. Smith. Terrestrial and submarine evidence for the extent and timing of the Last Glacial Maximum and the onset of deglaciation on the maritime-Antarctic and sub-Antarctic islands. *Quaternary Science Reviews* (2013), <http://dx.doi.org/10.1016/j.quascirev.2013.12.001>

- Special Issue in *Global and Planetary Change* focused on the Scotia Sea tectonic evolution and related ice sheet and paleoceanographic changes is planned for publication 2014 (A. Maldonado, I. Dalziel and Philip Leat, Editors). This volume includes results from the Scotia Arc Symposium: Geodynamic Evolution and Global Implications (14-16 May, 2013, Granada, Spain).

## **ii) Major reports, including linkages to major SCAR activities (e.g., advice to the Treaty or IPCC)**

Involvement of members of the PAIS scientific community in international programmes and networks has provided science-based advice to SCAR activities and major scientific programs and Policy makers. To date, members of the PAIS scientific community have been involved in the following reports:

- Lead authors for the International Ocean Drilling Program (IODP) Science Plan 2013-2023.
- Lead and contributor authors for the ERICON Science Perspective 2015-2030: Scientific Research in Polar Seas.
- Lead and Contributing Authors of 5<sup>th</sup> Assessment Report (AR5 - 2013): The Physical Science Basis. Intergovernmental Panel of Climate Change (IPCC).
- Invited participation in the COP19 “Day of the Cryosphere: Climate Change Today in Polar and Mountain Regions” (7 November, 2013, Warsaw, Poland). A side activity to the United Nations Framework Convention on Climate Change.
- SCAR Lecture in PAIS topics to the ATCM XXXVII-CEP XVII meetings (30 April, 2014, Brasilia, Brasil).
- Invited participants in the SCAR Horizon Scan retreat (21-23 April, 2014, Queenstown, New Zealand).
- Professor Tim Naish awarded the 2014 Martha T Muse Prize for Science and Policy in Antarctica.

PAIS will continue to provide reports on its activities to SCAR as required. In addition, PAIS will contribute, when requested, reports for international and national programmes, and government bodies.

## **iii) Workshops and meetings**

PAIS work on facilitating coordination and collaborations between different multidisciplinary and interdisciplinary international groups is largely conducted through community workshops and meetings. Some of the already completed and future activities include:

- Antarctic and Southern Ocean Drilling workshop. Kick-off meeting for community to organize projects in the PAIS latitudinal transect strategy. Portland, USA, July 2012.
- Wilkes Land IODP 813 MeBo proposal working group meeting. Granada, Spain, 2013.
- Scotia Arc Symposium: Geodynamic Evolution and Global Implications. Granada, Spain, May, 2013.
- Eastern Ross Sea IODP Drilling proposal writing workshop, St Petersburg, USA, June 2013.
- Joint model-data workshop for the Late Pleistocene evolution of the Greenland and Antarctic ice sheets. Chamonix, May 22-24, 2014, (just before the IGS International Symposium on Observations, Modelling and Prediction of the Cryospheric Contribution to Sea Level Change).
- Multiproxy approach to the reconstruction of climate of the Pliocene Workshop, Barcelona, Spain, September 2014.

- PAIS Subcommittee meetings during the SCAR OSC, Auckland, New Zealand, 2014. PRAMSO and SDLS (23 August, 2014)
- PAIS open community meeting during the SCAR OSC (25 August 2014), and PAIS Steering Committee meeting (27 August, 2014).

In addition, PAIS will convene scientific sessions and meetings of the Steering Committee and subcommittees during large international meetings such as AGU and EGU 2014 and 2015, SCAR OSC 2014 in Auckland (NZ), ASLO (Spain) 2015, and ISAES XII in Goa (India) 2015.

#### iv) Education and Outreach

- PAIS has committed funds in support of the “Polar Marine Diatom Workshop” Salamanca, Spain, 19th-24th July 2015. This is a training course for PhD and Master students giving them a unique opportunity to interact and discuss topical issues in the Polar Regions. Diatoms are very diverse, abundant and ecologically specialized, therefore, they are perfect indicators of environmental changes. Main topics include: 1) The evolution of sea-ice communities and sea-ice extent; 2) Variations in the diatom assemblage across oceanographic fronts; 3) Pelagic-benthic coupling based on the evolution of diatom communities; 4) The timing of climatic events in polar regions; 5) The modern environmental change relative to climatic or other natural and/or anthropogenic environmental impacts. The last Polar Marine Diatom Workshop was attended by 37 people from 16 nationalities (Australia, Chile, Denmark, France, Germany, India, Indonesia, Japan, New Zealand, Norway, Poland, Spain, Sweden, Tunisia, UK and USA).
- PAIS has provided funding for making one of the QSR special volume papers fully Open Access.
- PAIS has provided funding for students and early career scientists to attend workshops and conferences listed previously

#### v) Databases

PAIS supports continued development of the Antarctic Data Library System for Cooperative Research (SDLS). The SDLS now contains most processed data from marine multichannel seismic surveys that have been carried out around Antarctica. The SDLS provides open access worldwide to Antarctic multichannel seismic-reflection data collected by many countries to study the structure of Earth's crust of Antarctica. The new website that now provides open access to Antarctic multichannel seismic-reflection data online is <http://sdls.ogs.trieste.it/> -- Operated and administered at the Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS) by Nigel Wardell.

While PAIS does not directly support other data archiving infrastructure, it will maximize the effectiveness of its limited budget by encouraging responsible archiving of data and samples to established data centres and repositories. Among these databases the most relevant to the data to be generated by PAIS are: 1) PANGAEA the data Publisher for Earth & Environmental Science- <http://www.pangaea.de/> This data repository holds all data from the two past ANDRILL drilling seasons will receive data from the future Coulman High drilling (Table 1), as well as a wealth of data from marine sediment cores from the Southern Ocean. 2) The IODP data bases and core repositories <http://www.iodp.org/access-data-and-samples> also hold all cores and data obtained during past Antarctic margin and Southern Ocean drilling by the Deep Sea Drilling Project (DSDP), the Ocean Drilling Program (ODP) and the Integrated Ocean Drilling Program (IODP). 3) The IPEV IMAGES Programme Sub-Antarctic and Antarctic portal - [http://gcmd.gsfc.nasa.gov/KeywordSearch/Home.do?Portal=amd\\_fr](http://gcmd.gsfc.nasa.gov/KeywordSearch/Home.do?Portal=amd_fr), which contains data from both marine and ice core records. Other databases included NOAA NCDC/NSIDC, and national programmes metadata systems.

#### vi) Data and information activities

International and national programmes of relevance to PAIS produce video journals, video animations and blogs(e.g., <http://andrift.org/static/media.html>; <http://www.youtube.com/watch?v=uvzrK24YJyQ>).

Brochures are available for all major international drilling initiatives. Links to videos and brochures will be made available through the PAIS webpage.

#### **4. Budgetary Implications**

Main expenditure to date is related to the funding of two workshops in 2014; the funding of early career and senior scientists to attend proposal-writing workshops considered in the PAIS Implementation Plans; and providing support for open access to articles relevant to PAIS. In addition, PAIS has committed funding for the Polar Marine Diatom Training Workshop. Although this workshop will take place in 2015, the funding will be provided with 2014 allocation. Other expenses for 2014 include support for workshops and meetings during SCAR-OSC, and the AGU Fall meeting. We request funding at the same level for the next two years.

#### **5. Future Plans**

##### **2014-2016:**

- Subglacial access from the ice plain over the grounding zone of Whillans Ice Stream, 2014-15 austral field season.
- Shallow drilling on the Amundsen Sea Embayment shelf and in Pine Island Bay with MeBo is scheduled to take place in February to March 2015 on RV Polarstern cruise PS90 (Gohl et al.).
- A site survey cruise to augment that dataset available for planning drilling proposed in IODP proposal 732-Full2 is scheduled to take place in January-February 2015 on RRS James Clark Ross cruise JR298 (Larter et al.).
- KOPRI seismic site survey for the IODP proposal 751-full2 for January-February 2015, with the research vessel ARAON.
- Field seasons for Tottem Glacier (Armand et al) seismic and coring cruise 2015-2016.
- The list of the approved proposals, submitted to the FP7/Eurofleets project, is expected to be released by September 2014. Three proposals were submitted for collecting new sediment cores, seismic, multibeam and oceanographic data from the Antarctic margin.
- Preparation for the implementation of national field programs in 2015-2016.
- XXXIII SCAR Meetings and Open Science Conference, 22 August-3 September Auckland, New Zealand: PAIS sessions, workshops and business meetings as indicated above;
- Multiproxy approach to the reconstruction of climate of the Pliocene Workshop, Barcelona, Spain, September 2014.
- Polar Marine Diatom Training Workshop, Salamanca, Spain, 19th-24th July 2015;
- Publication of Special issue "Deglacial history of the Antarctic Ice Sheet", edited by Bentley, M., O'Cofaigh, C. and Anderson, J. Quaternary Science Reviews, September 2014.
- Publication of the special volume in Global and Planetary Change: The Scotia Arc: Geodynamic Evolution and Global Implications; edited by A. Maldonado, I. Dalziel, and P. Leat.
- Publication of co-authored papers resulting from the SCAR Horizon SCAN;
- Publication of the IODP 318 Synthesis Paper in Dev. Of Mar. Geol Series, Vol. 7, 2014;
- Continue analyses in data from ANDRILL SMS and MIS; and Wilkes Land IODP Expedition 318. Integration with other ODP Legs, CRP and data-model comparisons;
- Continue guiding the revision of IODP and ANDRILL proposals being reviewed by science panels and national programmes;

- Continue fostering the development of new proposal to the IODP and other international programmes (i.e., ICDP).
- PAIS sessions in major international meetings (SCAR OSC, AGU, EGU, ISAES and ASLO, 2014-2015);
- Support for PAIS-related workshops and business meetings to be conducted in parallel with international meetings as indicated above;
- PAIS reports to SCAR;
- Input to databases;
- Outreach via National/International Programmes.
- Work on cross-linkages with other programmes (i.e., ice-core & marine core integration, develop links with SERCE and PAIS);

## Appendices

### Appendix 1: Table 1 of the Implementation Plan

This table is unchanged from the original Implementation Plan. Updates on progress of projects are included in section 2ii of the main text of the report.

<b>Projects</b>	<b>Location</b>	<b>Objectives</b>	<b>Year</b>	<b>Implementation 2013-2015</b>
<b>Current</b>				
ANDRILL SMS & MIS	Ross Sea	Pleistocene-Miocene glacial history	2007-2008	Continue review of sedimentary cores from SMS & MIS programmes.  Comparison-integration with Exp 318, ODP Legs & CRP, and available onshore data.  Provide data to numerical GIA-ice sheet modelling community.
IODP 318	Wilkes Land	Holocene to Eocene Greenhouse palaeoclimate and glacial history	2010	Continue review of sedimentary cores from Exp 318.  Comparison-integration with ANDRILL, CRP, ODP Legs, and available onshore data.  Work on Holocene ice-core and marine-core integration.  Provide data to numerical GIA-ice sheet modeling community.  Workshop planned for 2014
Subglacial Lake Ellsworth	30 km from the ice divide between Pine Island Glacier and the Institute ice stream	Life forms in the water and clues to past climate in the lake-bed sediments	2009-2014	Continue drilling to sample subglacial/lake sediments.  Review of sediment data & provide data to numerical ice sheet modeling community.
Subglacial WISSARD (LISSARD & RAGES) Drilling	Whillans Ice Stream	Marine Ice Sheet Stability and Subglacial Life Habitats in West Antarctica	2009-2015	Analyze water, sediment and geophysical data and samples collected during the 2012-2013 field season.  Planning of the 2013-2014 field season.
WAIS Divide	WAIS ice flow divide	Climate, ice sheet history and cryobiology	2010-2013	2013 field season ended: Ice cores record of past climate and greenhouse gases in the atmosphere that extends back 68,000 years.  WAIS divide meeting, 24-25 September, Scripps (USA)
AGAP	Gamburtsev Mountains	Initial ice sheet formation, subglacial hydrological processes	2008-2009	Continue review of data obtained and provide data to numerical ice sheet modeling community.

<b>Approved</b>				
Amundsen Sea shelf - MeBo	Amundsen Sea Embayment shelf	Basic shelf stratigraphy, glacial onset, LGM retreat ages	Approved 2014-15	Planning and implementation of MeBo drilling in the Amundsen Sea
Totten Glacier seismic and coring cruises (US, Australia)	Totten Glacier	Basic shelf stratigraphy, Pleistocene ice sheet dynamics, LGM retreat.	Approved 2014 & 2015	Planning and implementation of NSF eastern Wilkes Land dredging & Totten Glacier surveys  Planning and implementation of Australian led international coring cruise to the Totten Glacier
E Ross Sea shelf - SHALDRIL	Southeastern Ross Sea	Cenozoic evolution of West Antarctica and early development of WAIS	Approved currently on hold	
<b>Proposed</b>				
IODP 732-Full2	West of Antarctic Peninsula and Bellingshausen Sea	Sediment drifts off the Antarctic Peninsula and West Antarctica; Late Miocene to Quaternary paleoceanography & ice sheet history	At JR-FB to be scheduled	Possibly scheduled for 2016/17
IODP 751-Full2	Eastern Ross Sea	Ocean-ice sheet interactions and West Antarctic Ice Sheet vulnerability: clues from the Neogene and Quaternary record of the outer Ross Sea continental margin	submitted Oct. 2013. Panel has sent for external review	Continue fostering IODP proposal for Eastern Ross Sea IODP drilling.  PAIS co-funding for writing workshop (June 2013, USA) for the submission of a revised proposal to the IODP in October 2013.
IODP 839-Full (former 784-Full2)	Amundsen Sea Embayment	Development and sensitivity of the West Antarctic Ice Sheet tested from drill records of the Amundsen Sea Embayment	Re-submitted Oct 2013. Panel has sent for external review	Continue fostering IODP proposals for Amundsen Sea Embayment.
ANDRILL Coulman High	Central-southern Ross Sea	Palaeogene to lower Miocene ice sheet behaviour & environments during greenhouse gas levels	Re-submission to NSF and ICDP in Jan 2014 and IODP in Apr 2014	Continue fostering IODP proposal for Coulman High
IODP 813-Full	Eastern Wilkes Land; Adélie Land & George V Land shelf	Greenhouse to Icehouse Antarctic paleoclimate and ice history from George V Land and Adélie Land shelf sediments	At the ECORD-FB to be scheduled	Possibly scheduled for 2015/16 or 2016/17; suitable ship must be allocated
IODP 847-Pre	Drake Passage	Plio-Pleistocene reconstruction of ocean, atmosphere and ice-sheet interactions through the Drake Passage	submitted Oct. 2013. Panel recommended to submit full proposal	Continue fostering IODP proposal for Drake Passage/Scotia Sea
IODP 848-Pre (former 829-Pre)	Weddell Sea	Late Neogene ice-sheet and sea-level history of the Weddell Sea	Re-submitted Oct. 2013 – Panel recommended	Continue fostering IODP proposal for Weddell Sea

			to submit full proposal	
<b>Planned</b>				
WAIS-Drill	West Antarctica	Ice sheet history from subglacial sediments	2015-	
EPICA	Dome C, Dronning Maud Land	Deep ice core drilling	1996-ongoing	
IODP southern Indian Ocean (former IODP 824-Pre)	Conrad Rise, Del Caño Rise, South Indian Ocean	Antarctic Cryosphere and Southern Ocean Responses to Glacial-Interglacial Climate Change: Transect drilling across the Indian Ocean sector of the (ACC)	Re-submission planned for Oct 2014	
IODP SW Pacific Ocean	SW Pacific paleoceanography between New Zealand and Ross Sea	Cenozoic suborbital climate variability, biogeochemical cycles, Antarctic ice sheets, tectonic evolution	Submission planned for Oct 2014	
IODP-MSP Antarctic Peninsula	Pacific Antarctic Peninsula shelf	Paleohistory of Antarctic Peninsula ice streams, Boyd Strait and Palmer Deep outlet systems	Submission planned for Oct. 2014	
ICECAP/ICEBRIDGE	Wilkes Land (Wilkes and Aurora subglacial basins, Victoria Land)	Lithosphere and sub glacial conditions in East Antarctic basins	2008-ongoing	
Rapid Access Ice Drill (RAID)	Antarctic Ice Sheet	Development of rapid access ice drill for deep drilling of basal ice sheets and sub-ice bedrock in Antarctica	First tests in 2015; expected scientific projects from 2017/18	
IODP 821-Full2	SE Pacific paleoceanography (SEPAP)	Cenozoic suborbital climate variability, biogeochemical cycles, Antarctic ice sheets, tectonic evolution	submitted Oct. 2013 – Panel rejected-	Continue fostering IODP proposal for SE Pac Ocean