



Past Antarctic Ice Sheet Dynamics (PAIS) Implementation Plan



1. Introduction ~ 1 page.

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. PAIS builds on the success of SCAR-ACE (Antarctic Climate Evolution), but with a new focus on the ice sheet rather than palaeoclimate reconstructions. 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-abyss” 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. The PAIS Scientific Programme will be led by a Steering Committee (SC) of 15-20 persons (Appendix I). The steering committee has a wide knowledge of thematic issues and has appropriate regional (field), technical and logistical experience. The SC will include a Data Coordinator and a member from APECS. SC members will serve for a 3-year term, with the possibility of extension depending on contribution and performance. The founding co-chairs will stand down in 2016, to avoid complete rotations of the SC. The SC will meet at least once a year in coordination with major international symposia including AGU and EGU.

Six subcommittees have been established to implement the scientific objectives of PAIS:

- *Palaeoclimate Records from the Antarctic Margin and Southern Ocean (PRAMSO).*
- *Palaeotopographic-Palaeobathymetric Reconstructions.*
- *Subglacial Geophysics.*
- *Ice Cores and Marine Core Synthesis.*
- *Recent Ice Sheet Reconstruction.*
- *Deep-Time Ice Sheet Reconstructions.*

The subcommittees provide the overall leadership, direction and management for their respective topics. Membership of these committees allows PAIS to widen involvement in the programme in terms of expertise, gender and nationality. In addition, a PAIS sub-committee on Data Management, guided by the Data Coordinator, will 1) engage in cross-linkage activities and the facilitation of cross-SRP data sharing via web-based utilities, and 2) maintain ongoing communication with national funding programmes, currently expanding their emphasis on responsible and cost-effective data management, protection, archiving, and sharing. During the life of PAIS, it is expected that new subcommittees will be established as needed to fulfil PAIS objectives

2. Deliverables, Timeline and Milestones ~ 3-5 pages.

I. Primary publications in peer-reviewed journals

PAIS will deliver its scientific outcomes through publications in peer-reviewed journals. To date, PAIS has already established a strong record of publishing scientific findings in peer-reviewed journals (e.g. papers in *Nature*, *Science* and *Nature Geosciences*), including:

- 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 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, 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., Stckley, 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 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).
- Special issue of *Quaternary Science Reviews*, "Deglacial history of the Antarctic Ice Sheet", edited by Bentley, M., O'Cofaigh, C. and Anderson, J.

Work within PAIS is expected to continue to result on high-impact publications on data and modelling of ice sheet dynamics during past-elevated CO₂ and temperatures.

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 5th Assessment Report (AR5 - 2013): The Physical Science Basis. of the Intergovernmental Panel of Climate Change (IPCC)

It is expected that this kind of involvement will continue during the life of PAIS starting in April 2014 with participation in the SCAR Horizon SCAN Retreat in New Zealand.

III. Other reports and grey literature

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.

IV. Workshops and other key 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 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.
- Workshops of the PAIS Subcommittees during the SCAR OSC, Auckland, New Zealand, 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), and ISAES XII in Goa (India) 2015.

V. Capacity building and education activities

PAIS will endeavour to support and encourage the next generation of Antarctic scientists by:

- National representation in Steering Committee and leadership/membership of sub-committees.
- Link with training and education activities conducted by international programmes such as ANDRILL, IODP, and national programs.
- Early career scientists in Steering Committee & in the leadership of sub-committees.
- Bursaries for travel and subsistence for early career and students to participate in workshops and meetings.
- Funding of 1-2 graduate students a year to attend the Urbino Palaeoclimate School and the Karthaus Summer School on Ice Sheets and Glaciers in the Climate System.

VI. New data and/or meta-data (including plans for archiving)

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, which contains data from both marine and ice core records. Other databases included NOAA NCDC/NSIDC, and national programmes metadata systems.

VII. Brochures, and other PR material

International and national programmes of relevance to PAIS produce video journals, video animations and blogs (e.g., <http://andrill.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. In addition, a poster and slide presentation about PAIS are currently being produced.

VIII. Linkages to other international programmes and activities

The very nature of PAIS science is international in scope. Even in its planning stages, PAIS has already established partnerships with APEX (Arctic Paleoclimate and its Extremes), IODP (International Ocean Discovery Program), ANDRILL (Antarctic Geological Drilling Program), ICECAP (International Climate and Environmental Change Assessment Project), AGAP (Antarctica’s Gamburtsev Province Project), EPICA (European Project for Ice Coring in Antarctica), PAGES (Past Global Changes), PLIOMAX (Pliocene Maximum Sea Level Project), PALSEA (Sea Level and Ice Sheet Evolution), among other national Antarctic research centres and multi-national research projects. PAIS is also well aligned with other SCAR Programme Planning Groups, particularly AntClim21 in topics related to cryosphere and sea level; Ant-Eco in topics related to palaeoecology, evolution, and refugia; ISMASS (Ice Sheet Mass Balance and Sea Level) regarding the use of ice core and marine core data for sea level change research; and SERCE in topics related to past ice sheet dynamics and sea level. Specific links between PAIS subcommittees and other programmes are listed in Appendix I.

Include a Timeline of what will be done, by when and by whom.

PAIS continent-to-abyss transects will encompass more than the eight years of the proposed PAIS Programme, but they build on ongoing, planned, and to-be-planned projects (Table 1) that should guarantee important outcomes during the life of PAIS and form the seed for such research projects to continue into the future.

Table 1 Overview of current, approved, proposed and planned projects, their objectives and their status, including a timeline for their implementation when available.

Projects	Location	Objectives	Year	Implementation 2013-2015
Current				
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.
Approved				
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	
Proposed				
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 to submit full proposal	Continue fostering IODP proposal for Weddell Sea
Planned				
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

3. Appendices and References

Appendix I: Structure and membership of PAIS

1) PAIS Steering Committee required expertise:

- Geophysics (sea-floor morphology, seismic stratigraphy, regional structure and basin analysis)
- Sedimentology (glacial/interglacial sequences and processes onshore-nearshore-offshore, high resolution stratigraphy, etc.)
- Palaeoceanography (ocean-basin history, water mass processes, sediment-ocean-air interfaces, sea ice, ice rafting, etc)
- Geochemistry (tracer geochemistry, mineralogical studies, biogeochemistry, carbon cycle, ice-sheet and ice-rafted sediment provenance, etc.)
- Geochronology and palaeomagnetism (age-dating techniques, rock-magnetic properties, chronostratigraphy)
- Palaeontology (biostratigraphy, palaeoecology, evolution of polar biota, palaeoenvironmental proxies)
- Ice sheet modelling (used to 'test' hypotheses derived from interpretation of the geological record and establish past accumulation patterns by integrating models results with internal ice-sheet layers identified by ice-penetrating radar)
- Glacial Isostatic Adjustment (GIA) modelling
- Palaeoclimate modelling (ice-sheet models coupled with atmosphere-ocean General Circulation Models (GCM's) to examine glaciation feedback mechanisms and to examine physical processes responsible for ice sheet configurations outlined in component 8)
- Ice cores for marine-ice core comparisons over the past ~1 million years (air temperatures vs surface water temperatures, CO₂, and ground-truthing palaeoclimate models)
- Tectonics and climate change (interactions among climate change, ocean circulation, the ice sheet dynamics, and Antarctic tectonism).
- Data management representative (geologic, geophysical, and glaciological data)
- Technological development (drilling/coring/sampling systems, geophysical data acquisition).

2) Tentative membership of the PAIS Steering Committee considering thematic components, nationalities, and gender:

Name	Affiliation	Country	Expertise - relevance to PAIS
Carlota Escutia, co-chair	IACT-Univ Granada	Spain	Seismic stratigraphy, Sedimentology - Paleoclimate and ice sheet records, IODP
Robert DeConto, co-chair	Univ. of Massachusetts	USA	Ice sheet modelling
Robert Larter	British Antarctic Survey	UK	Geology and Geophysics – Paleo-ice sheets
Karsten Gohl	Alfred Wegener Institut	Germany	Geophysics - Lithospheric processes, MeBO, IODP
Laura De Santis	OGS	Italy	Geophysics - Glacial evolution, PRAMSO

Ross D. Powell	Northern Illinois University	USA	Sedimentology and Geophysics - Subglacial geology and marine-ending glaciers
Michael Bentley	Durham University	UK	Glacial geomorphology, Cosmogenic dating – Ice sheets and sea level
Barbara Stenni	University of Trieste	Italy	Ice Cores
Rob McKay/Tim Naish	Victoria University of Wellington	New Zealand	Cyclostratigraphy – Ocean - Climate history
Julia Welner	University of Houston	USA	Sedimentology - Glacial processes
Paolo Stochhi	NIOZ	The Netherlands	GIA modelling
Jongkuk Hong	KOPRI	South Korea	Seismic and radar - Subglacial geology
Yusuke Sugamuna	NIRP	Japan	Paleomagnetism- Geochronology
Alex Payne	Victoria University of Wellington	New Zealand	Technological development
Anton van Putte	Royal Belgium Institute for Natural Sciences	Belgium	SCADM
TBD			Paleontology
TBD			Paleoceanography
TBD			Geology, volcanism – ice sheet land records
TBD			Geochemistry
TBN			APECS