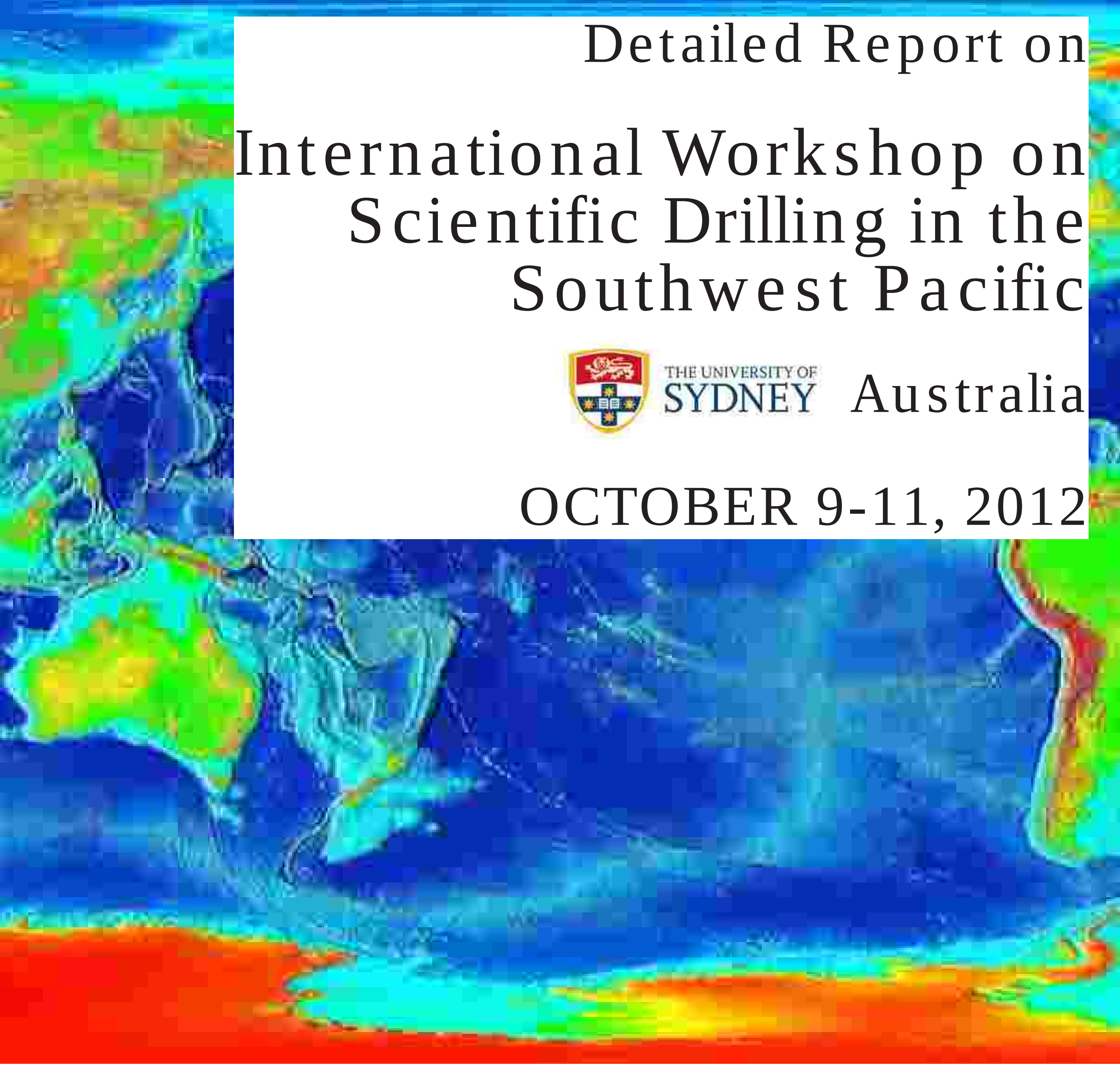
Detailed Report on

International Workshop on Scientific Drilling in the Southwest Pacific

THE UNIVERSITY OF SYDNEY

Australia

OCTOBER 9-11, 2012



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Australian and New Zealand Integrated Ocean Drilling Program Consortium

IODP INTEGRATED OCEAN DRILLING PROGRAM

Web publication of the Integrated Ocean Drilling Program
[IODP-MI to provide link]

Detailed Report on

Southwest Pacific IODP Workshop

Sydney, Australia

October 9-11, 2012

by
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Neville Exon
Maria Seton
Minoru Ikehara
Walter Roest
Chris Hollis
and other workshop participants

SW Pacific IODP Workshop October 2012 - Detailed Report

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Overview

Recent geophysical surveys and geological studies in the southwest Pacific Ocean have improved scientists' understanding of geological evolution and helped to crystallize new research goals. In the current phase of the Integrated Ocean Drilling Program (IODP), there have been five regional expeditions: Canterbury Basin Sea Level (Expedition 317), Wilkes Land Glacial History off Antarctica (Expedition 318), Great Barrier Reef Environmental Changes (Expedition 325), South Pacific Gyre Subseafloor Life (Expedition 329), and Louisville Seamount Trail (Expedition 330). Of six current IODP proposals, four are ready to drill. To review the latest research in the region, briefly outline possible future IODP expeditions, and set up working groups to develop compelling new drilling proposals in the global science context, a workshop was organized at the University of Sydney with a diverse group of 80 scientists. As the *JOIDES Resolution* may be in the region fairly soon, the workshop participants agreed on the urgent need to build strong science proposals. The workshop covered all fields of geoscience as well as drilling targets that extended from the equator to Antarctica. High-quality contributions and a positive and cooperative atmosphere ensured its success. The four science themes of the new IODP science plan were addressed. An additional resource-oriented theme considered possible co-investment opportunities involving IODP vessels. In each theme, new full and add-on proposals were identified, with the aim of submitting most by the proposal deadline in April 2013:

• Climate and ocean change: marine Paleogene proposals, namely Lord Howe Rise and Campbell Plateau, and a Wilkes Land continental shelf Neogene proposal

• Deep biosphere: biosphere in organic rich Gulf of Papua sediments and several ancillary proposals

• Earth connections: formation of the Greater Ontong Java large igneous province; initiation of subduction and origin of sedimentary basins in the Lord Howe Rise region; and structure and dynamics of mantle flow in the northern Australian-Antarctic Discordance

• Earth in motion: the active Brothers Volcano system in the Kermadec Arc; active volcanic systems in the Manus Basin; the nature of the Tuaheni Landslides off northeast New Zealand; and near-trench-axis comparative drilling around the Pacific Ocean

• Marine resources: the nature and resource potential of gas hydrates off northeast New Zealand and deep stratigraphic drilling on the Lord Howe Rise related to both petroleum potential and research.

Many of the proposals are broad and multidisciplinary in nature, hence optimizing the scientific knowledge that can be produced by the use of IODP infrastructure. This is particularly the case for the proposals related to active volcanic systems in the Brothers Volcano and Manus Basin; the Cretaceous-Paleogene paleoenvironment, tectonic history, and petroleum potential of the Lord Howe Rise region; and slow-slip subduction, fluid flow, landslides, and gas hydrate potential of the Hikurangi subduction margin.

The workshop was hosted by the Australian-New Zealand IODP Consortium and the University of Sydney, with additional funding from IODP Management International, the U.S. Science Support Program, and the Japan Drilling Earth Science Consortium. Abstracts and program are available at http://www.iodp.org.au . The workshop results will be published in detail on the IODP Web site in a month or two, and later in *Scientific Drilling*.

Meeting organisers
Australian and New Zealand IODP consortium (ANZIC) and the University of Sydney.
Conveners

- Dr. Neville Exon, ANZIC Program Scientist, Australian National University, Australia (marine geology & geophysics)
- Dr. Maria Seton, Sydney University, Australia (plate tectonics)
- A/Prof. Stephen Gallagher, University of Melbourne, Australia (biostratigraphy)
- Associate Professor Minoru Ikehara, Kochi University, Japan (oceanography)
- Dr Walter Roest, IFREMER, France (geophysics)
- Dr Chris Hollis, GNS Science, Wellington, NZ (biostratigraphy)

Financial and in-kind support
Thanks are given to IODP-MI, USSSP, J-DESC, ANZIC and the University of Sydney for their generous support of this Workshop.

Themes
The themes are largely those in the new IODP Science Plan for 2013-2023 (http://www.iodp.org/doc_download/3217-low-resolution-pdf-versionpdf):

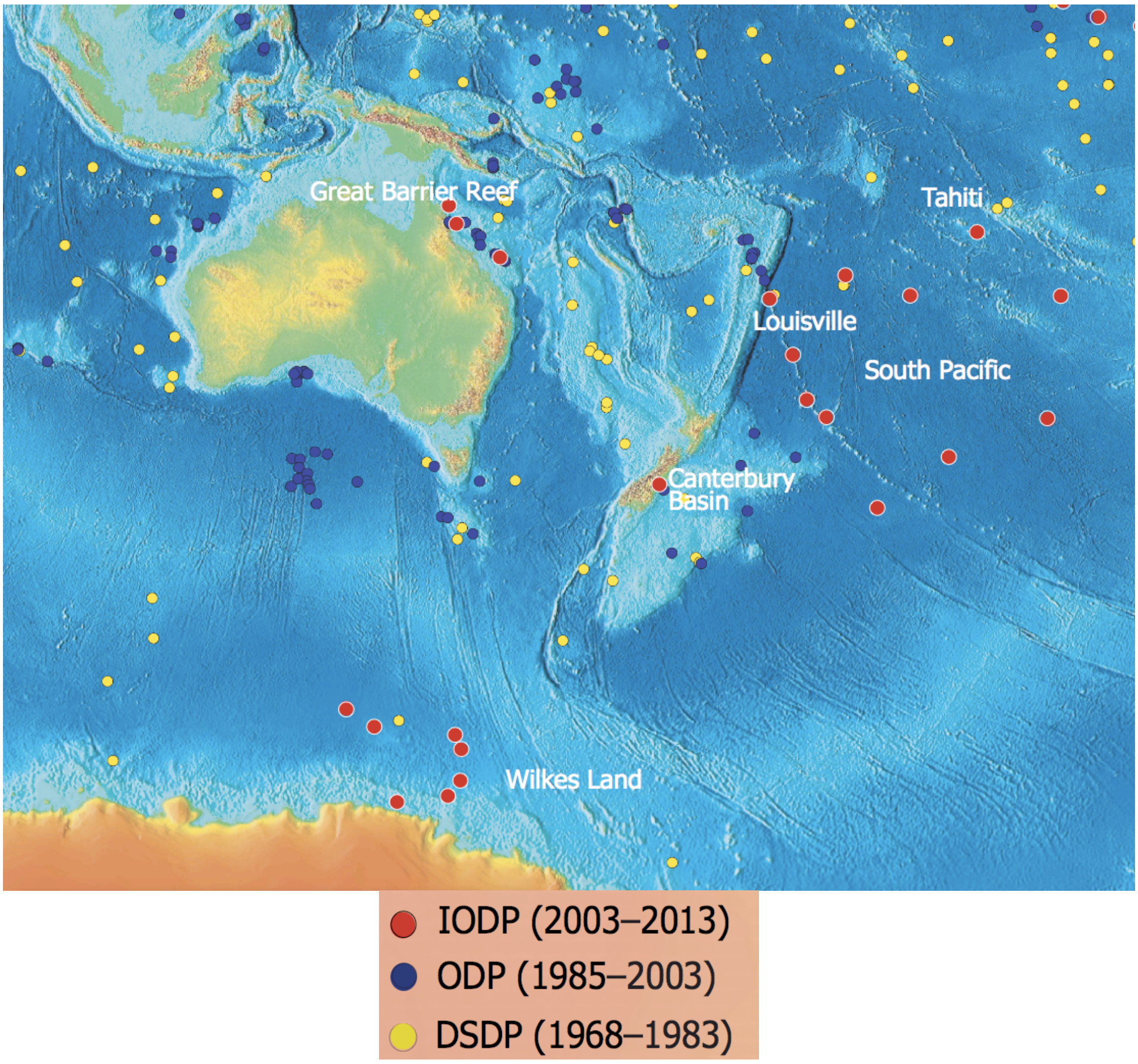
1) **Climate and Ocean Change: reading the past, informing the future**
This is designed to cover questions related to climate and paleoceanographic change in this complex region, on all time scales. Sub-committee co-chairs Rob McKay (NZ) and Jim Kennett (USA)

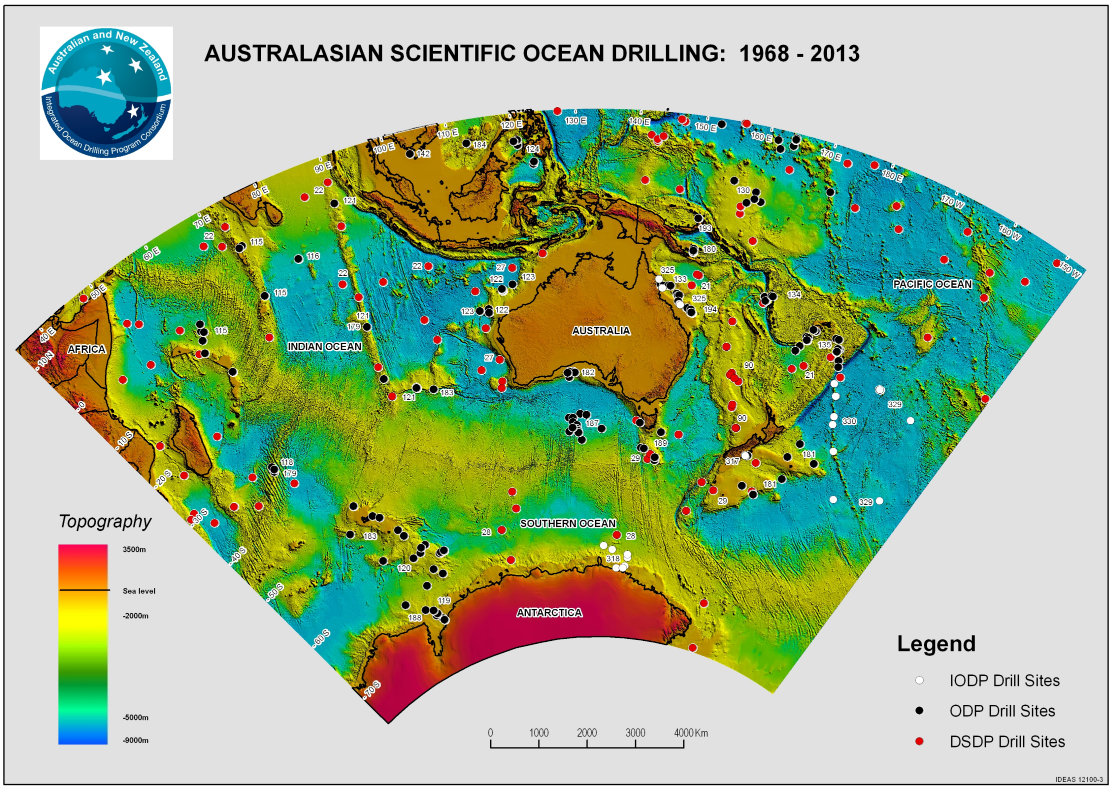
2) **Biosphere Frontiers: deep life, biodiversity, and environmental forcing of ecosystems**
Pioneering studies in the latest phase of IODP. There is almost nothing known about the deep biosphere in the region, so pioneering studies of both sediments and basalts should lead to exciting results. Sub-committee co-chairs Steven D'Hondt (USA) and Ken Takai (Japan)

3) **Earth Connections: deep processes and their impact on Earth's surface environment**
The links between surface lithosphere and deep earth processes are of great interest in this tectonically complex region. Sub-committee co-chairs Richard Arculus (Australia) and Mike Gurnis (USA)

4) **Earth in Motion: processes and hazards on human time scales**
This tectonically active region has its share of earthquakes, tsunamis and submarine slides that have impacted on populations and will continue to do so. Targeted scientific drilling will help address some of these hazards. Sub-committee co-chairs Laura Wallace (UTIG, USA) and Jim Mori (Japan)

5) Marine Resources: opportunities and responsibilities
What contribution can IODP make to the exploration, characterisation and responsible exploitation of marine resources in the Southwest Pacific region? These resources may include offshore oil and gas, gas hydrates, and offshore minerals. Sub-committee co-chairs Alex Malahoff (NZ) and Clinton Foster (Australia);


Great Barrier Reef
Tahiti
Louisville
South Pacific
Canterbury Basin
Wilkes Land
IODP (2003–2013)
ODP (1985–2003)
DSDP (1968–1983)


AUSTRALASIAN SCIENTIFIC OCEAN DRILLING: 1968 - 2013
AFRICA
INDIAN OCEAN
AUSTRALIA
PACIFIC OCEAN
SOUTHERN OCEAN
ANTARCTICA
Topography
3500m
Sea level
-2000m
-5000m
-9000m
Legend
IODP Drill Sites
ODP Drill Sites
DSDP Drill Sites

Theme 1: Climate and Ocean Change: reading the past, informing the future

This theme is designed to cover questions related to climate and paleoceanographic change in this complex region, on all time scales

Sub-committee co-chairs: Rob McKay (NZ) and Jim Kennett (USA)

This theme summarizes a critical need to drill multiple depth and latitudinal transects of sediment cores in the Southwest Pacific, including the Pacific sector of the Antarctic margin, using a variety of ship-based and floating ice-based platforms. These sediment core transects (Fig. 1.1) are required to produce pole to equator climatic and paleoceanographic gradients during key intervals of Cenozoic climatic evolution to test competing hypotheses posited to explain causes of major climate change. This is fundamental for our basic understanding of the implications of modern climate change, including stability or instability of the Antarctic ice sheets. The scientific objectives of a suite of proposals presented at the Workshop are to address all four of the primary scientific challenges identified in the International Ocean Discovery Program ODP Science:

- 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?
- Challenge 4: How resilient is the ocean to chemical perturbations

The following summary of the workshop proceedings is divided into two broad sub-themes documenting proposals for: 1) Paleogene, and 2) Neogene drilling targets, although overlap exists for specific time intervals.

1.1. Paleogene Transect -Tropics to Antarctica

The main aim of the proposed work in this sub-theme is to better understand linkages between major climatic shifts that occurred from the tropics to the high southern latitudes during the Paleogene. This research will focus on testing hypotheses posited to explain mechanisms for extreme warmth at high latitudes during the hyper-greenhouse worlds of the Early Paleogene, and for the inception of the Antarctic Ice Sheets at the Eocene/Oligocene boundary. The SW Pacific ocean is critically located in this context, as the prevailing hypothesis over the past four decades for the initiation and expansion of the Antarctic Ice Sheet invokes changes in ocean heat transport through poleward penetration of warm subtropical currents. The most notable of these currents may have occurred along the eastern margin of Australia resulting in increased heat transport to the Antarctic margin. It was postulated that the rifting between Australia and Antarctica beginning in the latest Eocene allowed for the development of a proto-Antarctic Circumpolar Current, which disrupted this meridional heat transport from subtropical regions to the Antarctic continent, triggering the development of the first ice sheets (Tasmanian Gateway Hypothesis; Fig 1.2A). Antarctic glacial development continued through the Cenozoic in response to increasing isolation due to expansion of Southern Ocean seaways and associated feedbacks. Recent investigations using general circulation models (GCM) and drill-core data challenged this view in suggesting that, even with a closed Tasmanian Gateway. late Eocene heat transport to the polar regions was not elevated significantly compared to the modern ocean. This was because a Southern Ocean circulating gyre [the proto Ross Gyre] prevented penetration of subtropical surface currents to higher latitudes (Fig. 1.2B). These studies instead attributed the extreme warmth of the Antarctic region during Eocene times solely to high levels of radiative forcing related to elevated greenhouse gas concentrations. However this hypothesis itself has since been challenged because of conflicting paleotemperature estimates at key locations. These data are instead consistent with the Tasmanian Gateway Hypothesis invoking tectonically driven circulation changes influencing heat distribution, long-term shifts in the carbon cycle and Cenozoic climatic evolution. Fundamental questions have thus been raised that require transects of ocean-drilled cores in the southwest Pacific at key locations to test competing hypotheses invoked to explain long-term Cenozoic climate evolution. Related to this, the evolution of the Southern Ocean gateways is also important in the context of the deep overturning circulation, with the long-term cooling observed in the $\delta^{18}O$ benthic isotope records largely being a direct consequence of sea surface cooling in regions of active bottom water formation at high southern latitudes. The several related proposals (Fig. 1.1) aim to reconstruct southwest Pacific changes in:

- Meridional SST and other oceanographic gradients.
- Carbonate Compensation Depth history.
- Gyral circulation including the proto Ross Sea Gyre.
- Mode of deep-water circulation and relations with global climate.
- Intensity and patterns of Southern Hemisphere winds.
- Antarctic climatic and cryosphere development.

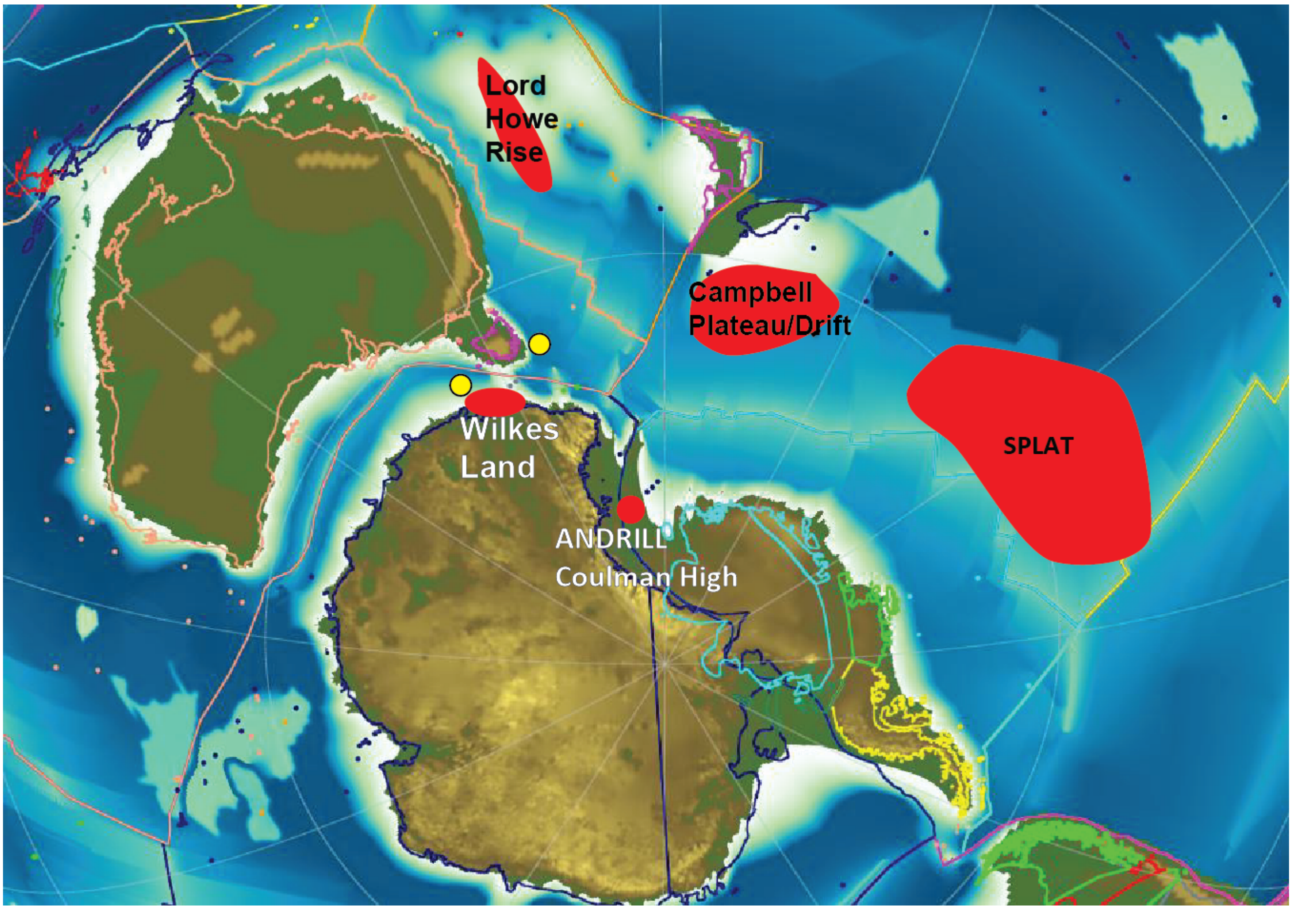


Fig 1.1: Planned drilling regions (red areas) relative to tectonic configuration at 55 Ma. Pre-existing Paleogene drill cores are also shown (yellow dots).

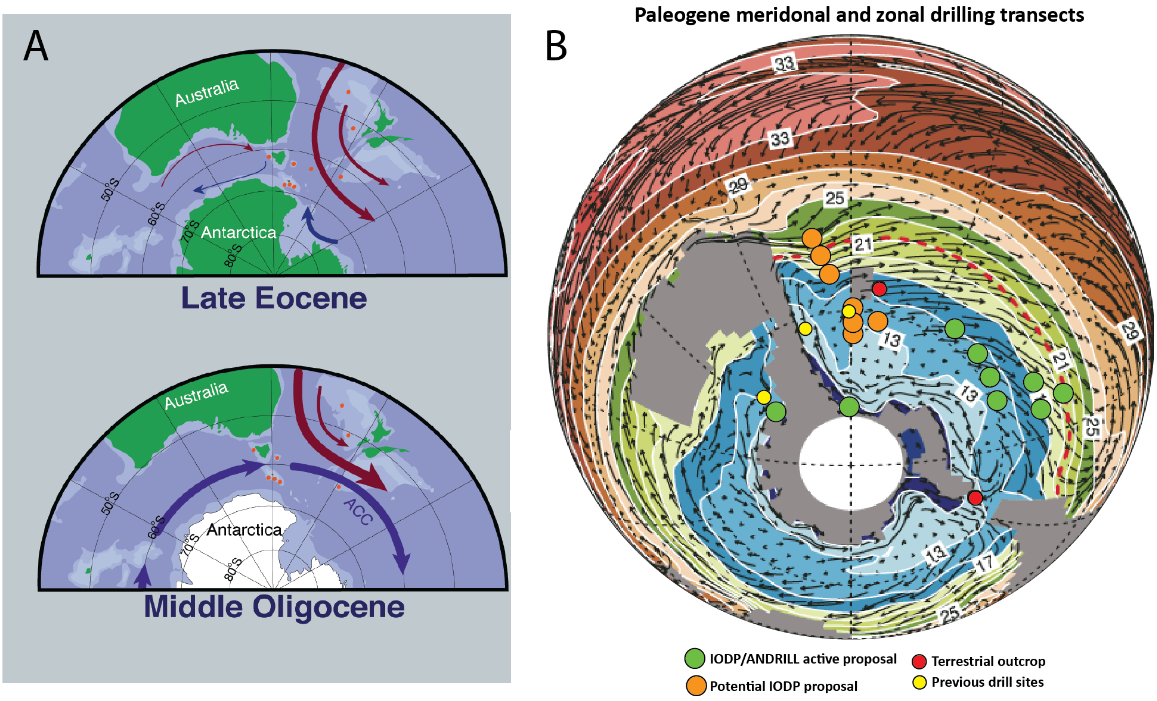


Fig. 1.2: Proposed Southern Ocean paleo-circulation models with a closed Tasmanian gateway during the Eocene (top left and right) and open gateway in the Oligocene (bottom left). Approximate locations of proposed drill sites and pre-existing cores are shown in panel B. (Figure B modified after Hollis et al., 2009)

1.1.1. IODP 567 Full - Paleogene South Pacific Latitude Transect (SPLAT)

Proponents: Debbie Thomas, Mitch Lyle, Dave Rea, Ted Moore, and Ingrid Hendy

Drilling is proposed to elucidate the subpolar Pacific climate, oceanographic structure, and biogeochemical cycling of the very warm Eocene through the transition to Icehouse conditions in the Oligocene. Most drill-sites are positioned along anomaly 25n, 56 Ma, and spaced between paleolatitudes of 55° to 70°S. Two sites are located on anomaly 18, 40 Ma, to best capture the Eocene-Oligocene transition. It is also proposed to redrill Site 277 to obtain a high-resolution, shallow sub-Antarctic Paleogene time series.

Drilling the South Pacific Latitude Transect sites is necessary to test:

- Reconstruction of meridional SST gradients
- Models of proto Ross Gyre and surface water circulation
- Mode of deep-water circulation and relationship to global climate
- Intensity and pattern of Southern Hemisphere winds

This proposal will extend a Paleogene Pacific transect begun by ODP Leg 199 to study the very warm climate regime of the early Eocene. This proposal, under the aegis of the IODP Extreme Climates Initiative, is intended to investigate how the Eocene Earth maintained high global temperatures and high heat transport to the polar regions despite receiving near modern levels of solar energy at the top of the atmosphere. A series of new drill sites have been selected to capture records of the Paleocene-Eocene boundary event (sites set on anomaly 25n, at 56 Ma) and the sharp transition at the Eocene-Oligocene boundary (sites set on anomaly 18, at 40 Ma). It is also proposed to redrill DSDP Site 277, one of the classic Paleogene high latitude South Pacific spot-cored records, to obtain a continuous record of the shallow subantarctic South Pacific from the Paleocene to late Oligocene. The proposed work is set in the South Pacific Ocean since such high latitude records are unobtainable in the Northern Hemisphere of the Pacific. Recovered sediments will be used to characterize changing water masses, deep and shallow ocean temperature, latitudinal temperature gradients, and the strength of upwelling. Further, it will be possible to estimate the strength of the zonal winds to study both the atmospheric and oceanic climatic subsystems. Results will be compared to those of Leg 199, which focused on Paleogene equatorial Pacific.

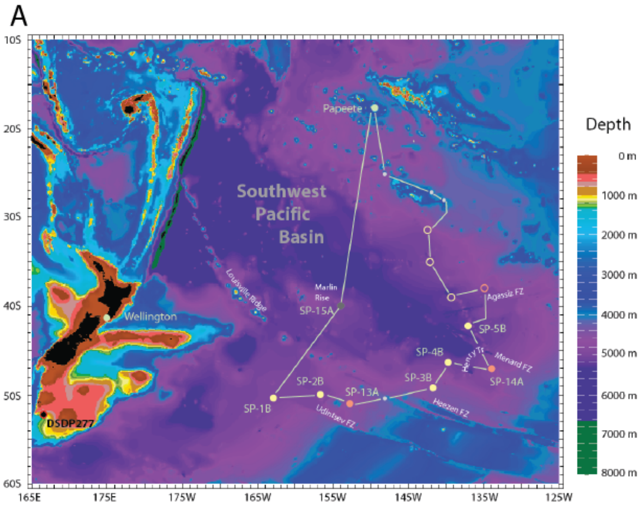
Sites in support of this proposal were surveyed in 2005. We recovered Paleogene carbonates at pelagic depths and expect that much of the sediment proposed to be drilled at modern latitudes of 50°S will be carbonates, opening up a full range of paleoceanographic proxy-based investigations. Results of surveying and coring in the Southwest Pacific Basin indicate that, in addition to the Eocene paleoclimate objectives, three long-standing questions of Southern Ocean paleoenvironmental evolution can be documented:

- CCD history for the Southern Ocean
- Paleogene history of Antarctic ice cover based on records of ice rafted debris
- paleoceanographic development of the Antarctic Circumpolar Current using backtracked positions of the sites directly west of the proto-Drake Passage

The last objective is a theme of the Environmental Change portion of the IODP Initial Science Plan.

Any of the proposed drill sites situated on 56 Ma crust would also be a desirable target for basement studies of older oceanic crust. An APL that proposes to rotary core into the basement at one of the paleoceanographic sites would add significant value to the overall expedition by recovering basalt suitable for detailed petrologic analysis.

A

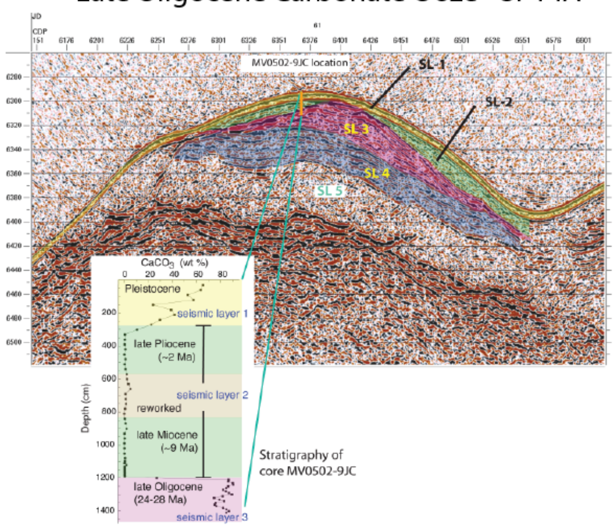


B

Proposed Drill site summary

Site Name	Water Depth (m)	Penetration (m)		
		Sed	Bsm	Total
SP-1B	4971	245	2	247
SP-2B	5075	145	2	147
SP-3B	4703	83	2	85
SP-4B	5186	58	2	60
SP-5B	5210	30	2	32
SP-13A	4772	162	2	164
SP-14A	4658	179	2	181
SP-15A	4778	89	2	91
DSDP 277	1214	480	0	480

C



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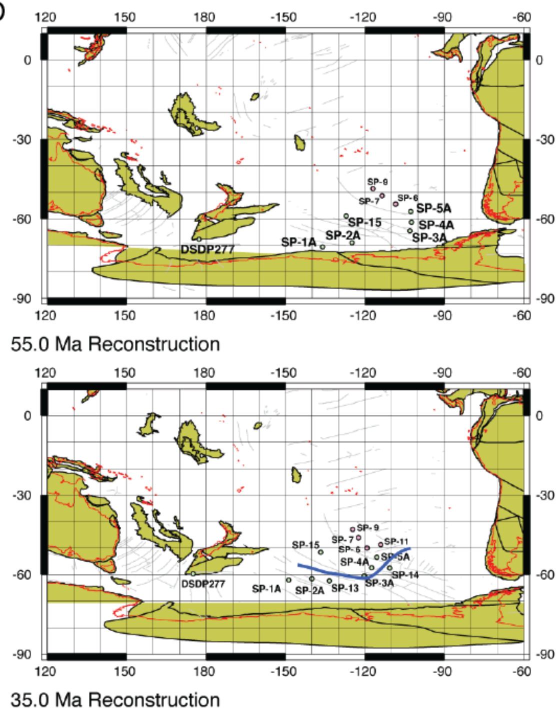


Fig. 1.3: Summary of Paleogene South Pacific Latitude Transect drilling targets A) Drill site locations; B) Planned drilling depths; C) Seismic profile for SP14A (from Lyle 2007); D) Drill sites relative to tectonic reconstructions. Figures from IODP 657 Full Proprosal.

1.1.2. ANDRILL Coulman High Project: The Antarctic end of a SW Pacific Paleogene transect?

Contributors: Richard Levy, Bruce Luyendyk, Rob DeConto, David Harwood, David Pollard, Alex Pyne, Frank Rack, Amelia Shevenelle, Chris Sorlien, Doug Wilson, and the ANDRILL Science Committee.

The ANDRILL (ANtarctic DRILLing) program proposes to drill two ~900 m holes into Paleogene to lowest Miocene sediments beneath the Ross Ice Shelf, at an extensively surveyed location on the Coulman High (CH). Recovery of the targeted strata will provide a new, high-quality stratigraphic record from a period when atmospheric CO_2 was comparable to concentrations projected for the next century. Of particular relevance is the response of the polar regions to elevated levels of greenhouse gases and the impact that regional amplification of surface temperatures has on the cryosphere. Examination of sediments deposited during the targeted time intervals offers a window into the range of environments and ecosystems that existed in the Ross Sea region during warm, high-CO_2 "greenhouse" conditions that dominated the Eocene and cooler moderate- to low-CO_2 conditions that developed in the Oligocene. Direct information on physical, biological, and ecological conditions at the drill sites will allow new constraints to be placed on estimates of ice volume variability, marine and terrestrial temperatures, timing and nature of major tectonic episodes, development of Antarctica's marine, terrestrial, and sea-ice biota, and model simulations of past and future climates and ice sheets. The Coulman High drill sites (Fig. 1.4) are located 120 km northeast of Scott Base and McMurdo Station on the Ross Ice Shelf where it is ~ 260 m thick and moving north at ~ 2m/day in ~810 m of water. Technical advances will allow the recovery of high-quality sediment cores below this fast moving shelf ice. During the 2010-11 Antarctic field season a multinational team of scientists, engineers and drillers used the ANDRILL hot water drilling system to access the sub-ice shelf environment. A suite of data and samples were collected to characterize the water column (current velocity, conductivity, temperature, and pressure), survey the ice-shelf boundary layer and sea-floor (video), and examine Holocene ice shelf calving history (sediment cores). The international ANDRILL team is working to establish formal partnerships and aims to drill during the 2015-17 austral field seasons.

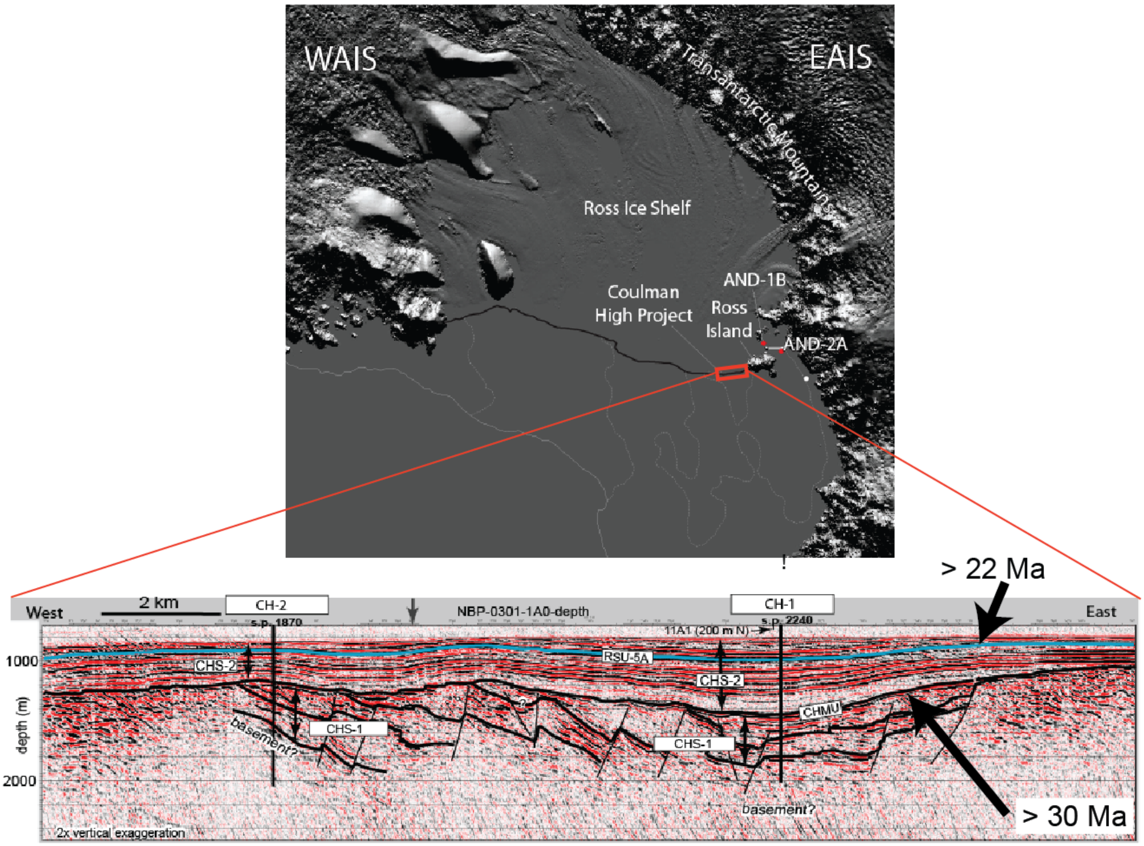


Fig. 1.4: Location and seismic stratigraphy for ANDRILL Coulman High Project drilling targets.

1.1.3. IODP Pre-proposal 813: Greenhouse to Icehouse Antarctic paleoclimate and ice history from George V Land and Adélie Land shelf sediments (Wilkes Land, East Antarctica)

Contributors: Trevor Williams, Carlota Escutia, Laura De Santis, Stephen Pekar, Henk Brinkhuis

Along the George V and Adélie Land (GVAL) shelf of Antarctica, shallow-buried strata contain a record of Antarctica's climate and ice history from the lush forests of the Eocene greenhouse to the dynamic ice sheet margins of the Neogene. Over these times, Antarctica and the Southern Ocean have played a central role in influencing sea level, deep-water formation, ocean circulation, and exchange of carbon dioxide with the atmosphere. Yet there are currently very few direct records of Antarctic climate and ice conditions from close to the continent. On the GVAL shelf, short piston cores and dredges have recovered Cretaceous and Eocene sediment at the sea-bed. In 2010, IODP Expedition 318 shelf sites recovered earliest Oligocene and early Pliocene diamicts, providing direct records of ice advances across the shelf at these times, and confirming that target sediments are accessible at shallow burial depths. However, drilling conditions from the JOIDES Resolution were a challenge, and here we propose to use a sea-bed drill for improved core recovery and easier access to new sites.

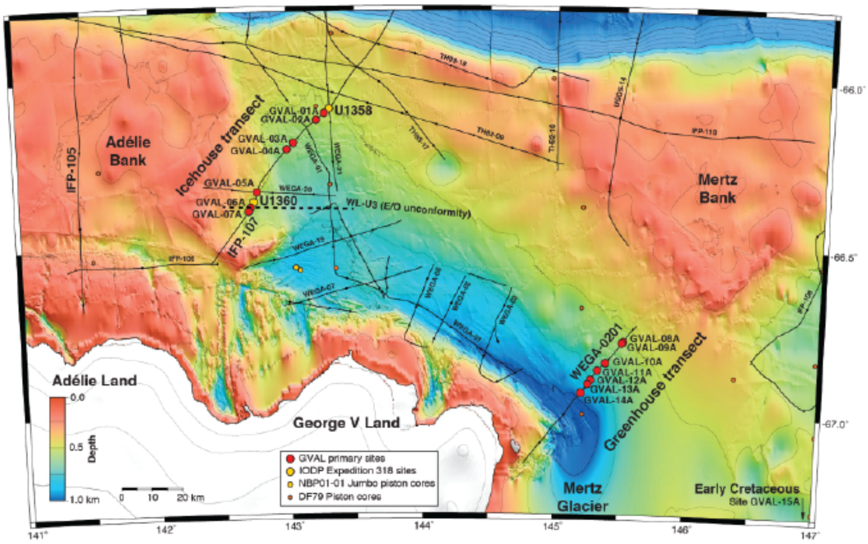
Two stratigraphic transects of shallow (~50m) sites (Figs. 1.5 and 1.6) are proposed to investigate Antarctica's role in icehouse and greenhouse climates, and the transitions between the two. To investigate Oligocene to Pliocene ice sheet dynamics, we target erosional and downlap surfaces to date and characterize major episodes of ice sheet advance and retreat. These direct records of ice extent on the shelf can be set in the context of Southern Ocean records of temperature, ice-rafted debris (IRD) and latitudinal fluctuations of the opal belt, and hence we can relate ice behavior to paleoclimate conditions. The ice and climate history of the GVAL margin can provide warm-world scenarios to help understand ice sheet instability in analogous future warm climates. In the greenhouse target intervals, temperature and vegetation records will: provide high-latitude constraints on pole-equator temperature gradients and their evolution; the proximity of the sites to the coastal lowlands of GVAL will enable us to assess the hypothesized role of thawing permafrost in Eocene hyperthermal events; and late Eocene cooling and possible pre-cursor glaciations can also be documented by drilling. This proposal addresses the IODP science plan's objectives: "How does Earth's climate respond to increased CO2?" and "How do ice sheets and sea level respond to a warming climate?"

For Paleoclimate and ice sheet dynamics objectives, we plan to investigate:

- The timing and character of major ice advances over the shelf, and how this relates to records of IRD, sea level and oxygen isotopes. We aim to sample the earliest Eocene/Oligocene ice advance (~34 Ma), Oligocene warmth, the mid-Miocene climate optimum, cooling during the mid-Miocene climate transition (~14 Ma), and early Pliocene climate fluctuations (~5-3 Ma).
- Climate cooling in the late Eocene in advance of main glacial inception at the Eocene/Oligocene boundary; what were the paleoenvironmental conditions, and were there precursor glaciations?
- Antarctica's climate during the early Eocene climatic optimum, including cyclicity, hyperthermals, temperatures and vegetation. This will extend the short time window obtained at distal Site U1356 (Expedition 318), at a site closer to Antarctica.
- Cretaceous hothouse conditions (non-marine sediments): are they stable or cyclic, and how do conditions compare to the Eocene climatic optimum?

Drilling will also address seismic-stratigraphic, glacial-isostatic, and tectonic objectives to:

- Date the major changes in shelf prograded wedge geometry and the major unconformities.
- Constrain the timing and character of rifting between the Wilkes margin and Australia.
- Assess whether the predictions of glacial isostatic adjustment (GIA) is recorded in the ice-proximal sediments (e.g., relative sea level rise adjacent to expanding ice sheets).



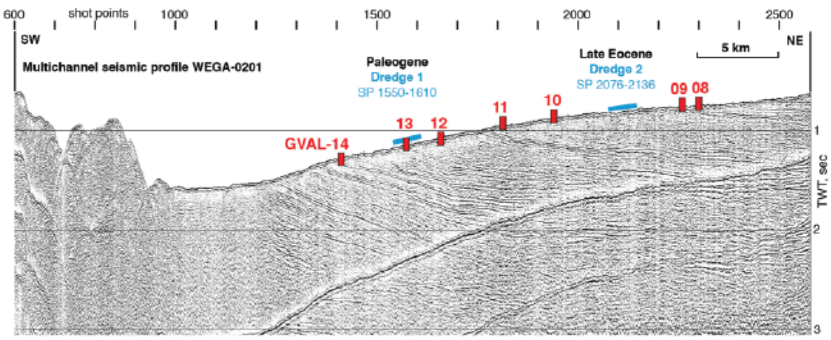


Fig. 1.5: Multibeam bathymetry and seismic profile demonstrating drilling strategy to obtain a series of short cores from dipping strata to obtain a Paleocene to Oligocene "Greenhouse" transect (inner shelf) and a Neogene to Quaternary "Icehouse" transect (outer shelf). Existing dredges from the region show the existence of these strata. Figures from IODP-Pre proposal 813.

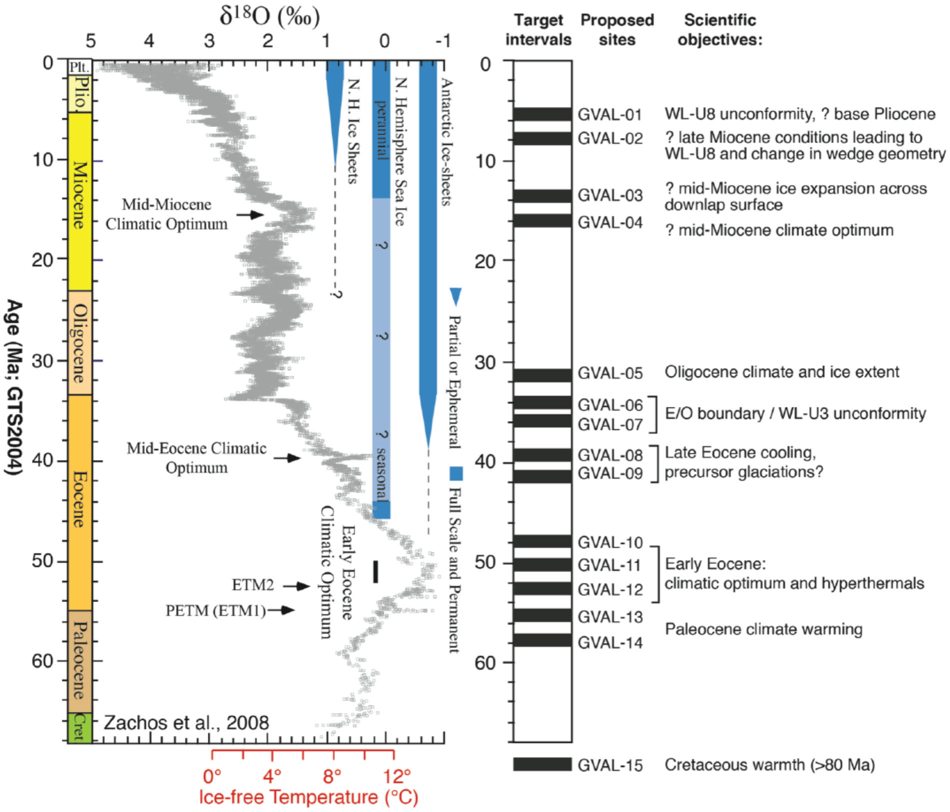


Fig. 1.6. Potential targeted time intervals and climatic events for the proposed short-core transect on the Wilkes Land continental shelf using a Mission Specific Platform. Modified from Zachos et al. 2008.

1.1.4. Lord Howe Rise

Contributors: Jerry Deckens, Chris Hollis, and Bradley Opdyke

Introduction

The 'Tasman Frontier' is a sector of the southwest Pacific that lies between eastern Australia, western New Zealand, and New Caledonia (**Fig. 1.7**). The region includes the Tasman Sea oceanic basin of Cretaceous-Eocene age, continental ridges and troughs, and a region of Eocene-Quaternary arcs and backarcs. Crustal components thought to have continental affinities include the Lord Howe Rise (LHR), Challenger Plateau, New Caledonia Trough (NCT), and the Norfolk Ridge System.

Future ocean drilling in the Tasman Frontier is intriguing, because sedimentary records could address and couple several major challenges spanning different themes. There is sincere interest in developing a proposal that would focus on the following questions:

(1) How and why does subduction initiation (SI) occur?

(1a) Did plate convergence precede and induce SI, or did SI happen spontaneously? Observations regarding timing, distribution, and style of deformation across a large region would be acquired to test alternate SI model predictions through comparison to known plate tectonic reconfiguration.

(1b) What vertical stresses occurred during SI? The magnitude and timing of uplift and subsidence across a broad region would be determined through drilling specific targets, ones that will enable evaluation and refinement of geodynamic models. Far-field uplift and subsidence, as strongly indicated from seismic stratigraphy, challenges existing geodynamic theory.

(2) Was the Eocene southwest Pacific anomalously warm? New proxy data would be generated from a range of sites to assess past surface water conditions in this seemingly climate-sensitive region, and to constrain the depth of the Paleogene CCD. Available data from the region are controversial and problematic; they do not conform to existing paleoclimate and paleoceanographic model simulations.

(3) Does SI relate to past climate?

(3a) Was regional bathymetry during the Paleogene much different than at present? Proposed sites would target horizons that, from available seismic stratigaphy, suggest much of the TF was at or near sea level in the early Eocene, which would impact climate model simulations significantly.

(3b) Did SI coincide with Early Eocene warmth? New and targeted drilling would allow firm documentation on encompassing ideas that regional deformation, and by inference, major plate reconfiguration corresponds in time with maximum Cenozoic warmth.

(4) How and why do Neogene oceanographic changes in the region relate to those elsewhere? Records collected on the path to the above primary objectives would enable a fuller understanding of this issue.

The rationale and background for SI objectives in the Tasman Frontier are presented later in this report. Here we briefly note the scientific rationale for paleoceanographic components, the reason drilling can now occur, and overall drilling plan.

Background

Eocene tectonic changes occurred when atmospheric pCO_2 levels were probably above 1000 ppmv and Earth last existed in a fully "greenhouse" climate state (Pearson et al., 2009; Pagani et al., 2011; Hönisch et al., 2012). Certainly, average Earth surface temperatures were much warmer during the Early Eocene Climatic Optimum (EECO; 52-49 Ma), as known from the fossil record, geochemical proxies, and the absence of large continental ice sheets (Zachos et al., 2008). Global climate models can simulate these conditions (Huber and Caballero, 2011; Lunt et al., 2012), but only with very high pCO_2 or climate sensitivity (such as 8-16 times pre-industrial levels of CO2). Observations from the equatorial Pacific (Tripati et al. 2003; Kozdon et al. 2011) and other regions (Douglas et al., 2011) are consistent with these model simulations. However, proxy records from the southwest Pacific (Bijl et al., 2009; Hollis et al., 2009, 2012) and Southern Ocean (Pross et al., 2012) challenge models, suggesting warmer temperatures than any model results (Hollis et al., 2012; Lunt et al., 2012). What were pCO_2 and climate sensitivity in the Eocene? Why were the middle to high latitudes of the Southwest Pacific so much warmer than models predict? One intriguing possibility is that Tonga-Kermadec (TK) SI uplifted the region and significantly impacted southern hemisphere oceanography. Additional records from the southwest Pacific are required to better understand paleogeography, and to explain major discrepancies between data and models.

The Earth Science community still faces an outstanding paleoclimate question after decades of research: why does Earth oscillate between multi-million year icehouse and greenhouse climate states? High pCO_2 is implicated, but why was pCO_2 in the early Eocene much higher than today? Tectonic processes affect input and output fluxes of carbon to the ocean and atmosphere, and the peak in Cenozoic warmth (ca. 52-49 Ma) apparently coincides with the major change in Pacific plate motion. A consequence of western Pacific SI was a switch from continental-arc volcanism to volcanism at intra-oceanic subduction systems. This may have resulted in a long-term reduction in atmospheric pCO_2 because magma rising through oceanic crust is depleted in carbon compared to continental crust (Lee et al. 2013). Although this and other possibilities for the apparent temporal correlation exist, we posit that Eocene SI is coupled to major changes in regional geography, global climate, and biotic evolution.

Only new drilling at specific sites will enable precise dating of structural changes associated with TK SI. The road to understanding TK SI becomes universally fascinating because the necessary stratigraphic records to accomplish the goal address major paleoceanographic problems. Was the southwest Pacific anomalously warm in the Eocene because of very different paleogeography? Does initiation of global cooling since the early Eocene actually correspond to TK SI and major changes in plate motion? How and do teleconnections occur between sedimentation in the Tasman Sea and elsewhere?

Prior drilling and renewed interest

Two previous scientific drilling cruises have obtained sediment cores in our study region: DSDP Legs 21 and 90 (**Fig. 1.7**). Leg 21 (1972) was drilled sites scattered across the SW Pacific, but including one in the NCB (206) and two on the LHR (207 and 208). Leg 90 (1982/1983) drilled four successful sites on LHR (588, 590-592) and one on Challenger Plateau (593). Reading Site Report Chapters lead to the following.

The Neogene sequences captured during Leg 90 are fairly good from a recovery standpoint. Sites 588, 590, 591, and 593 each have sediment sections that were collected in multiple holes using an APC tool. The sediment is mostly foraminiferal-bearing nannofossil ooze and ideally suited for many paleoceanographic investigations. Notably, however, the sites span a wide area and a limited depth range. Additional Neogene records from new sites could improve our understanding of Miocene-Pliocene oceanography in the region significantly.

In complete contrast, the early Paleogene record from the Tasman Frontier is very poorly documented. Partial sediment sequences of highly variable composition and highly variable core quality have been recovered at six locations.

Site 206 has 7 rotary-drilled spot cores across a ~120 m interval deposited between the early Paleocene and late Eocene. Despite sedimentary depth, ~614-730 mbsf, most of the record is foram-bearing nannofossil ooze. Interestingly, much of the upper Paleocene may be absent (perhaps because of erosion). However, other than being incomplete, some cores from within the sequence, especially around the P/E boundary are highly disturbed because of drilling, slumping, or both.

Site 207 has a fascinating record, although again rotary cored. Below a major unconformity, “A fine, apparently continuous sequence [with] abundant, well-preserved foraminifera can be correlated with the Bortonian (late middle Eocene) to Mangaorapan (middle Early Eocene) stages of New Zealand”. In fact, the base of this ~140 m-thick unit of foram-bearing nannofossil ooze contains microfossil assemblages that absolutely correspond to the late stages of EECO. The section is then underlain by a complicated and condensed interval of early Eocene through early Paleocene calcareous mudstones that contain biotic elements suggesting a proximal neritic source. Beneath this are upper Cretaceous mudstones and ultimately rhyolite.

Site 208 has 6 rotary-drilled spot cores across a ~90 m interval deposited between the early Paleocene and late Eocene. The upper part of this record is glass, diatom and radiolarian bearing nannofossil chalk of middle Eocene age. The lower part of this record is the same, but without glass, and of early to middle Paleocene in age.

Site 588 recovered ~3 m of middle Eocene foraminiferal bearing nannofossil chalk. The hole was terminated because of failure with the XCB system and because Neogene objectives had been accomplished.

Site 592 obtained ~75% of a ~58 m section of upper Eocene nannofossil ooze to chalk in a single hole using a still malfunctioning XCB tool. The sequence has apparent ash horizons and biotic indications of shallow water depth. The hole was terminated for time reasons.

Site 593 recovered two cores of late Eocene age, one 6.6 m of volcanogenic turbidites, the other 8.6 m of foram bearing nannofossil chalk. Both cores were recovered with a still faulty XCB tool.

The juxtaposition of the available sequences at Sites 207 and 592 is important and telling, especially with new seismic lines. The two sites are located about 50 km apart, but have very different Eocene sedimentary records. The upper Eocene interval at Site 592 is entirely missing at Site 207, presumably because of shallow erosion.

To summarize: our total collection of lower Paleogene sedimentary material from the immense Tasman Frontier area, which appears to have been very complex during the Paleocene and Eocene, is about ~360 m in stratigraphic sense, and most comes from three holes almost randomly placed over forty years ago and cored using rotary technique. We now have a clear rationale for drilling the region, and can advance our understanding immeasurably. New drilling will allow us to determine the timing and direction of regional convergence, the timing, areal extent, and magnitude of vertical motions, and the paleogeography and paleoclimate of the region.

The recent compilation of seismic-reflection data across the Tasman Frontier (Sutherland et al., 2010; Sutherland et al., 2012) represents a huge leap forward for potential scientific drilling in the area (**Fig. 1.7**), because it provides a firm basis for interpreting seismic stratigraphy, for realizing the significance of unusual observations, and for locating primary coring targets. The Tasman Frontier has approximately 100,000 line km of seismic-reflection data collected over the past four decades. However, the region also has complex sovereign boundaries (New Zealand, Australia, France, Tonga, Fiji, Vanuatu), and most data were obtained within the scope of unrelated academic, industry and government projects. The net result was a massive amount of data with limited connectivity.

Over the last decade, work demanded by the United Nations Convention on the Law of the Sea has led to resolution of sovereign seabed boundaries, to systematic compilation of seismic-reflection data, and to collection of new data with specific intent to link geophysical data through existing DSDP boreholes. All seismic-reflection data that can be released in the public domain are now freely available through a collaboration between New Zealand (GNS), Australia (GA), and New Caledonia (DIMENC/ADECAL) (Sutherland et al., 2012). To a large degree, the impetus for a drilling proposal corresponds to the convergence of independent scientific thought for why the region needs drilling, and the publication and initial interpretations of considerable geophysical data for how this extensive region can be drilled.

The primary tectonic and paleoclimate objectives have a similar generic requirement: collection of Eocene sediment cores across a range of latitude, longitude and water depth, which can be dated with reasonable precision, and which hold information that can be placed into broad context. We offer a tentative map of drill sites, and plan to submit a proposal on this in the near future.

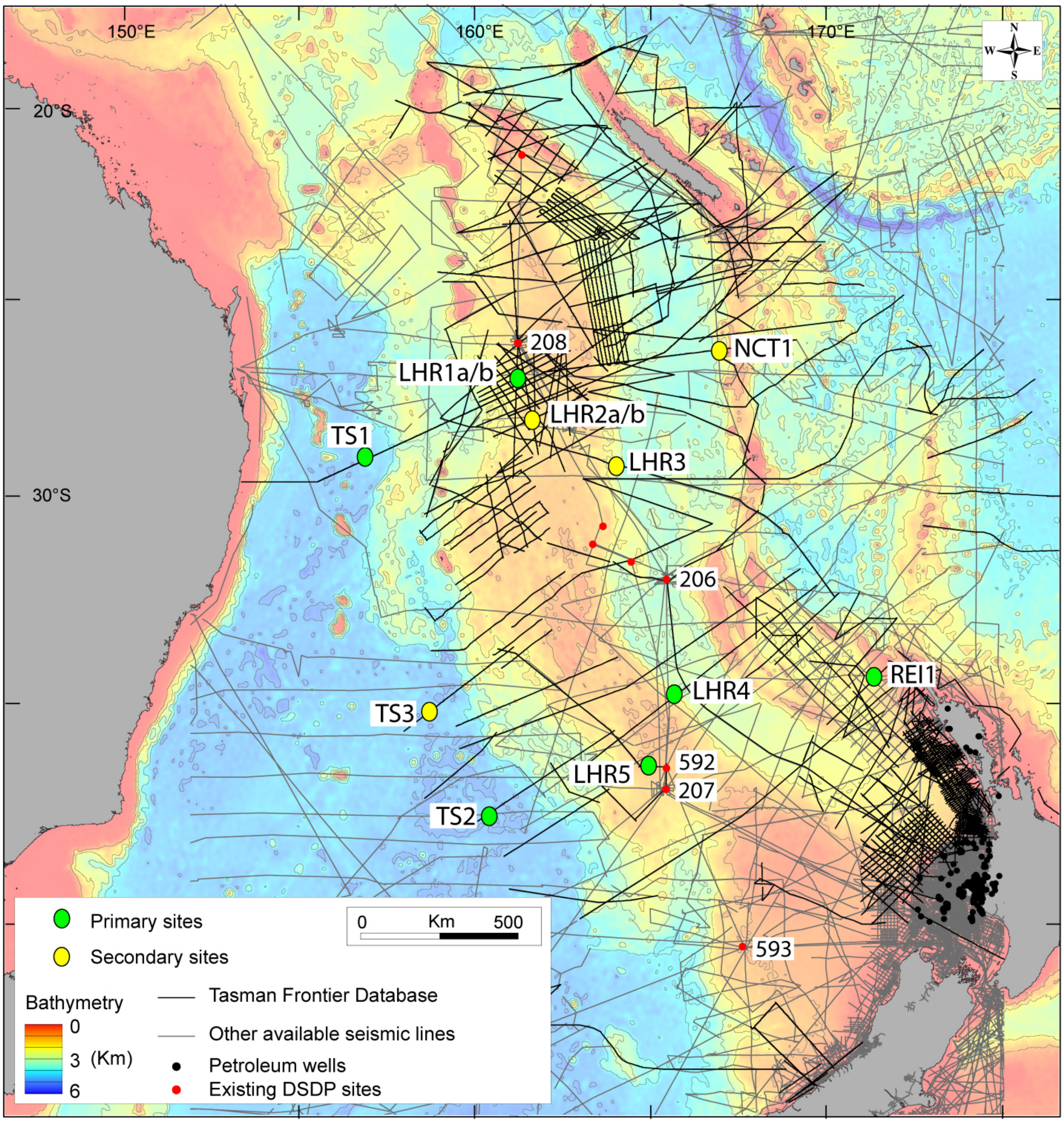


Fig. 1.7: Existing borehole and seismic information for the Tasman Frontier, along with potential drill sites.

1.1.5. Campbell Plateau (Western Campbell Plateau & Campbell Drift)

Contributors: Chris Hollis, Sandra Kirtland-Turner, Bradley Opdyke, Bryan Davy, Denise Kulhanek and Richard Norris,

Two regions on the Campbell Plateau (Figs. 1.8 and 1.9) are identified as having significant potential for paleoceanographic advances with possibilities of a single expedition or two linked expeditions to investigate the evolution of Cretaceous-Paleogene climate and ocean circulation at high southern paleolatitudes. Both regions have sufficient seismic data to identify major scientific targets and their potential but currently have insufficient supporting seismic data to carry out the proposed drilling.

Western Campbell Plateau: DSDP Site 277 (Leg 29), southwest Campbell Plateau, drilled a near-continuous carbonate ooze section that provided the initial stable isotope stratigraphy for the Paleogene (Shackleton and Kennett, 1975): from late Paleocene to middle Oligocene. New biostratigraphic and isotopic studies show that all nannofossil, foraminiferal and radiolarian zones are represented, despite a short-lived hiatus at the middle/late Eocene boundary, and that a condensed

Paleocene-Eocene thermal maximum is preserved. One current IODP proposal and an earlier ODP pre-proposal incorporate re-drilling of this site as part of a wider drilling program. Another option presented here is to conduct a focused drilling expedition on the western Campbell Plateau region, either to target higher latitude sites (north-south transect) or sites with potential for high sedimentation rates and high terrigenous input (west-east transect).

Campbell Drift: Drilling of ODP Site 1121 (Leg 181) revealed that the Campbell "Drift," previously believed to be a Neogene contourite drift, was Paleocene in age. Biostratigraphic and geochemical analyses of the Paleocene sediments identify drift-like high rates of sedimentation (2-11 cm/ky) combined with an *in situ* paleoclimate record comparable to the recently drilled Paleogene-Miocene drift sequence off Newfoundland (IODP Expedition 342). A reprocessed seismic line provides a cross-section of Campbell Drift and indicates that a more complete Paleogene sequence is preserved up-slope.

Targeted drilling of Campbell Plateau depth transects has the potential to yield expanded Cretaceous-Paleogene sections with robust age control and a multi-proxy record of climatic and oceanographic change in a high-latitude setting that is well positioned to examine the evolution of thermohaline circulation and polar to tropical teleconnections through the Cretaceous-Cenozoic greenhouse-icehouse transition.

This proposal directly address Challenge 1, 2 and 4 in the Climate and Ocean Change Theme from the IODP Science Plan.

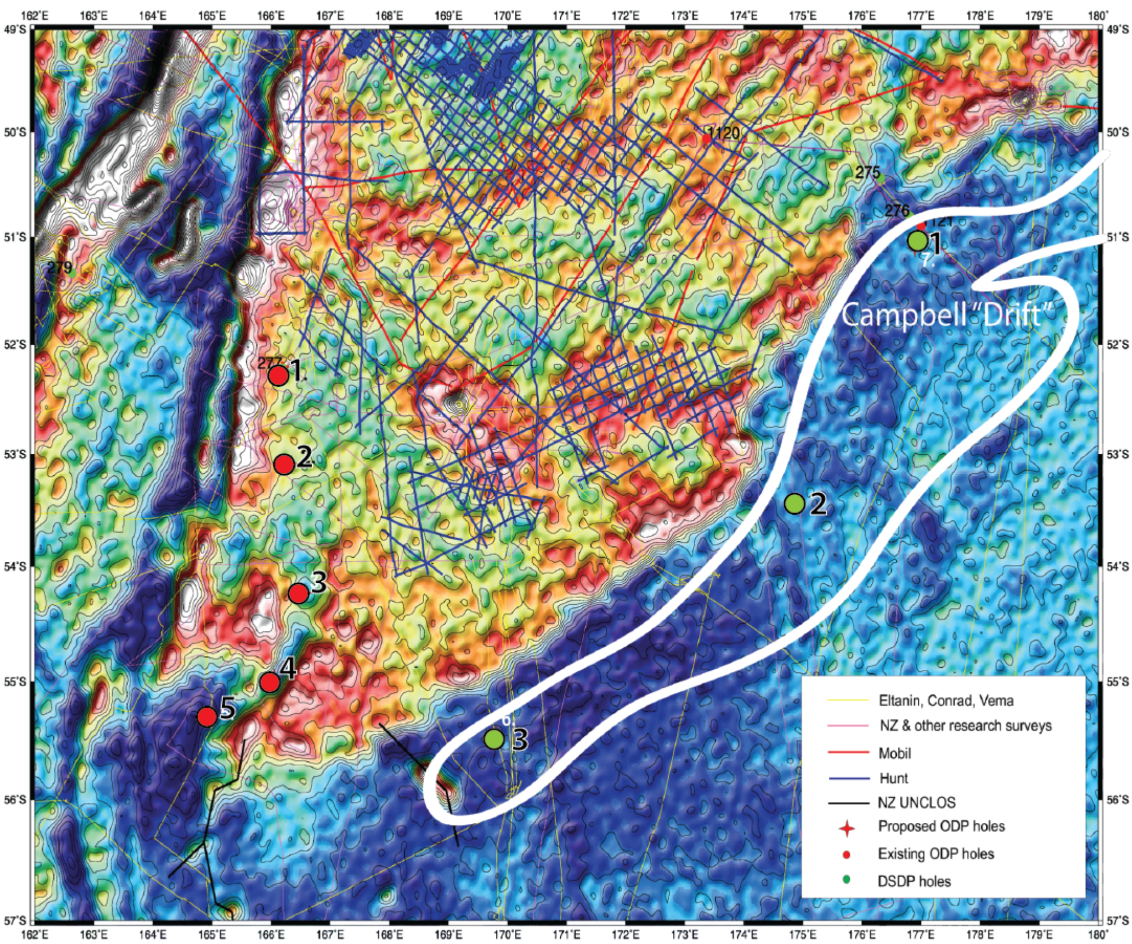


Fig. 1.8: Bathymetic map and potential drill sites on the Campbell Plateau (red circles) and in the Campbell Drift (green circles). Preexisting seismic lines are also shown.

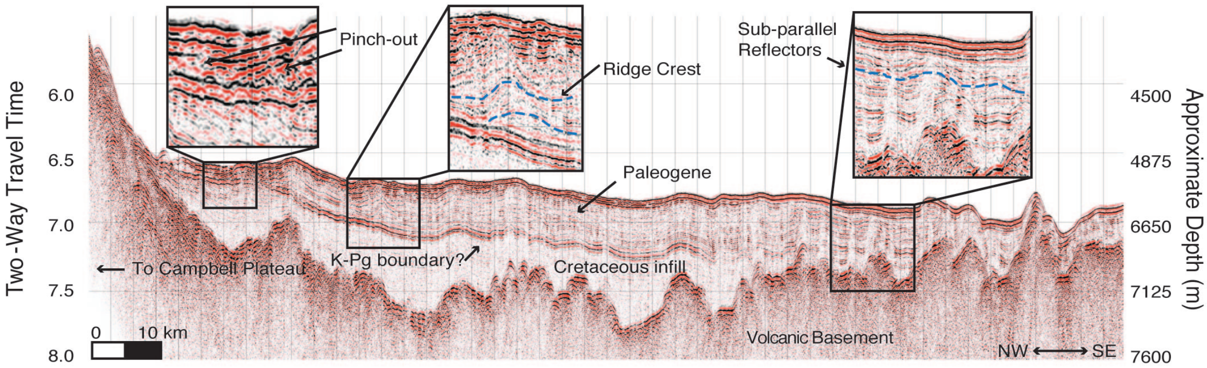


Fig 1.9: Seismic reflection profile of Ewing Line 9201 showing a cross-section of the Campbell "Drift" from 53°50.9392'S, 174°22.4946'E to 55°16.3181'S, 174°40.1100'E. Drilling at ODP Site 1121 further northeast along the drift (50°53.876'S, 176°59.862'E) recovered Paleocene sediments below ~32 mbsf. Boxes indicate seismic features indicative of drift sedimentation, including pinched-out reflectors, a ridge crest formed by continuous overlay of upslope migrating down-lapping reflectors, and sub-parallel reflectors in the Paleocene sediments that to not correspond to the basement structure.

1.2. Neogene and Quaternary climate and ocean change

The Neogene and Quaternary experienced the permanent development of the East Antarctic Ice Sheet during the mid-Miocene and the modern Southern Ocean sea ice belt by the mid-Pleistocene. CO_2 levels were largely below 300 ppm through much of the Neogene (i.e., at pre-industrial levels) although during the Mid-Miocene Climate Optimum (MMCO, ~17-15 ma) and Pliocene Warm Period (~5-3 Ma), CO_2 was moderately elevated (350-400 ppm), both of which were characterized by reduced West Antarctic Ice Sheet extent. During the Pliocene Warm Period, the Equatorial Pacific was characterized by permanent "El Niño-like" conditions with a reduced East to West sea surface temperature gradient, and an expanded western Pacific warm pool. Termination of the "permanent El-Niño-like" conditions by the Late Pleistocene was roughly co-incident with the restriction of the Indonesian seaway, expansion of Southern Ocean sea ice, and significant glacial expansion in West Antarctica and the Northern Hemisphere. While El-Niño like conditions are anticipated to result in increase heat transport to polar regions, cooling in the Southern Ocean may also influence lower latitudes via regulation of atmosphere-ocean gas exchange and heat transport related to changes in intermediate and deep water formation and surface ocean currents (e.g. Fig. 1.10). The proposals discussed in this subtheme include obtaining a direct record of West Antarctic Ice Sheet variability on the outer Ross Sea continental shelf and related oceanographic change on the Antarctic continental slope, as well as on the Wilkes Land continental shelf (see sub-theme 1). Proposals to drill equatorial records on changes in Indonesian through-flow and associated influences on the West Pacific Warm Pool, as well as a high-resolution Late Quaternary coral reef record from the Sabine Bank/Bouganville region are also discussed. To investigate pole-to-equator linkages, there are sufficient pre-existing drill cores that document the Neogene history of the Deep Pacific Inflow of Antarctic sourced bottom waters into the Pacific (ODP Leg 181), as well as variations in subtropical inflow in to the SW Pacific (DSDP Leg 90). However, there is a significant paucity of high-quality Neogene to Quaternary climatic records from within the path of the Antarctic Circumpolar Current in the vicinity of the Polar Front, a strongly influential region for the global carbon cycle and ocean heat budget. Neogene development of the Polar Front was associated with major changes involving siliceous planktonic diversity, evolution and productivity that are in need of high-resolution documentation. Better understanding of the evolution of the Polar Front and its biotic development would strongly benefit from a meridional transect of cores drilled using modern technology in the vicinity of DSDP Site 279. Drilling thjs Neogene objective would require little time and could potentially take place during the proposed expedition to the nearby Campbell Plateau.

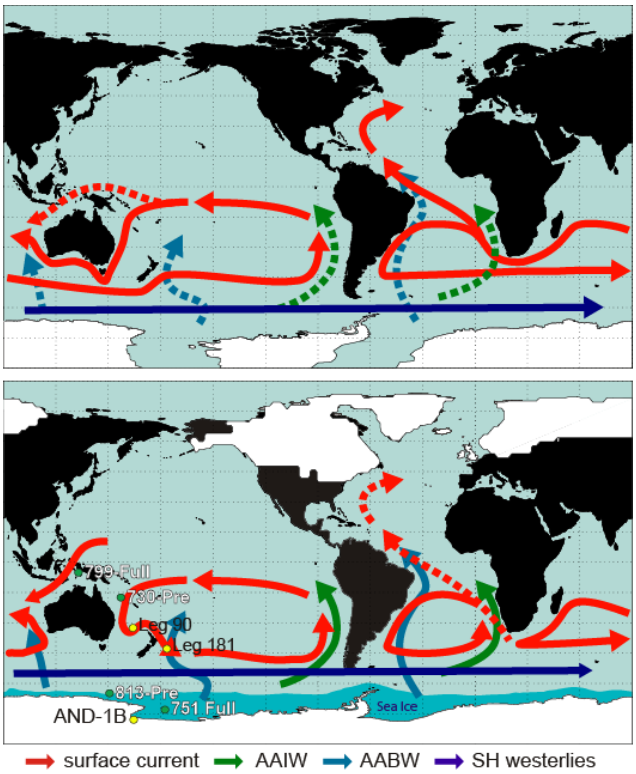


Fig 1.10: Hypothesized changes in surface and subsurface ocean circulation related to Southern Ocean cooling (dotted line indicate reduced water mass production). The SW Pacific region is situated in a key location that documents changes in inter-oceanic basin exchange via restriction of the South Pacific gyre, as well as the passage of Antarctic Bottom Water entering the Pacific Ocean via the Deep Western Boundary offshore of New Zealand. This region is also well placed to examine controls on equatorial processes, such as El Niño, which is heavily influenced by the extent of the Western Pacific Warm and tectonically induced changes in the Indonesian through-flow. Proposed (green circles) and relevant pre-existing drill-sites (yellow circles) are also shown. Figure modified from McKay et al. (2012)

1.3. Tropical regions

1.3.1. IODP Full-proposal 799: Western Pacific Warm Pool – Yair Rosenthal

Contributors: Yair Rosenthal, Gregory Mountain, Braddock Linsley, James Wright, Stella Woodard, John Higgins, Jess Adkins, Christina Ravelo and Mahyar Mohtadi

The Indo-Pacific Warm Pool is the largest reservoir of warm surface water on earth, the major source of heat to the atmosphere, and a location of deep atmospheric convection and heavy rainfall. Small variations in the sea surface temperature (SST) of the Western Pacific Warm Pool (WPWP) influence the location and strength of convection in the rising limb of the Hadley and Walker circulations, perturbing planetary scale atmospheric circulation, atmospheric heating, and tropical hydrology. Studies of climate variability in the WPWP have relied primarily on the single low sedimentation-rate ODP site 806B from the Ontong Java Plateau, which serves as the warm end-member used to monitor zonal and merdional gradients throughout the Neogene. Higher-resolution sites are available from marginal seas in the western equatorial Pacific, but they are strongly impacted by local processes. Thus there is a gap in the spatial and temporal coverage of the WPWP that prevents us from assessing climate change in this region on various time scales. Over the past decade new coring efforts have demonstrated the possibility of obtaining records from key locations in the WPWP with comparable resolution to records from the high latitude oceans, cave deposits and ice cores. While substantial progress in understanding WPWP climate variability has been made by studying long piston cores, there are fundamental questions that cannot be addressed without recovering longer records than those afforded by conventional and long piston coring.

It is proposed to drill 11 sites, strategically located (Fig. 1.11) to address questions related to the relationships between millennial-scale variability in the tropical Pacific and in the northern Atlantic; the controls on tropical Pacific SST and SST gradient on various time scales; the response of the hydrologic cycle on those time scales and mechanisms controlling these variations; the evolution of the WPWP from the middle Miocene to the present; the relationships between changes in the equatorial Pacific mean climate state and dynamical processes (e.g., ENSO) and how do they relate to the Plio-Pleistocene transitions. The proposal includes low sedimentation-rate sites selected to reconstruct secular trends and orbital scale variability in WPWP paleoceanography since the mid Miocene and sites from rapidly accumulating sediments selected to assess centennial to millennial climate variability, and monitor the Indonesian Through-flow variability. Pore water measurements will be used to reconstruct the deep ocean temperature salinity and $\delta^{18}O$ during the LGM, as well as changes in seawater chemistry (e.g., Mg/Ca and $\delta^{11}B$) during the Neogene.

Specific objectives include:

- What is the spatial and temporal extent of millennial variability in the WPWP?
- Is there an ice volume threshold for a North Atlantic-equatorial Pacific link controlling the appearance of millennial-scale climate variability in the western equatorial Pacific (WEP) as suggested for the north Atlantic?
- Do hydrologic changes in the western parts of the WPWP respond strictly to changes in East Asian monsoons or are they independently teleconnected to the North Atlantic region?
- What are the relationships (coherency and phase) among orbital changes in WPWP SST, thermocline structure, deep ocean temperature and global ice volume? What are the associated changes in WPWP hydrology?
- Are weak monsoons during terminations that are so prominent in speleothem records, also a feature of the WPWP? Are the trends observed during the Holocene typical of other interglacials and how are they affected by the global climate state?
- What is the long-term (mid-Miocene to present) evolution of WPWP SST?
- What are the changes in the Indonesian Through-flow (ITF) on orbital and millennial time scales?
- What was the oxygen isotopic composition of intermediate and deepwater masses in the western equatorial Pacific during the last glacial maximum (LGM) as reconstructed from pore-water profiles?
- What were the secular changes in seawater chemistry since the mid-Miocene and what are the implications for paleoceanographic reconstructions e.g., accuracy of Mg/Ca-derived temperatures, pH and continental weathering?

NSF-ODP funding site-survey proposal is scheduled on R/V Revelle in early 2013 for Sites WP1-9. These data files will be submitted for the April 1, 2013 PEP meeting. Seismic data for sites 10&11, as well as permission from Indonesia to drill sites WP7 and WP10 is also being sought.

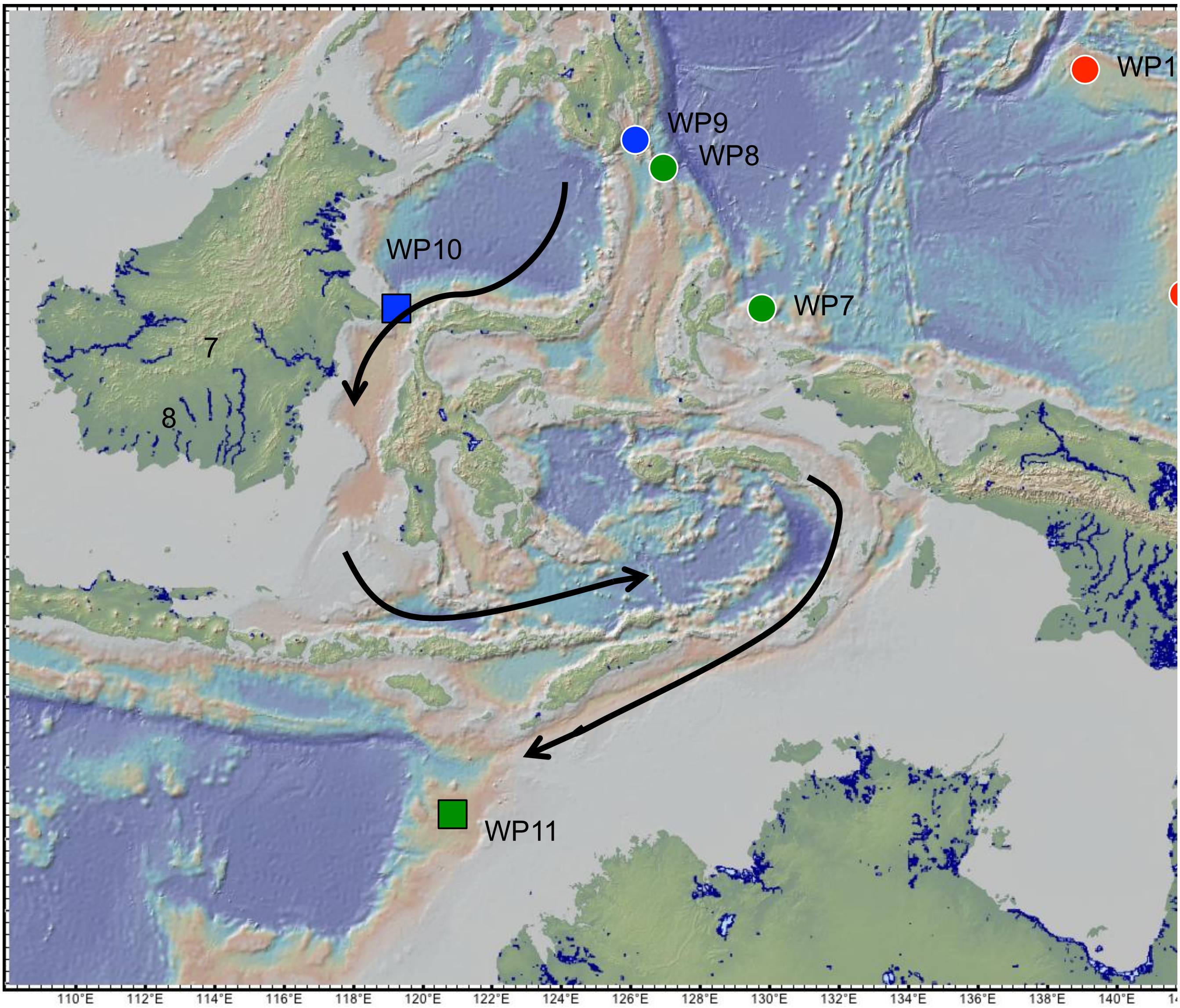


Fig. 1.11: The Location of proposed drilling targets for the West Pacific Warm Pool.

1.3.2. IODP Pre-proposal 730: Sabine & Bougainville Banks history

Contributors: Frederick W Taylor, James A. Austin, Jr., Bernard Pelletier, Guy Cabioch, Terrence M. Quinn, Laura Wallace, and Chuan-Chou Shen

Recovery of pre-late Holocene fossil coral heads suitable for climate reconstructions remains a great challenge. However, appropriate drilling methods for high core recovery rates applied at both Sabine Bank and Bougainville Guyot, central New Hebrides arc, could produce coral samples of unprecedented quality and ages. Both features crossed the trench outer rise and are entering the New Hebrides trench thus causing rapid subsidence. At slowly subsiding, stable, and uplifting sites meteoric diagenesis renders most corals unacceptable for paleoclimate records because they reside above sea level much of the time. However, rapidly subsiding substrates potentially accumulate fossil corals in a vertical sequence that can be well preserved as demonstrated by IODP Leg 134 Site 831 on Bougainville Guyot. From Site 831b at 238 mbsf a nearly pristine *Porites* sp. coral produced a detailed 15-yr record of climate dated in the MIS 9 – 11 age range. It was preserved because it subsided rapidly into the New Hebrides trench and resided deep within the paleo-reef in marine water most of the time. The only problem was that core recovery rates were extremely low. Future drilling at Bougainville Guyot can be based on results of Leg 134 and appropriate drilling methods could recover many such well preserved corals. Fifty km west a Sabine Bank living coral produced a modern coral climate record that demonstrates the potential for fossil corals from the area to represent crucial aspects of paleoclimate variability. As in the case of Bougainville Guyot, Sabine Bank is approaching the trench and subsides at a rate determined by outer rise flexure shape and the plate convergence rate. The bank rises from depths of ~4000 m and is about 10 x 4 km on its bowl-shaped surface where water depths range from ~5 to 40 m. To explore a drilling strategy at Sabine Bank, we conducted multi-beam and MCS surveys and found at least 500 m of reef accumulation. Exact amounts of reef and its ages depend on many factors including coral growth and subsidence rates and details of sea-level history, but subsidence of 0.5 to 2 mm/yr and reasonable reef accumulation rates would have allowed reef accumulation during much of the last postglacial sea-level rise and the high stands of MIS 3-7. In addition to the surface of Sabine Bank, several terraces that may offer drilling targets step down its flanks at depths of 30-32 m, 40-45 m, and deeper. We are in the process of attempting to re-date the Bougainville Guyot corals of Site 831 by modern U-series methods that may better define the subsidence rates and drilling prospects for both the Bougainville and Sabine reef systems.

In summary, relatively rapid subsidence at both Bougainville Guyot and Sabine Bank enhances the probability of recovering corals from important intervals because: 1. Subsidence creates accommodation space on the reef platform so that more corals representing more paleosea-level intervals can be preserved in vertical succession. 2. Regressions are less likely to have subaerially exposed the reef platform because it was subsiding significantly as sea level fell; sea level remains on-bank longer to deposit before regressing down the fore reef slopes; 3. Overall, subsidence expands the coral record vertically unlike where the substrate is stable or uplifting. Although not the focus of this proposal, the reef chronostratigraphy from Sabine Bank also would offer important insights into aspects of the tectonic history and geodynamics of the New Hebrides subduction margin. This proposal directly addresses Challenges 1 and 2 from the Climate and Ocean Change Theme in the IODP Science Plan.

1.4. Antarctic Regions

1.4.1. IODP Full-proposal 751: Ross Sea – West Antarctic Ice Sheet history

Contributors: Phil Bart, Laura DeSantis, Sophie Warny, Charlotte Sjunneskog, Richard Levy, Amelia Shevenell, Lou Bartek, Frank Rack, David Pollard, Fabio Florindo, Nicholas Eyles, Sherwood Wise Jr., Jong Kuk Hong and Rob McKay.

The primary objective of this drilling proposal (see Fig. 1.12 for setting) is to address hypotheses concerning WAIS advance and retreat from full-glacial configurations from the perspective of the eastern Ross Sea continental shelf and continental rise stratigraphy. This area receives drainage from the Pacific sector of the WAIS and the seismic-stratigraphic framework is the best documented of any Antarctic sector (Fig. 1.12). Six drill sites are proposed to determine sediment ages and paleoenvironmental data needed to test hypotheses concerning WAIS dynamics on the Ross Sea continental shelf, and associated sedimentation on the continental rise. Recent modeling indicates that four factors exert major influence on the West Antarctic Ice Sheet (WAIS): changes in sea level, atmospheric temperature, precipitation and ocean temperature. The model relies on the assumptions that these factors co-vary between glacial and interglacial states, can be directly deduced from $\delta^{18}O$ composite records, and that there were no changes in the continental shelf morphology that altered warm water intrusion. This drilling builds on the results from two ANDRILL drill-cores from the inner shelf in the western Ross Sea, that obtained a discontinuous 20 million year long record of expansion and retreat of grounded ice on the Ross Sea continental shelf. Drilling in the eastern Ross Sea will ultimately complete a transect of cores from the inner shelf (ANDRILL sites) to the outer Ross Sea continental shelf (this study) and into the southern sector of the Southern Ocean (this study and IODP Exp 318). The outer shelf cores will document advance and retreat of WAIS (since the late

Miocene) and possibly EAIS (in the early Miocene) onto the outer shelf in the Eastern Ross Sea, while the more continuous record from the upper continental slope will document sedimentation directly related to changes in ice sheet (e.g. turbidite delivery, ice rafted debris, biogenic sedimentation) and sea ice extent and water masses (biogenic productivity/geochemistry) forming in the Ross Sea continental shelf and down-flowing into the Southern Ocean (and vice versa upwelling of oceanic current into the continental shelf and flowing under the Ross ice shelf). Correlation of these records to the ANDRILL records will allow for assessment of the aforementioned mass balance controls that may have influenced marine-based ice sheet variability throughout the entire Ross Embayment in the Neogene. In addition, it will compliment and assist in the interpretation of the recently obtained IODP cores U1359 and 1361 from the lower continental rise on the Wilkes Land margin. The Wilkes Land margin cores record turbidite delivery and ice rafting resulting directly from marine-based ice sheet variability on the continental shelf sector of Wilkes Land, as well as ice rafting and water masses from the Ross Sea. The Ross Sea IODP proposal full-751 is strongly linked to the Amundsen-Bellingshausen Sea IODP proposal full-784 and to the SO Pacific new proposals (to be submitted). For further details on links among the WAIS proposals, see report of the Southern Ocean Drilling Workshop held in Portland, USA, 2012.

The primary objectives are to characterize key intervals in the development of the West Antarctic Ice Sheet (WAIS), to provide robust chronological and paleoenvironmental constraints for driving marine based ice sheet variability across the Ross Sea. Key Questions include:

- When did the WAIS become fully glaciated?
- How did WAIS respond to the Mid Miocene Climatic Optimum and Mid Miocene Shift? Was the transition towards colder climate gradual or abrupt?
- When was the last time of that significant amounts of freshwater were released to the continental shelf?
- What was the full extent of WAIS grounding line translations? How often did the grounding line reach the outer continental shelf in the Eastern Ross Sea during the Pliocene and Pleistocene?
- How is the early Pliocene warmth manifested on the continental shelf? What were the sea surface temperature changes?
- What is the role of sea ice for the regional Pliocene climate development?
- Can the outer continental shelf records be correlated with the inner shelf ANDRILL and the deep sea proxy records (e.g. prolonged retreat events/glacial unconformities)?
- Can the continental slope sites provide a more continuous sediment record that link the continental shelf to deep sea records?
- When did the modern sea ice belt develop? How extensive and thick was the belt during the Miocene, Pliocene and Pleistocene interglacial periods?

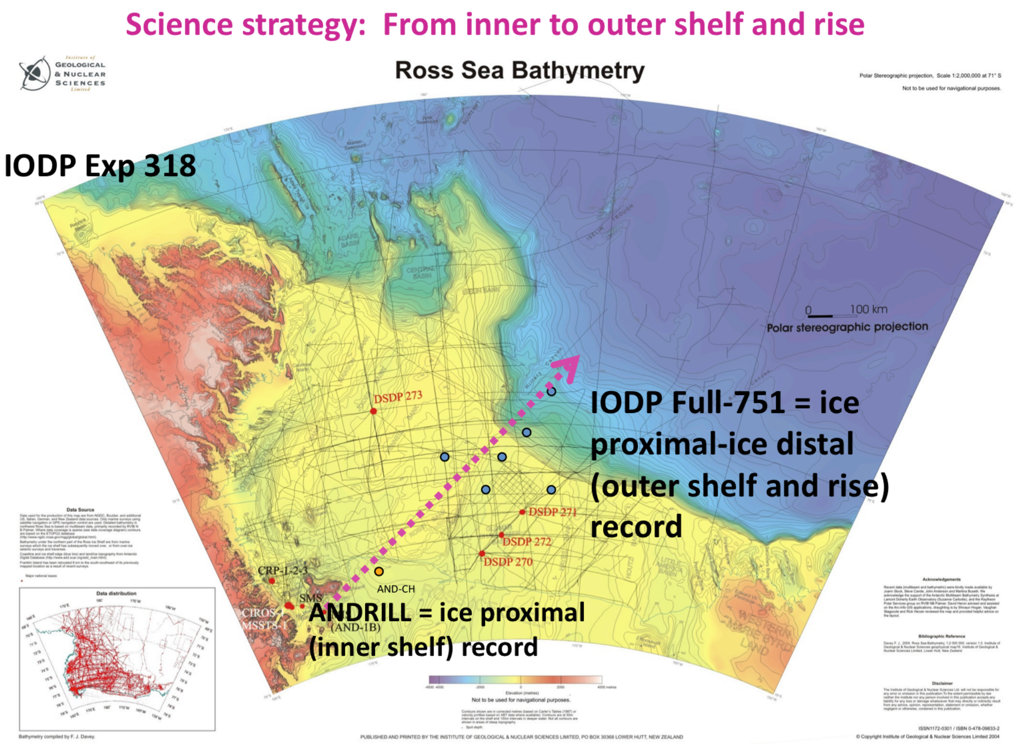


Fig. 1.12: Proposed IODP drill sites on the outer Ross Sea continental shelf to complete a transect of inner shelf to outer shelf ice sheet variability through the Neogene, and a record of associated change on the Ross Sea and Wilkes Land (IODP Exp 318) continental slope/rises

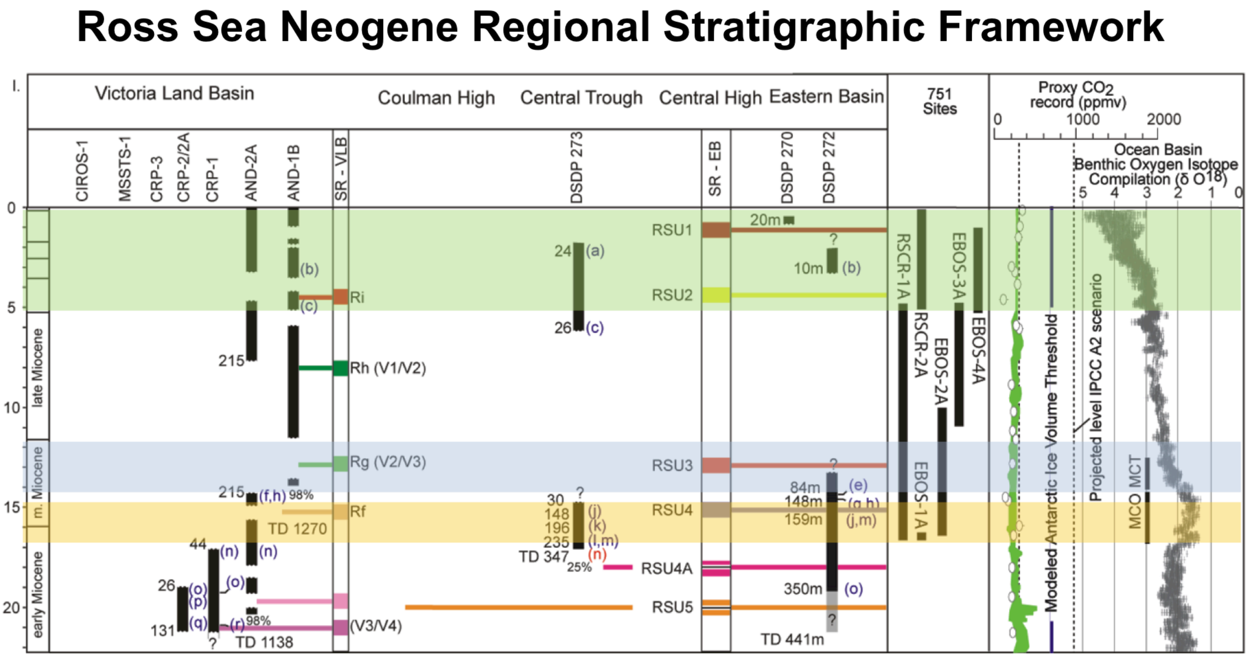


Fig. 1.13: Stratigraphic framework for the Ross Sea. Note the Victoria Land basins are located on the inner shelf in the Western Ross Sea. The proposed Full-751 sites are anticipated to provide a complimentary record from the outer continental shelf and continental slope in the Eastern Ross Sea in order to provide a broader insight into basin wide variability of marine ice sheets in the Ross Sea through the Neogene.

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To be completed

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Theme 2: Biosphere Frontiers: deep life, biodiversity, and environmental forcing of ecosystems

Pioneering studies in the latest phase of IODP. There is almost nothing known about the deep biosphere in the region, so pioneering studies of both sediments and basalts should lead to exciting results.

Sub-committee co-chairs Steven D'Hondt (USA) and Ken Takai (Japan)

- Gulf of Papua (full program) – Jerry Dickens
- DSDP Site 262 (APL), Timor Trough
- Brothers Caldera (APL?)
- Hikurangi Subduction Margin (APL?)
- Tonga Trench (APL?)

2.1. Dynamic cycling of carbon on continental slopes: Source-to-sink sedimentation in the Gulf of Papua

Contributor: Gerald R. Dickens,

Multi-disciplinary: a bridge between climate and ocean change, biosphere frontiers and Earth connections

Carbon cycling within sediment connects many research avenues but rarely has been the focus of ocean drilling. Organic carbon and carbonate land on the seafloor at variable rates, depending on location and time. Microbes consume organic carbon, generating a range of products, especially gas. Carbon, as methane or dissolved bicarbonate, returns to the ocean. The generalities of this dynamic carbon cycling are known, but several basic issues and many details are not. This is especially true for sediment along continental slopes – the jungles of carbon mass and microbial life compared to the deserts mostly drilled to date. Southern Papua New Guinea and the adjacent Gulf of Papua (GoP) represent an outstanding location to understand the sources and sinks of carbon to and from the ocean along a continental margin. Several very large rivers draining southern PNG, especially the Fly, deliver enormous amounts of terrigenous siliciclastic material and organic matter to the GoP inner shelf each year. In contrast, the northern extension of the Great Barrier Reef, which covers the western shelf, and several large isolated platforms generate substantial quantities of biogenic neritic carbonate. Combined with pelagic sources, both organic carbon and carbonate accumulate on the slope, but at highly variable rates in space and time because of modern differences in geography and oceanography, and past changes in sea level, climate and tectonics. In any case, extreme sedimentation characterizes some regions of the GoP. The GoP is a relatively closed system with relatively pristine carbon inputs. It is also fairly well mapped. Arguably, the GoP is the best margin anywhere for a source-to-sink understanding of carbon cycling along continental slopes. The goal here is to push a drilling proposal in the GoP that will quantify carbon inputs and outputs to and from the ocean over time by targeting sites in that span a wide range in these fluxes.

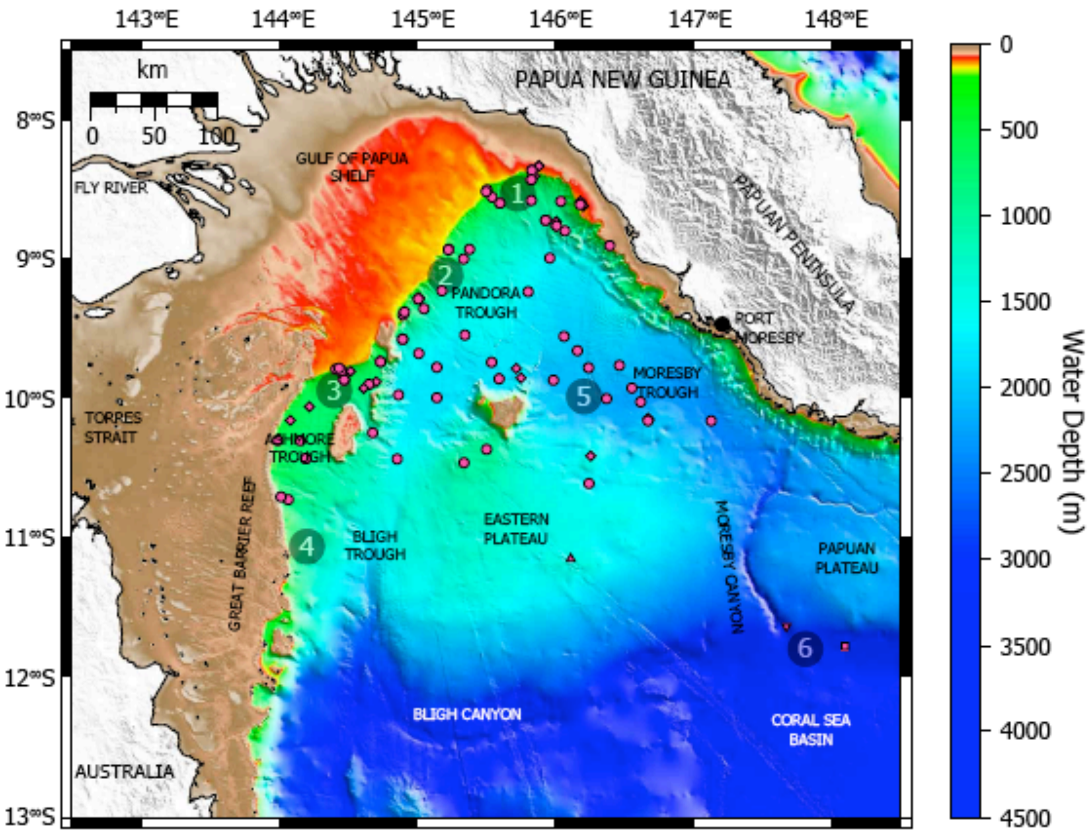

Fig 2.1: Bathymetric map of the Gulf of Papua showing available piston cores (pink) and possible drill areas: (1) very rapid Holocene (interglacial) siliciclastic accumulation; (2) very rapid glacial siliciclastic accumulation; very rapid glacial siliciclastic mixed with interglacial carbonate; (4) mixed siliciclastic carbonate margin (northern extension of Great Barrier Reef); (5) siliciclastic accumulation in proximal basin; (6) siliciclastic accumulation in distal, deep-sea basin. The general idea is to track carbon accumulation over space and time for a relatively closed system, where the main carbon sources (e.g., Fly River and GBR) are known and can be modeled.

2.2. Preliminary results of microbial diversity in SW Pacific sediments by cultivation and molecular methods and future directions

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The contribution of the Laboratory of Microbiology in Extreme Environments (LMEE, UMR6197) to Southwest Pacific Ocean IODP workshop included studies in progress of molecular and cultural diversity from subseafloor sediment samples collected during IODP cruises Legs 317 (Canterbury Basin), 329 (South Pacific Gyre) and 331 (Okinawa Trough) that were presented and discussed. Deep subsurface marine environmental samples are typically difficult to obtain. Moreover, these samples are usually characterized by low biomass and metabolic rates, making difficult to analyse the associated ecosystem. Deep sediment microbiology is a very challenging theme and in order to have a comprehensive understanding of microbial physiology, or to access metabolic pathways, cultivation of microorganisms is required. Although many different cultivation methods have been developed to mimic the *in situ* conditions, their environmental relevance remains undetermined. Therefore, new promising cultivation methods have been developed to increase the number of culturable prokaryotic species. Future research directions, including refinement of culture media, strategies based on cell-cell communications and high-throughput innovations might benefit IODP researches. We propose a combination of these approaches in order to promote cultivation of uncultured species.

Theme 3: Earth Connections: deep processes and their impact on Earth's surface environment

The links between surface lithosphere and deep earth processes are of great interest in this tectonically complex region.

Sub-committee co-chairs: Richard Arculus (Australia) and Mike Gurnis (USA)

Introduction

The Southwest Pacific is one of the most active areas of the world in terms of the connections between deep processes and their impact on Earth's surface. Flows of material and energy among global reservoirs drive long-term changes in Earth's structure and composition, cause volcanism and tectonism, and create hospitable environments for the development and evolution of life. Plate tectonic processes have been eclipsed at times in Earth's history by episodes of massive magmatic outpourings in small areas, events that may occur when hot mantle ascends rapidly from great depth to erupt on Earth's surface, forming oceanic plateaus and continental flood basalts (so called large igneous provinces, or LIPs). Within the Southwest Pacific, the largest such LIP occurs with the Ontong Java Plateau (OJP). The causes and environmental consequences of catastrophic OJP and LIP magmatism remain poorly constrained. Likewise, the processes that initiate new plate boundaries, a first-order problem in Earth dynamics, are poorly understood. At convergent plate boundaries, the initiation of subduction and formation of volcanic arcs remain enigmatic. The SW Pacific has a greater range of well preserved subduction initiation events than anywhere else on Earth. In summary, the Earth Connections Challenges presented in the new Science Plan (http://www.iodp.org/Science-Plan-for-2013-2023) are,

- What are the composition, structure, and dynamics of Earth's upper mantle?
- How are seafloor spreading and mantle melting linked to ocean crustal architecture?
- What are the mechanisms, magnitude, and history of chemical exchanges between the oceanic crust and seawater?
- How do subduction zones initiate, cycle volatiles, and generate continental crust?

An important aspect of IODP efforts to address all of these topics is the recovery and analysis of drill cores that can clearly document the structural, stratigraphic, magmatic and geochemical variations in time and space that characterize the connections between the Earth's surface and the convective and magmatic processes that occur in the Earth's interior, primarily the mantle. The Southwest Pacific has targets accessible to ocean drilling that will allow the community to address several of these Challenges.

The following are summaries of discussions of the Earth Connections group that transpired during the Sydney Workshop concerning the prospects of addressing the Challenges in the Science Plan through IODP Drilling in the Southwest Pacific.

3.1. Formation of LIPS and their impact on the global environment

The Ontong Java Plateau (Fig. 3.1) is the world's largest oceanic plateau and the most voluminous LIP on Earth being comprised of the High Plateau to the west and the Eastern Salient to the east (Fig. 1). Data from the Hikurangi (HP) and Manihiki Plateaus (MP) (e.g., Hoernle et al., 2010; Timm et al., 2011) and the Nauru Basin (NB) (Saunders, 1986) strongly suggest that basement lavas from each are related (Taylor, 2006; Chandler et al., 2012). The implication is that the Greater OJP Volcanic Event covered ~1% of the Earth's surface. The similar basalt chemistry and ages of eruptive episodes recorded by these constructs suggests a unique magmatic event in the history of the Earth. Such a huge outpouring of lava during the initial constructional phase of the Greater OJP is synchronous with the Oceanic Anoxic "Selli" Event, suggesting a significant impact on ocean chemistry (e.g., Tejada et al., 2009). However, the atmosphere appears to have been unaffected, consistent with the deep-water eruption environment recorded by the majority of basalts recovered by drilling and fieldwork.

Only Site 1184 (ODP Leg 192) on the OJP indicates subaerial eruptions. This location, on the Eastern Salient of the Plateau is not the one expected to have experienced subaerial eruptions. This would be closer to Site 1183 at the bathymetric high point of High Plateau (Fig. 3.1). If the OJP, MP, and HP were erupted as a single event, then Site 1184 is closer to the center of the reconstruction of these plateaus (Fig. 1 inset). During the workshop, Clive Neal (University of Notre Dame) made the case as to why the Greater Ontong Java Plateau should be a drilling target. He proposed a drilling campaign that involves the OJP Eastern Salient, MP and HP to test the Greater OJP hypothesis. However, to address how long each igneous event lasted, coring syn-LIP sediments in the Nauru Basin and on the Magellan Rise is recommended. Such drilling will also allow the environmental impact of this mega-LIP to be examined.

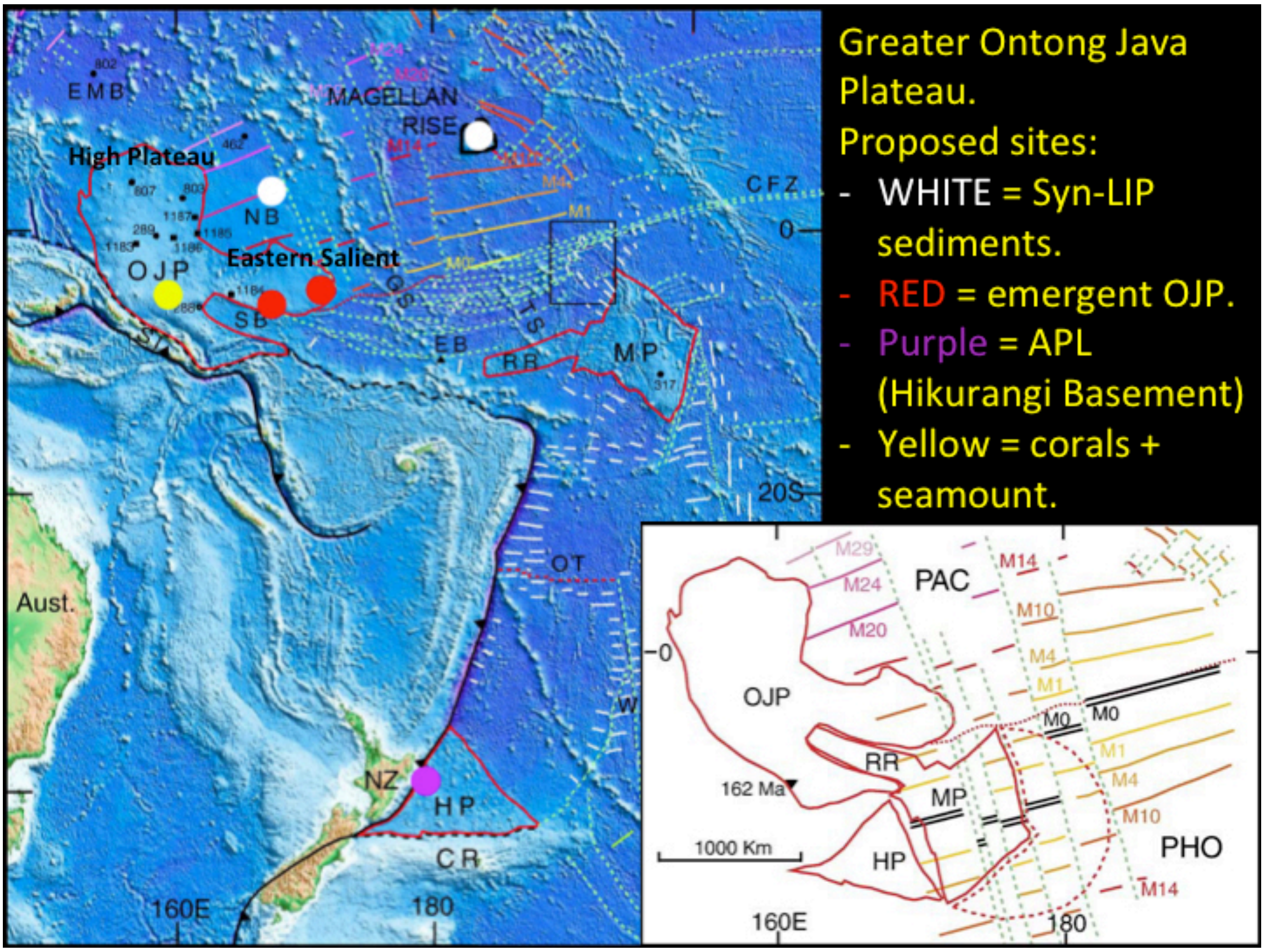

Fig. 3.1: Present configuration of LIPs in the SW Pacific (outlined in red) with proposed drilling sites. The inset shows the reconfiguration of the Greater Ontong Java Plateau suggesting the Omntong Java, Manihiki, and Hikurangi plateaus all formed in one event. Modified from Taylor (2006).

In addition to the environmental effects of LIP volcanism, drilling could also address the origin of the OJP. Models for the origin of the Plateau include a surfacing plume head, bolide impact, or an upper mantle origin but currently do not account for all of the observations thus far. During the Workshop, five strategically located drill sites were discussed to evaluate each one of the formation models as well as any environmental impacts with LIP formation. Three of these sites are on the OJP and two are in adjoining basins that contain syn-OJP sediment records. The latter aspect of the proposed work will complement proposal 630-Full to drill Cretaceous sedimentary sections (and basement) on the Manihiki Plateau and Magellan Rise east of the OJP. In addition, one of the on-plateau sites is listed as a prime target for riser drilling, which will penetrate basement to 3000 m and recover material from a section that intersects flows from a seamount atop the OJP (Tauu atoll) as well as basement reflectors that have been interpreted as representing a sequence of rapid (thick massive flows) and slow (thin pillowed flows) lava effusions from existing MCS site survey data. Two on-Plateau sites will recover the first basement from the Eastern Salient.

We need to test models of OJP formation that include a surfacing plume head, bolide impact, and upper mantle models through coring of Cretaceous sediments and basement both on and off the Plateau. Critical in this is the recovery of basement from the Eastern Salient of the OJP. The Cretaceous sediments, including the syn-OJP sections from the off-Plateau sites will be vital in constraining environmental changes in the Cretaceous surface environment as being contemporaneous (or not) with OJP formation. Understanding the environmental impact of OJP emplacement, the largest known flood basalt event, through detailed examination of Cretaceous syn-sedimentary records is key to assessing the environmental effects of oceanic plateau formation and how they differ from those of continental flood basalts. Temperature and thermal conductivity measurements will be critical for assessing heat flow and testing whether the mantle root (Richardson et al., 2000; Klosko et al., 2001) beneath the OJP is thermal or chemical in nature. Sediment and basement sections will be used to estimate subsidence of the seafloor at each site and by which the anomalous subsidence of the OJP can be quantified and, with comparison to results from previous OJP drilling, a comprehensive picture of OJP tectonic evolution will be generated.

A mechanism for obtaining a better understanding of the mechanism(s) of formation requires an integrated approach to LIP drilling. In the past, drilling has recovered a few hundred meters of basalt from the top of plateaus that can be 35 km thick. While this has provided excellent new insights to the formation of oceanic LIPs, a more sophisticated and integrated approach is required in order to take our understanding to the next level. In 2007, an international workshop was held in Coleraine, Northern Ireland, UK, to discuss the strategy for the scientific ocean drilling of LIPs in order to advance our understanding of these enigmatic igneous constructs (Neal et al., 2008). The conclusions of this workshop were that LIP science would be advanced in five key areas through scientific ocean drilling:

A. *Obtaining deep sections within multiple LIPs to examine magmatic (and therefore mantle source) variability through time (such drilling would also help investigate the limits of life on the sub surface);*
B. *Defining the nature of melting anomalies (i.e., compositional vs. thermal) that produce LIPs;*
C. *Defining precise durations of oceanic LIP events;*
D. *Defining modes of eruption-constant effusion over several million years or several large pulse events over the same time interval*;
E. *Establishing relationships among oceanic LIPs, Oceanic Anoxic Events (OAEs), and other major environmental changes (e.g., ocean acidification and fertilization).*

Therefore, the strategy for LIP drilling in the SW Pacific is as follows.

Deep sections of plateau basement can be obtained by using our knowledge of the structure of each plateau. For example, erosional canyons and faulted margins are known to exist and potential deep drilling sites could be:

- The erosional Kroenke Canyon on the eastern High Plateau of the OJP which is several kilometers deep extending into the basement;
- The northern rifted margin of the Stewart Basin (SB in Figure 1) on the Eastern Salient of the OJP;
- The Danger Troughs on the Manihiki Plateau (e.g., Viso et al., 2005; Hoernle et al., 2010);
- The northern rifted margin of the Hikurangi Plateau.

The nature of melting anomalies (compositional vs. thermal) can be addressed by drilling at the yellow site in Figure 3.1 and obtaining heat flow data from this site (as it sits above the mantle root defined by Richardson et al., 2000, and Klosko et al., 2001) and comparing this with heat flow data from an eastern salient site (red sites in Fig. 3.1), which lie away from the mantle root.

Key areas C., D., and E., can be partially addressed by:

- Obtaining cores from deeper within the plateau basement and obtaining Ar-Ar ages, comparing these with those obtained from rocks at the top of the lava pile.
- Drilling at the feather-edge of the plateaus as this may afford the opportunity to drill the first and last large and extensive flows erupted during plateau formation.
- Recovery of syn-LIP sediments is a key to answering duration and number of large eruptions that occurred to build the LIP (the white sites in Fig. 3.1). As has been shown by Snow et al. (2005) and Scudder et al. (2009), the trace element geochemistry of sediments can be used to define volcanic episodes even though no ash layers are present. Equating these "volcanic" horizons in the syn-LIP sediments with biostratigraphy allows eruptive episodes to be quantified. In addition, it allows an evaluation of the environmental impact of the eruption through the change in depositional environment and redox state of the oceans as well as the climate record during the Cretaceous (i.e., OAEs).

In addition to addressing all five of the major findings of the 2007 LIP report (Neal et al., 2008), other important issues can also be addressed.

- Drilling at the yellow site (Fig. 3.1) establishes a relationship, if any, between the late stage seamount volcanism on the OJP and the basement sequence (site survey data are reported in Inoue et al. (2008).
- By coring the corals on top of the seamount, sea-level changes over the last several million years in the SW Pacific can be addressed.
- Investigation that OJP volcanism was emergent on the Eastern Salient may be addressed by drilling at the red sites (Fig. 3.1).
- Opportunistic drilling through an Auxiliary Project Letter (APL) to a scheduled expedition to Hikurangi will allow penetration of 100 m or more of basement to recover the first in situ rocks from this oceanic plateau.

The Way Forward for LIP Drilling in the SW Pacific. The participants discussed a plan to submit a Multi-phase Drilling Proposal (MDP) to IODP by October 1st, 2013. This will be the umbrella proposal for specific drilling proposals to Manihiki (being prepared by Kai Hoernle and the German group as they have just finished extensive site survey work on this plateau – e.g., Hoernle et al., 2010), Ontong Java Plateau (as outlined above), and to the Nauru Basin and Magellan Rise (white sites in Fig. 3.1) to drill syn-LIP sediments. Magellan Rise was drilled during DSDP Leg 17 (Site 167), but recovery was poor. However, as this has already been drilled, no new site survey data are required. In Nauru Basin, syn-LIP sediments can be drilled with site survey data being available in Mochizuki et al. (2005).

In summary, LIP drilling in the SW Pacific can address can investigate mantle dyanmics and geochemistry, the limits of life in the subsurface, changes in ocean chemistry, climate change, and sea level rise. Such drilling would, therefore, address challenges 1, 2, 4, 6, 7, 8, 10, and 14 in the new IODP Science Plan.

3.2. Structure and dynamics of mantle flow

Workshop participants discussed the scientific opportunities for further study of the Australian–Antarctic Discordance (AAD) as the region presents us with unique opportunities to address the IODP Challenges concerning the composition, structure, and dynamics of Earth's upper mantle. Mike Gurnis (Caltech) described the region and the opportunities of testing alternative models of mantle flow below the Australian-Antarctic depth anomaly (Fig. 3.2).

The Australian–Antarctic Discordance (AAD), a ~600 km-long segment of the South East Indian Ridge south of Australia between 115 E and 128 E, is the deepest portion of the mid-ocean ridge system, as shown through maps of residual topography (Fig. 3.2). Not only is the Australian–Antarctic Discordance anomalous in terms of bathymetry, but it is also characterized by unusual sea-floor morphology, isotope geochemistry, petrology and seismic structure. Whatever the origin of the distinctive characteristics of the AAD, the temperature or composition (or potentially both) of the mantle below the AAD must be highly unusual. There are currently two distinctively different models used to explain the AAD. In either model, the mantle below the Southern Ocean is sampled by the Southeast Indian Ridge (SEIR) from about 45 Ma to the present and the products of that melting are incorporated into the Australian and Antarctic plates. According to Model 1, the AAD resulted from the sampling of both an ancient mantle wedge, depleted by prolonged melting, and mantle cooled by the long-lived Mesozoic subduction system (Gurnis and Müller, 2003). According to Model 2, the AAD resulted from the starving of the asthenosphere because flow within the asthenospheric mantle is restricted due to nearby thick continental lithospheric roots combined with a moderately fast spreading rate (Buck et al., 2009). In Model 1 the unusual mantle flow is a product of vertical flow from an ancient slab and mantle wedge, while in Model 2, the flow results from the localized reduction in horizontal mantle flow. According to Model 1, along the trace of the residual depth anomaly, a fundamental change occurred in the dominant mechanism causing the topography, first by sampling of refractory mantle from an old wedge and later by the sampling of cold mantle. This hypothesis can be tested with ocean floor recovered from drill holes along the depth anomaly. Leg 187 recovered samples from the top of the basaltic basement in sea floor aged 14 to 28 Ma, but in order to test these hypotheses we need samples that span the entire age range of the AAD from 0 to 45 Ma, including the deepest (and potentially most anomalous) segment of the sea floor at 134E, 38S. The broad range of existing observations combined with new oceanic drilling provides a globally unique opportunity to distinguish between opposing mechanical models of upper mantle flow.

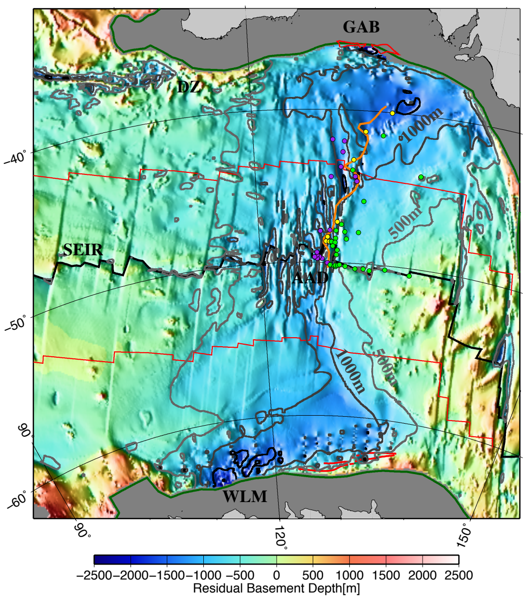

Fig. 2.2. Residual depth anomaly between Australia and Antarctica based on unloaded basement depth and lithospheric cooling. Residual depth anomaly contours are shown as 500 m (light gray), 1000 m (dark gray), and 1500 m (black). Basalt geochemistry data [Christie et al., 2004; Kempton et al., 2002] plotted as small circles for Pacific- type mantle source (green circles), mixed mantle source (yellow circles), and Indian mantle source (purple circles). Orange line shows boundary between Pacific- and Indian- type mantle [Christie et al. , 2004]. Continent- ocean boundaries are shown by green lines, peridotite ridges are shown by thick red lines, and 20 Ma isochron are shown by thin red lines. From Whittaker et al. (2010).

Workshop participants agreed that resolving the alternative hypotheses for the origin of the AAD would provide fundamental constrains on the viscosity structure and convective velocity within the mantle as well as how compositional and thermal anomalies are transported. However, the final outcome of the discussions in Sydney is that it is premature to submit a new proposal at this time. Specially, the largest depth anomaly is just south of the Australian continental shelf at 134E, 38S and indicates that the crustal structure is most anomalous there and indeed that the crust may be entirely absent (Whittaker, *et al*. 2010). Sample recovery within the most anomalous region is a worthy target in the long term to distinguish between the competing models. However, before any further drilling occurs, the crustal thickness and seismic velocity structure will need to be determined through seismic refraction, presumably with ocean bottom seismometers. The region remains high on the list of scientific targets from a geodynamic perspective, but further work is needed before a compelling IODP proposal can be assembled.

3.3. Initiation of Subduction and origin of deep-water sedimentary basins

Subduction systems are primary drivers of plate motions, mantle dynamics, and global geochemical cycles, but little is known about how subduction starts. What are the necessary initial conditions? How do forces and kinematics evolve? What are the short-term lithospheric consequences and surface signature: vertical movements, deep-water sedimentary basins, convergence, extension, and volcanism? The Southwest Pacific also provides an ideal opportunity to understand the process of large-scale subduction initiation because the Eocene onset of new subduction zones was accompanied by the most profound global reorganization of tectonic plates since the Late Cretaceous, and within the only part of Earth history with precisely-known plate motions (Gurnis et al. 2004; Steinberger et al. 2004).

Several speakers during the Sydney Workshop addressed the issue of subduction initiation, including Julien Collot (DIMENC, New Caledonia), Tim Stern (Victoria University of Wellington), and Rupert Sutherland (GNS). The primary goals of drilling are to provide timing, structural, petrologic and geochemical constraints on actual initiation events as well as associated changes in plate motions. Initiation of subduction (SI) and changes in plate motion are linked, as the largest driving and resisting forces associated with plate tectonics occur within subduction zones. By far the largest change in Pacific plate kinematics since 80 Ma is manifest as a bend in the Emperor-Hawaii seamount chain, notwithstanding any additional independent motion of the plume source. A westward swerve in Pacific plate motion occurred at about the time subduction zones initiated throughout the western Pacific. It follows that clarifying what happened in the western Pacific during Eocene time is likely to lead to fundamental insights into SI and the general physics of plate tectonics. There are two widely held views: either subduction initiates spontaneously or it has to be induced (Stern, 2004; Gurnis et al, 2004). In the spontaneous model, oceanic lithosphere ages, thickens, increases in density, and eventually sinks into the mantle under its own weight. In the induced model, externally applied compressive stresses are necessary to overcome the strength of the lithosphere and pre-existing faults before subduction can be induced.

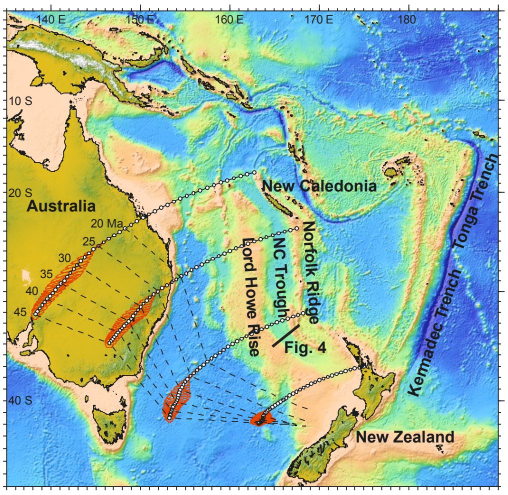

Fig. 3.3: Reconstruction of selected Australian plate points relative to a fixed Pacific plate. Note much higher convergence rates near New Caledonia (NC) shortly after subduction initiation (45-25 Ma).

Geochronology shows that the bend in the Emperor-Hawaii seamount chain started at ~50 Ma and may have occurred over a period of ~8 Myr (Sharp and Clague, 2006). The onset of plate motion change corresponds with the timing of Pacific-Farallon plate boundary rearrangement and termination of spreading in the Tasman Sea. This was followed by a change in direction and rapid increase in rate of Australia-Antarctic spreading with consequent northward acceleration of Australia and initiation of Australia-Pacific spreading southwest of New Zealand. Reconfiguration of plate boundaries in Antarctica, the Indian Ocean, and Asia reveal the truly global nature of this phase of tectonic change.

Most work on subduction initiation involving sampling by ocean drilling and submersibles has focused on initiation of Izu-Bonin-Mariana (IBM) subduction, which was synchronous with the change in Pacific Plate motion at ca. 50 Ma. The IBM work and hypothesis provides an important scientific framework to discuss the SW Pacific and develop a drilling strategy. Yoshihiko Tamura (JAMSTEC) provided an overview of project IBM to constrain the whole range of activity from new arc formation to formation of continental crust with ocean drilling. For IBM, the early arc was dominated by boninitic volcanism, which requires a high degree of partial melting of a source depleted in major elements but enriched in volatiles (Stern and Bloomer, 1992). Samples recovered from the Mariana forearc and ~1,500 km farther north near the Bonin islands reveal a volcanic stratigraphy containing basalts, which are similar to mid-ocean ridge basalt (MORB), that were the first to erupt in the nascent arc (52-49 Ma), which were then quickly followed by boninites (49-45 Ma), and then by normal arc lavas within several million years (Reagan *et al*., 2010; Ishizuka *et al*., 2011). IBM is a natural laboratory to constrain models of subduction initiation. Distinguishing between spontaneous and induced models is a central goal of upcoming (mid-2014) Expedition 351 of IODP to the Izu-Bonin Arc. However, there are limitations on constraining the IBM initiation event. First, the relative motion between the Philippine Sea Plate (PSP) and Pacific Plate (PAC) during the Eocene is unknown. Second, because the subduction zone has long transitioned from nascent to self-sustaining subduction initiation, we do not know the mechanics and structural evolution of the Pacific plate as it first started to subduct. Third, the intra-oceanic deep-water setting of IBM results in a highly-condensed sedimentary record of events. These issues can be resolved with further work in the SW Pacific, and indeed the Tonga-Kermadec example is part of the same 50 Ma subduction intiation event as IBM.

The question arose during discussion if a sampling strategy could be devised to provide the same kind of constraints on the evolution of arc volcanism during Tonga-Kermadec initiation as now exists in IBM. Recently, Todd *et al*. (2006) have shown through study of volcanic rocks in Fiji and the Tongan Islands that early volcanism was characterized by both MORB-like and boninitic volcanism.

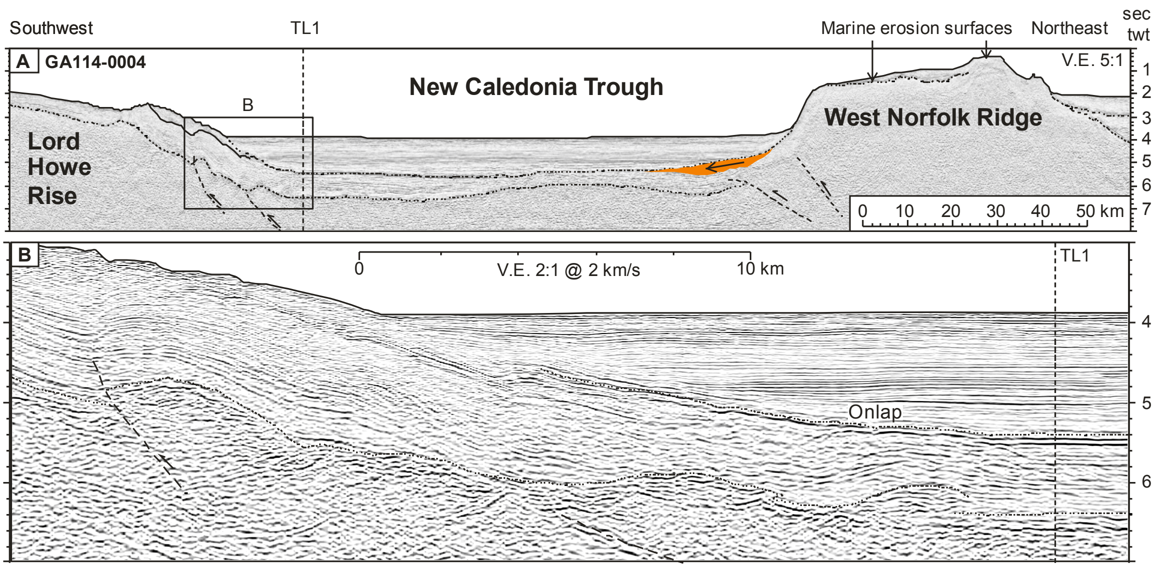

Fig. 3.4. Seismic section showing deformation, uplift of Norfolk Ridge (marine planation), with subsequent subsidence, and infilling of the New Caledonia Trough.

Unfortunately, the structural and temporal controls on the volcanic history are not nearly as well constrained as they are in the IBM. Fortunately, the Tonga-Kermadec forearc is as sediment-starved as in IBM, and strongly suggests that well designed submersible sampling along the Kermadec and Tonga Forearcs in several transects could provide the same level of constraints on early magmatims as at IBM. Such constraints would strongly complement the drilling strategy advocated on the LHR (see below).

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Most of the talks and subsequent discussion focused on initiation of the Tonga-Kermadec subduction zone. Records of subduction initiation are rarely well preserved, because of subsequent tectonic and volcanic disruption, but at Tonga-Kermadec, inititiation occurred near the margin of thinned continental crust (Norfolk Ridge, Lord Howe Rise) that was tectonically isolated by subsequent backarc spreading. Persistent Cenozoic submarine conditions led to continuous sedimentation in many places. Cessation of spreading in the Tasman Sea at 52-50 Ma and deformation of New Caledonia with a peak of high-pressure metamorphism at 44 Ma provide a direct temporal link between southwest Pacific events, IBM, and the Emperor-Hawaii bend. Australia-Pacific plate motions are precisely known since 44 Ma (Fig. 3.3) from ocean crust created at the southern end of the boundary, and via plate closure calculation (Cande and Stock, 2004; Sutherland, 1995). Eocene convergence rates varied from <1 cm/yr in New Zealand to 10 cm/yr near New Caledonia.

Seismic-reflection data (Fig. 3.4) reveal stratal records of Eocene change, including evidence for distal (>300 km) minor compression and >1 km of uplift-subsidence, and proximal uplift-subsidence of Norfolk Ridge and deep-water sedimentary basin formation in the New Caledonia Trough. The stratigraphic records of compression and vertical motions provide a unique opportunity to understand with high precision the temporal and spatial context of large-scale subduction intiation through geophysical surveys tied to IODP drilling. New seismic-reflection lines are needed to supplement a large recently-released dataset and hence define drilling targets, and transects of boreholes are needed to understand along-strike and proximal-distal relationships. The primary goals would be: to establish the regional timing and magnitude of deformation, uplift, and subsidence, to constrain the SI process; and to relate Tonga-Kermadec and IBM events to global plate motion changes and the evolution of global plate-driving forces.

Besides the detailed focus on the Lord Howe Rise, anomalous subsidence west of New Zealand at 34-22 Ma may be related to SI as described by Tim Stern (Victoria University of Wellington). West of New Zealand rapid tectonic subsidence of ~ 1.5 km at rates of about 150 m/my has been recorded from both bore-hole and seismic stratigraphy. Key features of these subsidence events are that they occur rapidly, virtually simultaneously over areas that span 200 x 200 km or more, and they appear to occur without any structuring in the crust. For these reasons it is likely that the subsidence is related to processes in the mantle. In particular, a long wavelength flow related to subduction initiation caused platform subsidence. The continental platform west and northwest of North Island New Zealand is ideally located to record long wavelength vertical movements linked to initiation of subduction at both the Tonga-Kermadec and Hikurangi margins. So far we see the rapid subsidence event for the period 34-22 Ma in both South Taranaki basin and 300 km to the north at the southern end of the New Caledonia basin. Extra stratigraphic data in the New Caledonia trough will allow us to test that this is indeed a regional event linked to subduction initiation.

Discussion also touched on a clear example of nascent subduction initiation just south of New Zealand, that is the Puysegur-Fiordland subduction zone that forms the northern extremity of the transpressional AUS-PAC plate margin. Although juvenile, and potentially not yet a self-sustaining subduction zone, the margin is characterized by convergence, a trench (gravitationally and bathymetrically), a Benioff zone (down to 170 km depth), and sparse, young calc-alkaline volcanism on the overriding Pacific plate. Previous geophysical surveys have shown that the morphology of Puysegur Ridge, a bathymetric high on the overriding Pacific plate, immediately east of the trench, shows a characteristic change from uplift to subsidence with increasing convergence between the Pacific and Australian plates. Comparison of the geophysics and geomorphology of the margin with geodynamic models, suggests that the margin is making a transition from forced to a self-sustaining subduction (Gurnis et al., 2003). No other subduction zone is known to be in this critical state and presents the community with a unique observational target to measure parameters that are fundamental to geodynamics. Discussion in breakout focused on the pros and cons of different studies, including ocean drilling. A modern geophysical survey with high-resolution seismic refraction and reflection over the Puysegur Ridge and Trench, however, were viewed as having much greater scientific payoff at this time, as obvious drilling targets could not yet be identified.

During the workshop it became clear that drilling on the Lord Howe Rise (LHR) provided the most compelling target to address the initiation of the Tonga-Kermadec subduction zone and relate the initiation event to the IBM system changes in Pacific Plate motion. Several breakout groups were organized to discuss in detail drilling strategy on the LHR and adjacent features (including normal Tasman Sea ocean floor to the west of LHR, the New Caledonia Trough, and the Norfolk Ridge). In addition, it became clear that many of the drilling objectives needed to place clear temporal controls on the timing of compression and uplift of the region would also meet the needs of constraining Eocene climate change objectives (see section 1.1). There was overwhelming support for submitting a Full Proposal to IODP by the April 1, 2013 deadline lead by R. Sutherland (New Zealand) and G. Dickens (USA) with additional proponents from Australia, France, Japan, New Caledonia, New Zealand and USA. It was thought that all of the drilling targets would require two IODP legs; this would involve both a north-south transect to constrain the time transgressive nature of subduction initiation from New Caledonia to the North Island of New Zealand as well as east west transects to constrain the time of compression and vertical motions. At this junction in time, the participants agreed to work in the coming months to find the highest priority targets that would simultaneous address the subduction initiation and Eocene climate change questions with a single IODP leg.

3.4. References

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Theme 4 Earth in Motion: processes and hazards on human time scales

This tectonically active region has its share of earthquakes, tsunamis and submarine slides that have impacted on populations and will continue to do so. Targeted scientific drilling will help address some of these hazards.

Sub-committee co-chairs: Laura Wallace (UTIG, USA) and Jim Mori (Japan)

Introduction

The Southwest Pacific is one of the most active regions in the world in terms of the earthquake and volcanic events that frequently occur on human time scales. Great earthquakes and large volcanic eruptions reoccur at intervals of decades to centuries. Also other smaller events, such as slow slip events and moderate eruptions, have even shorter repeat intervals that can be observed within a scientist's career. The sites of these events are prime targets for the ocean drilling program, where logging, coring and installing observatories in boreholes can be used to better understand dynamic processes such as the seismic and aseismic slip on megathrusts, the magmatic system under volcanoes, and the triggering of large landslides. In particular, the Earth in Motion Challenges listed in the new science plan are,

- What mechanisms control the occurrence of destructive earthquakes, landslides, and tsunami?
- What properties and processes govern the flow and storage of carbon in the subseafloor?
- How do fluids link subseafloor tectonic, thermal, and biogeochemical processes?

An important aspect of IODP efforts on these topics is monitoring active processes with borehole observatories. Sub-seafloor boreholes provide unique opportunities to measure earthquakes and crustal strain very close to the seismic source areas within megathrust zones. Also, the well-recognized importance of fluids associated with seismic activity and magmatic systems, can be studied with fluid flow and chemical measurements. Both the current and new science plans recognize the value of such monitoring programs and encourage the development of borehole observatories.

Coastal populations in the Southwest Pacific are extremely vulnerable to various types of severe geohazards, such as earthquakes, tsunamis, volcanic eruptions, and submarine landslides. For example, recent tsunamis from earthquakes in the Indian and Pacific Oceans have claimed thousands to hundreds of thousands of lives. So research for study and understanding of the hazards from great earthquakes and large volcanic eruptions is one of the most socially relevant components of IODP.

The following are summaries of discussions of Earth in Motion group about current IODP proposals in the southwest Pacific, and new ideas that can be potentially developed into successful proposals.

4.1. Hikurangi subduction margin IODP proposals to understand the origin of slow slip event behavior

Over the last decade, the discovery of episodic slow slip events (SSEs) at subduction margins around the globe has led to an explosion of new theories about fault mechanics and subduction interface deformation mechanisms and rheology. The northern Hikurangi margin is the only place on Earth where well-documented SSEs occur on a subduction interface within range of existing drilling capabilities. Drilling, down-hole measurements, sampling, and monitoring of the northern Hikurangi SSE source area provides a unique opportunity to definitively test hypotheses for the properties and

conditions leading to SSE occurrence, and ultimately, to unlock the secrets of slow slip. Furthermore, northern Hikurangi SSEs recur every one to two years (Fig. 1), and thus provide an excellent setting to monitor changes in deformation rate, in situ conditions, and rock physical properties within and surrounding the SSE source area throughout a slow slip cycle.
The Hikurangi margin is the subject of two existing IODP proposals, 781-MDP, "Multiphase Drilling Project: Unlocking the Secrets of Slow Slip by Drilling at the Northern Hikurangi Subduction Margin, New Zealand" and 781A-Full, "Unlocking the secrets of slow slip by drilling at the northern Hikurangi subduction margin, New Zealand: Riserless drilling to sample and monitor the forearc and subducting plate". Both of these proposals were submitted in October 2011, and following on from excellent external reviews, PEP has forwarded 781A-Full onto the Operations Task Force (OTF). The Hikurangi margin proponent group is in the process of developing a full proposal for the deep riser phase of 781-MDP. Much of the discussion in the Earth in Motion breakout group revolved around the development of the riser proposal. The Hikurangi proponents plan to submit the riser proposal to IODP in April 2013. Moreover, strategies for implementing the observatories in the riserless phase of drilling (781A-Full; Fig 4.1) were also discussed, particularly with regards to the logistics of obtaining ROVs and ship time to service and download the observatory data.

A number of ideas for the riser drilling strategy were discussed. Obtaining high quality cores across the SSE source area is of utmost importance in the riser drilling phase of the proposed Hikurangi drilling project. On the recent JFAST expedition, core recovery was only ~30%. One way to circumvent the poor core recovery is to drill multiple holes through the fault zone. Although it is not practical to drill multiple, deep holes through the Hikurangi subduction zone, one approach could be to drill multiple sidetrack cores branching from the primary deep hole through the SSE source area. For the deep hole observatory, participants agreed that the most important observables will be of variations in fluid pressure during the SSE cycle, and continuous observations of strain across the fault zone during SSEs in order to understand the width of the shear zone over which SSEs occur. Breakout participants agreed that a method to continuously monitor casing deformation should be developed. It is also clear that many lessons will be learned from the NanTroSEIZE deep observatories that can be applied to Hikurangi.

Auxiliary studies that are needed to undertake the proposed riser phase of drilling at north Hikurangi were also discussed during the breakout. These include the need for a 3D seismic survey, and possibilities around conducting a 3D Vertical Seismic Profiling (VSP) experiment in the riser pilot hole (proposed to be drilled during the riserless drilling phase, 781A-Full).

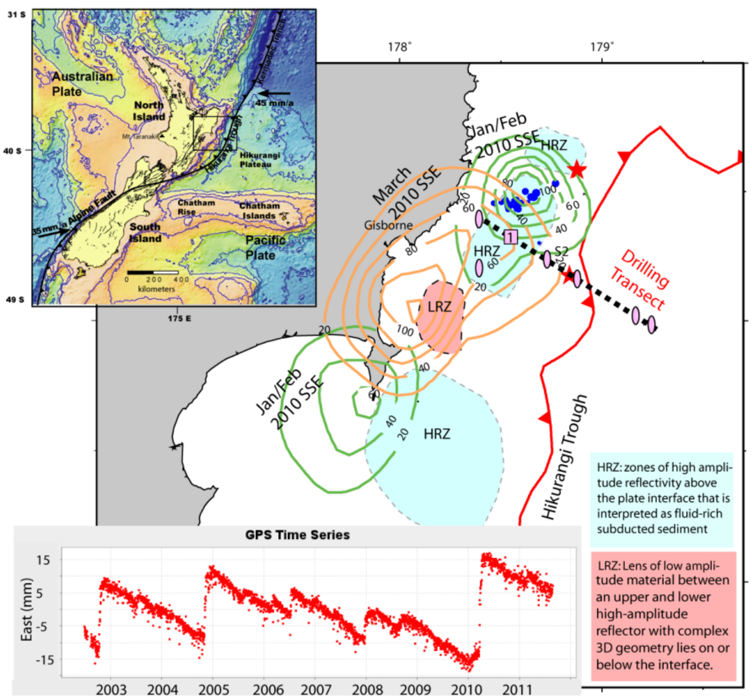

Fig. 4.1: Tectonic setting (upper left inset) and location of slip on the interface in the January/February (green contours) and the March/April (orange contours) 2010 SSEs (Wallace and Beavan, 2010) and the reflective properties of the subduction interface (Bell et al., 2010; see key for explanation) at northern Hikurangi. Black dashed line shows the location of the proposed drilling transect line (see also Fig. 4.2), pink square shows the proposed riser drilling site and pink ellipses are the other sites in the riserless transect. Blue dots are locations of triggered seismicity during the January/February 2010 SSE. Red stars are the location of two tsunamigenic subduction interface earthquakes (Mw 6.9-7.1) in March and May of 1947. Inset figure in lower left shows the east component of the position timeseries for a cGPS site near Gisborne to demonstrate the repeatability of SSEs since they were first observed in 2002.

Another major topic of discussion during the breakouts was the strong relevance of the Hikurangi drilling project to understanding Japan's subduction zones. Yoshihiro Ito (Tohoku University) presented interesting new results from absolute pressure gauges that were deployed above the offshore Japan Trench prior to and during the 2011 Tohoku Giant earthquake. These data show that the 2011 earthquake and tsunami was preceded by a large slow slip event on the shallow subduction thrust, as well as an earlier SSE in 2008 (Ito et al., in press). The depths, magnitudes, and durations of the newly identified Japan Trench SSEs are similar to the north Hikurangi SSEs. The Japan Trench SSE source area is not accessible using scientific drilling due to the great water depths, and depths below the seafloor to the SSE source (~10 km deep). However, the group agreed that the northern Hikurangi SSE source area provides an excellent analogue to the Japan Trench SSE source. Moreover, many other striking similarities exist between subduction margin tectonics at the Japan Trench and northern Hikurangi margin (subduction of old, Cretaceous crust, thin incoming sedimentary section, and the occurrence of subduction erosion).

To summarize the forward path, the Hikurangi proponents are in the process of developing a riser proposal to be submitted to IODP in April 2013. Proponents are currently developing a strategy for the funding and logistics of the observatories in the riserless proposal (781A-Full), and proposals to conduct auxiliary studies (heatflow, OBS, seismics, seafloor pressure gauges) are either submitted or are planned for the near future.

4.1.1. Global comparison of slip behavior at the toe of subduction margin trenches

In the 2011 Tohoku Mw 9.0 earthquake, the largest slip (>50 m) occurred on the shallowest portion of the subduction thrust (Ito et al., 2011; Kodaira et al., 2012). The unexpectedly large slip near the toe of the subduction thrust contributed greatly to the huge tsunami that followed the earthquake (Maeda et al., 2011). At the Nankai Trough, vitrinite reflectance studies of IODP cores from the shallow fault zone (<500 m) suggest frictional heating; Sakaguchi et al. (2011) interpret these data to indicate that large, seismic slip has propagated close to the trench in previous megathrust earthquakes at Nankai. These observations yield a new picture of shallow megathrust seismic behavior, which differs fundamentally from the more traditional view that the shallow megathrust is largely aseismic (Fig. 4.2). These new observations beg the question: Do subduction megathrusts elsewhere commonly undergo large, seismic slip all the way to the trench? Answering this has profound implications for assessing subduction megathrust seismic and tsunami hazards worldwide.

To address this problem, Shuichi Kodaira (JAMSTEC) presented the idea during the Earth in Motion breakout that a comparative study of shallow cores through many of the world's active subduction thrusts is needed. In particular, comparisons between cores to the plate interface at the frontal thrusts of subduction margins in Japan, New Zealand, Sumatra, Alaska, and Costa Rica (where active IODP proposals/projects already exist) would give us an excellent start on trying to achieve some understanding of shallow megathrust seismic behavior. Shallow cores from IODP drilling already exist from the frontal thrust at the Japan Trench (JFAST) and the Nankai Trough (NanTroSEIZE), as well as a few other subduction margins (such as Barbados). The Hikurangi margin offers a particularly exciting setting to look at this problem, as it exhibits vastly different contemporary slip behavior along strike. The megathrust at Northern Hikurangi margin is dominated by episodic slow slip and aseismic creep processes, while southern Hikurangi is the site of deep interseismic locking (similar to Nankai and Cascadia). Moreover, north Hikurangi is dominated by subduction erosion, while a well-developed accretionary wedge exists at southern Hikurangi. Obtaining an along-strike transect of shallow frontal thrust cores at the Hikurangi margin would allow assessment of shallow megathrust slip behavior and how this varies with subduction margin tectonics and contemporary slip behavior.

Logging and coring the shallow frontal thrust at north Hikurangi is already proposed as part of 781A-Full. Due to the shallow water depths (generally <3000 m) along the Hikurangi Trench, it would be feasible to do additional shallow cores with the anticipated MeBo II, which will be designed to operate in up to 4000 m water depth and is anticipated to be able to take 200 m cores. The group decided that a Mission Specific Platform (MSP) proposal to use MeBo to acquire a series of cores in an along-strike transect at the Hikurangi margin, in combination with already-proposed JR drilling through the frontal thrust at north Hikurangi should provide sufficient data to characterize whether or not the Hikurangi margin undergoes seismic slip to trench, and if there is any along-strike variation in this behavior.

To push this effort forward, the group decided that an international workshop should be organized to look at this problem with scientific ocean drilling globally. A special session on this topic entitled "Slip to the Trench" is also planned for the next Japan Geoscience Union meeting in May 2013. Strategies will be developed to write APLs to obtain shallow cores that capitalize on future JR, MeBo, and Chikyu operations in the vicinity of other active subduction thrusts to help build an important global database of shallow megathrust seismic behavior.

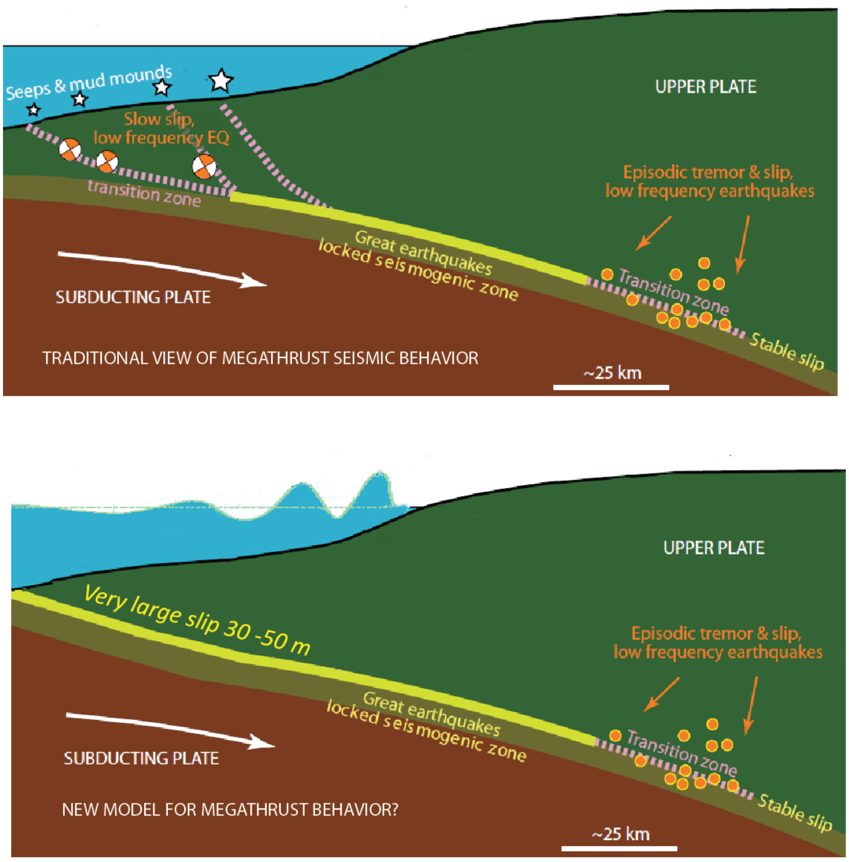

Fig. 4.2: Schematic cross-section through a hypothetical subduction megathrust illustrating the traditional model for megathrust seismic behavior (top) and the scientific community's new understanding of possible shallow megathrust behavior based on observations from the Tohoku 2011 earthquake.

4.1.2. Slow slip – fast flow: a thermal anomaly linked to fluid expulsion during slow slip events? Porangahau Ridge, Hikurangi Margin, New Zealand

It has long been suggested that focussed fluid expulsion from the subduction interface to the seafloor should lead to thermal anomalies although documented examples are rare. On the Porangahau Ridge, Hikurangi Margin, east of New Zealand, we have observed evidence for pronounced upwarping of the base of gas hydrate stability that is thought to be caused by expulsion of warm fluids (Pecher et al., 2010). The ridge shows many other anomalies including; 1) pronounced high- and low-resistivity regions - interpreted as being caused by gas hydrate occurrence and salinity from active gas hydrate formation, respectively (Toulmin et al., 2010), 2) high methane flux inferred from geochemical profiles (Coffin et al., in press), 3) a recently discovered gas flare (Bialas, 2011), and 4) unusual microbiology communities Hamdan et al., 2011). Recent analyses of seismic data link the ridge to a splay fault that reaches to the subduction interface. Intriguingly, slow slip has been observed recently along this part of the margin and it is possible that the splay fault underlying the Porangahau Ridge marks the seaward edge of the slow slip region (Wallace et al., in press) (Figs. 4.3, 4.4).

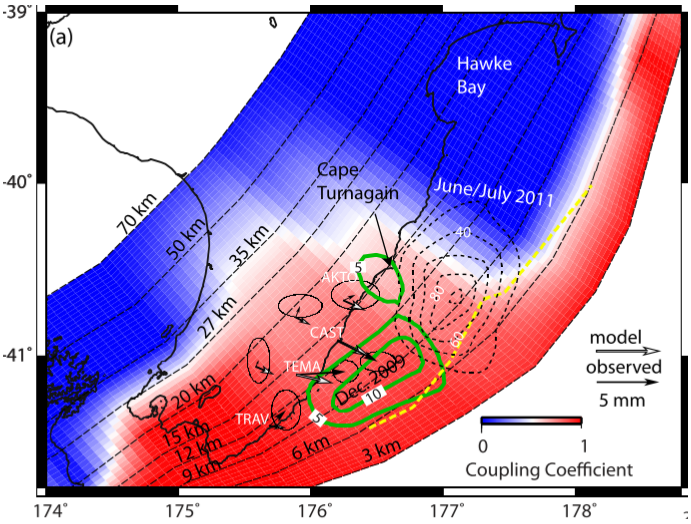

Fig. 4.3: Study area and slow slip in June/July 2011 (dashed black contours) and December 2009 (green contours) at southern Hikurangi margin. The study area and transect in Figure 4 are directly above the source of slow slip in June/July 2011. (Figure form Wallace et al., in press).

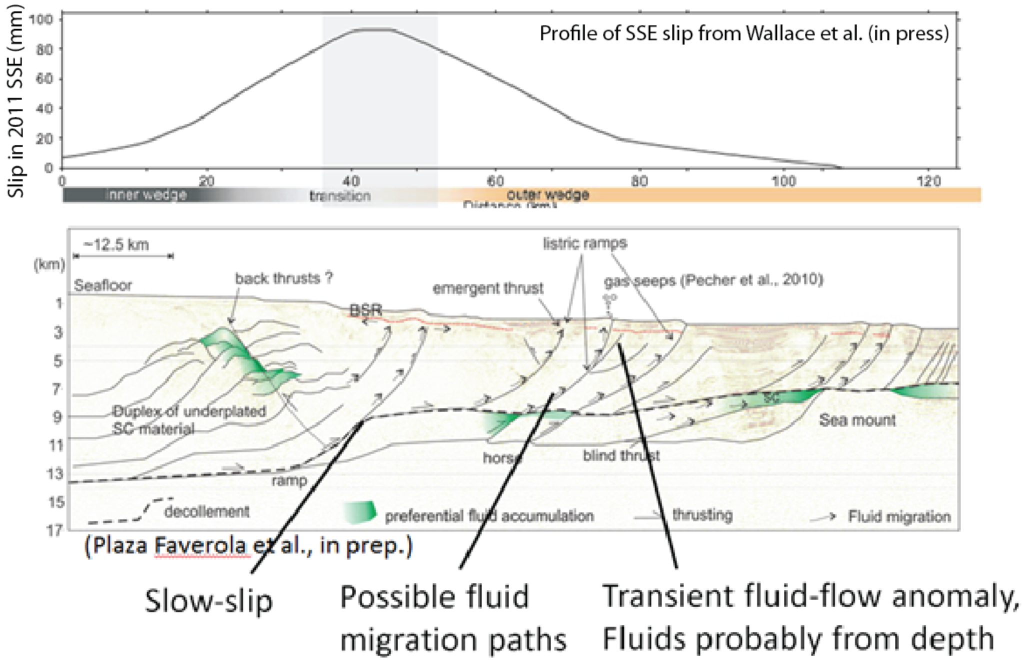

Fig. 4.4: Possible link between slow slip, structure of the subduction zone, and the Porangahau Ridge (here, marked by gas seeps).

It is hypothesized that the fluids that cause the observed anomalies beneath the Porangahau Ridge are expelled from the subduction interface during slow-slip events. Ingo Pecher, Stuart Henrys, Andreia Plaza Faverola, and Laura Wallace, while acknowledging that the presented ideas were still in their infancies, sought feedback form the Earth in Motion breakout group on whether and how IODP drilling of the Porangahau Ridge may advance our knowledge of the effect of slow slip events on near-seafloor fluid flow.

In particular it was suggested to investigate whether fluids beneath the ridge originate from the subduction interface based on pore-water geochemistry, and how the inferred thermal anomaly extends beneath the seafloor, potentially reflecting transient advective heat-flow pulses, based on temperature logging.

Based on the discussion during the Earth in Motion breakout, it is clear that the ideas behind the proposed hypothesis need further investigation prior to constructing a drilling proposal. Participants agreed that this project has potential to become a Mission-Specific Platform proposal, possibly using MeBo-II. Logging of the holes would be needed (particularly for temperature), so whether or not MeBo II could be used would depend on whether or not a logging capability is planned as part of MeBo II's development. Obviously some form of shallow borehole observatory is also required to address the time-varying component of the proposed project, particularly to look at near surface temperature (and possibly, hydrological) variations throughout the slow slip cycle. Proponents are currently looking at the feasibility of developing this proposal into an MSP.

4.2. Proposed Ancillary Project Letter: Creeping gas hydrate slides? Slow sliding of gas-hydrate-bearing landslides on the Hikurangi Margin, New Zealand

Gas hydrates have been linked to submarine landslides for over two decades. It is generally thought that solid and potentially grain-cementing gas hydrate increases sediment strength. The driving factor for gas-hydrate-related slope instability is currently assumed to be linked to hydrate dissociation causing sediment weakening and overpressure. Recent studies however, suggest that the gas hydrate zone may in itself be a zone of sediment weakness.

Submarine slope failures along the western edge of the Tuaheni Basin on the Hikurangi Margin east of New Zealand bear the hallmarks of slowly creeping landslides, earthflows, which are common on land but are virtually unknown in the marine environment [*Mountjoy et al*., 2009].

The Tuaheni Basin is within the target region of IODP Proposal 781A-Full (Unlocking the secrets of slow slip by drilling at the northern Hikurangi subduction margin, New Zealand: Riserless drilling to sample and monitor the forearc and subducting plate, D. Saffer et al.). Seismic reflection data indicate the basin contains widespread gas hydrates [*Navalpakam et al*., 2012]. Slow submarine sliding appears to coincide with the gas hydrate stability zone.

Ingo Pecher, Joshu Mountjoy, and others, propose that these slides would be an ideal APL in association with 781A-Full to test whether and how gas hydrates may cause slow sliding. Two possible mechanisms to consider are 1) hydro-fracturing of a shallow gas hydrate zone [*Crutchley et al*., 2010; *Ellis et al*., 2010]; and 2) sediment weakening caused by the interaction between gas hydrate and sediment grains.

These landslides are already the focus of a remote drilling campaign using the University of Bremen's drill rig MeBo tentatively planned for 2015 and led by collaborators in this proposed APL (K. Huhn, N. Kukowski: SlamZ - Slide activity on the Hikurangi margin, New Zealand), and proposed 3-D high-resolution (P-Cable) seismic surveying. MeBo can drill to ~70 m beneath the seafloor and will provide lithologic, stratigraphic and geotechnical information, but with current capabilities will not reach the basal shear zone of the landslides. Information on stratigraphy, lithology, and gas hydrate distribution in undisturbed sediments away from the slides will be obtained from logging-while-drilling (LWD) planned as part of Proposal 781A.

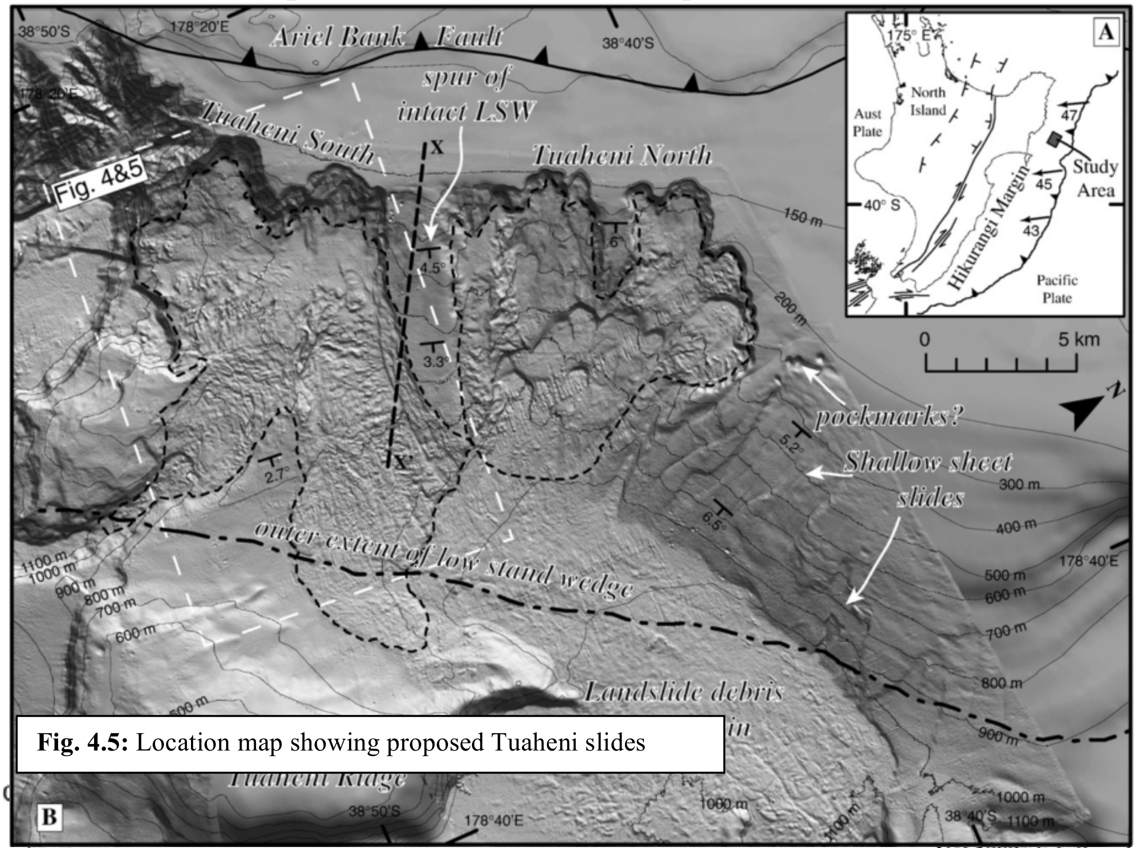

Fig. 4.5: Location map showing proposed Tuaheni slides

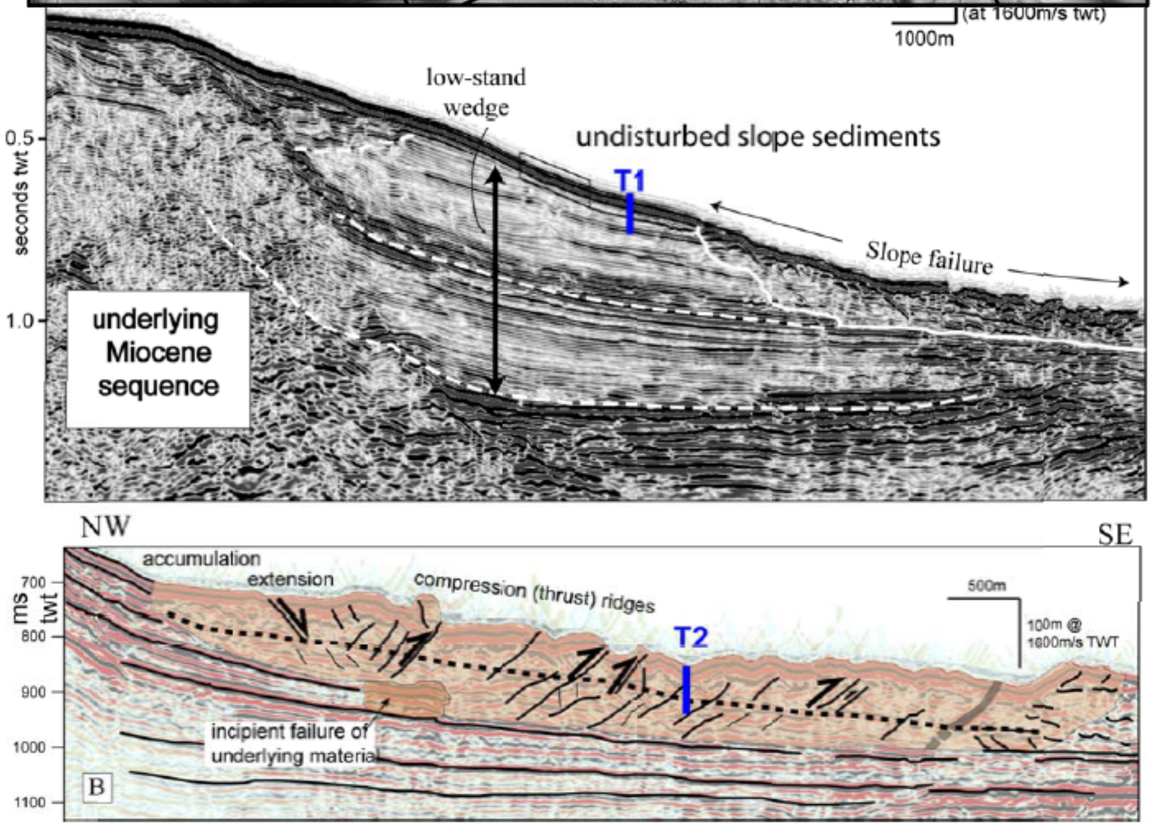

Fig. 4.6: Seismic profiles through the Tuaheni Slides (from SlamZ proposal). Seismic profiles through the Tuaheni Slides (from SlamZ proposal). The surface morphology and internal architecture of these slides (combination of extensional and compressional features) suggests episodic re-mobilization of debris [Mountjoy et al., 2009]. T1 and T2 are proposed MeBo sites

The proposed APL will focus on penetrating the entire slide down to below the slide interface, roughly 150 mbsf. It is tentatively suggested to drill an LWD hole for calibration of seismic data followed by a coring hole, including targeted pressure coring to preserve gas hydrates (at the time of compilation of this report, the proponents also plan to investigate feasibility of pressure-while drilling measurements). The proponents anticipate obtaining information on gas hydrate saturation, hydrate habitat, lithology, geochemical and physical properties. Combined with MeBo and seismic data, it is planned to reconstruct timing and modes of sliding as well as develop a quantitative model for rheology-controlled creeping seafloor failures facilitated by the role of gas hydrates. If it is found that creep behaviour in these landslides is linked to gas hydrates, the results will constitute a paradigm shift for the role of gas hydrates in submarine sliding, i.e., the presence of gas hydrates may facilitate sliding rather than stabilize slopes.

This proposed APL was presented during the Earth in Motion breakout. Participants in the breakout were generally supportive, particularly because drilling would take place in the 781A study area using equipment already on board for 781A. A concern raised was whether the published findings from previous analyses that the slides are indeed "creeping" (i.e., remobilized repeatedly) were accurate. It was suggested to investigate whether ocean-bottom pressure recorders, similar to those planned to be deployed further downslope for slow-slip studies, may be used to support the hypothesis of creeping. It was also pointed out that MeBo II, if available, should be capable of penetrating the entire slide sequence but it was acknowledged this would not allow critical LWD or pressure coring.

Proponents will develop this into an APL pending advice on scheduling of 781A-Full.

4.3. Brothers Volcano, Multidisciplinary Drilling Project

Cornel de Ronde proposed a new drilling project at Brothers Volcano, which is a 3 km wide caldera in 1100 to 1800 m below sea level, located along the Kermadec subduction zone. Investigations at this active volcano and hydrothermal system would address several different topics as described in other IODP science plan themes, such as understanding mineral deposits and characterizing biological communities in hydrothermal systems. At this single volcano, end-member conditions of temperature, pH, and mineral composition are observed. As related to the Earth in Motion theme, physical volcanology and structural processes of caldera formation can be studied. Moreover, the hydrothermal thermal system reflects the ex-solution of gases from the active magmatic system, so eruption processes can also be studied.

To further the development of this proposal, a workshop is scheduled for November 2012 in Portugal, and preparation of a pre-proposal is anticipated by April, 2013

4.4. References

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Theme 5: Marine Resources: opportunities and responsibilities

What contribution can IODP make to the exploration, characterisation and responsible exploitation of marine resources in the Southwest Pacific region? These resources may include offshore oil and gas, gas hydrates, and offshore minerals.

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The aim of this theme was to determine the contribution that IODP could make to the exploration, characterisation and responsible exploitation of marine resources in the Southwest Pacific region. These resources might include offshore oil and gas, gas hydrates, and offshore minerals. Whilst the scientific achievements and goals of IODP were the main reasons for this workshop, in these uncertain economic times it is essential to consider how Australia and New Zealand can increase the economic benefits of participating in the program. All IODP research in the Southwest Pacific has economic benefits – from advancing knowledge in poorly know marine territories to income from port visits. The best way to realise these benefits is by promoting excellent scientific proposals.

There are additional opportunities to draw economic benefits from IODP participation:

- Incorporating "marine resource" considerations into standard scientific proposals;
- Developing targeted "marine resources" proposals in co-funding arrangements with government and industry (Complementary Project Proposal = CPP);
- Commercial hire of IODP drilling vessels when they are in the region.

The three target areas for resources that were discussed and those scientists most involved were:

- Petroleum potential of the Lord Howe Rise: Riko Hashimoto (Geoscience Australia), Shinichi Kuramoto (JAMSTEC, *Chikyu*), David Divins (Ocean Leadership, *JOIDES Resolution*), Rosemary Quinn (GNS Science)
- Metals potential of SW Pacific island arcs and back arc basins, most notably Brothers Volcano (NZ) and the Manus Basin (PNG): Cornel de Ronde (GNS Science), Peter Crowhurst (Nautilus Minerals), Chris Yeats (CSIRO), Joanna Parr (CSIRO)
- Gas Hydrates potential off New Zealand: Ingo Pecher (University of Auckland & GNS Science)

5.1. Petroleum potential of the Lord Howe Rise

[see also Theme 1: *Climate Change* and Theme 4: *Earth Connections*]

This is the largest submerged continent in the world and there are fundamental questions about its petroleum potential related to the largely unknown history and fabric of the rise. The rise contains a number of deep rift basins that are well characterised by seismic profiling, but may or may not contain source, reservoir and cap rocks. Sparse stratigraphic information is limited to early DSDP wells (Legs 21 and 90). Potential exploration targets are believed to be Cretaceous, but the uppermost

Cretaceous was reached only in two holes. Without basic stratigraphic information the next stage in assessment of petroleum potential cannot be achieved.

Drilling into the Cretaceous-Paleogene sequence would provide information that can help to resolve questions of Cretaceous subduction and palaeogeography, and the origin of basins and ridges. Furthermore, the Cretaceous-Paleogene sediments will provide valuable information on climate and ocean change in this region, with impacts throughout the Southwest Pacific, and resolve questions about Cenozoic tectonics.

It is clear that deep stratigraphic drilling on the Lord Howe Rise warrants its own IODP leg in terms of the outstanding scientific questions from a global perspective, and its direct resource interest to Australia, New Zealand and New Caledonia.

There are potential safety issues to address, because the drilling would be into potentially hydrocarbon-bearing sequences and structures. Accordingly, a detailed seismic site survey is required to assess safety. Geoscience Australia has high-resolution multi-beam bathymetry and high-quality regional seismic profiles of some target areas to aid in such a survey. The IODP riser drilling vessel *Chikyu* is open to joint funding proposals (CPPs) and is possibly available late in 2014.

A workshop to prepare a Lord Howe Rise proposal is being hosted by GNS Science in middle February with the aim of submitting an IODP full proposal in April 2013.

5.2. Metals potential of Southwest Pacific island arcs and back arc basins

[see also Theme 3: *Earth in Motion*]

Many of the island nations of the Southwest Pacific have limited land area with scarce mineral resources, but massive maritime territories with largely unexplored mineral potential. The economic attraction of the nascent deep sea mining industry to these countries is obvious. It’s estimated that more than a million square kilometres of seafloor in the Asia-Pacific Region is under exploration licence, providing researchers with an outstanding opportunity to leverage the often high-quality site survey data generated by mineral explorers to draft drilling proposals that will address fundamental scientific questions related to volcanology, crustal fluid fluxes, subduction input of volatiles into the oceans, and the limits and origin of life on Earth.

Although many of the arcs and back arcs of the region are of high scientific interest; two of the most heavily surveyed areas, of interest to both the scientific community and the minerals industry, are Brothers Volcano, in the Kermadec Arc north of New Zealand, and the Manus Basin between New Britain and New Ireland.

5.2.1. Brothers Volcano

The Brothers volcano has been extensively surveyed from surface vessels and submersibles. However, it lacks deep drilling, which is needed to understand its subseafloor hydrology and potential to form large accumulations of Cu-Au mineralisation. Two distinct hydrothermal systems of very different end-member chemical compositions exist within the same area, and drilling provides the opportunity to address scientific questions relevant to microbiology (this could be a biological hotspot), volcanology, and to the formation of significant ore bodies.

A drilling strategy would ideally involve drilling directly into the hydrothermal system(s). Technical problems to be addressed include the friable nature of many of the host rocks, the high temperature

(300°C) and the very acid fluids (pH to 1.9). It was noted that 200°C is probably the upper limit for drilling, though the Japanese have drilled higher temperature systems. Drilling of adjacent 'recharge zones' offers a viable alternative drilling strategy. A seismic survey has been completed but it is of poor quality and unable to image the subseafloor effectively.

A workshop had been organised for mid November in Lisbon to prepare a drilling proposal. The aim is to submit an IODP pre-proposal by April 2013.

5.2.2. Manus Basin

The Manus back arc basin lies at the convergent boundary between the major Indo-Australian and Pacific plates, and exhibits a complex tectonic history, including reversal of subduction due to the arrival of the Ontong Java Plateau at the old subduction zone. The Eastern Manus Basin (EMB) is dominated by oblique rifting and contains excellent examples of single-centre and rift-associated felsic submarine volcanism. The volcanic rocks of the EMB are chemically and genetically related to the New Britain Arc. There are at least nineteen active sites of hydrothermal activity within the Manus Basin, making the area an ideal natural laboratory to investigate the controls on and inputs into ore forming processes on both a regional and local scale.

The basin has also attracted the interest of explorers for seafloor massive sulfide mineralization, most significantly Nautilus Minerals (who have plans to mine the Solwara 1 seafloor massive sulphide), and is therefore well surveyed relative to other back arc basins.

The contrast between a relatively mature, strongly mineralized system at Solwara 1 and a strongly hydrothermally active, less mineralized system at nearby North Su provide a unique opportunity to investigate the critical factors leading to ore formation in the submarine environment; the link between arc volcanism, back arc rifting and metallogenesis; and the limits of life in these extreme environments. The activities of Nautilus Minerals have generated an enormous quantity of high-quality site survey data at SuSu, including extensive visual mapping and surface sampling by ROV, 20cm-resolution bathymetry, deep tow magnetic and electromagnetic surveys and approximately 200 shallow drill holes, to depths of ~40m below the seafloor. The company is receptive to scientific research, and the combination of scientific interest and high quality near surface data make SuSu Knolls a highly attractive target for a future IODP Leg.

5.3. Gas Hydrates potential off New Zealand

Gas hydrates have been identified in wide areas east of the North Island of New Zealand on the Hikurangi margin, but drilling is needed to confirm their nature. The New Zealand Ministry of Business, Innovation, and Employment is currently funding a programme on gas hydrate assessment. The New Zealand government is interested in drilling gas hydrates for potential hydrocarbon resources but currently has not committed any funding for this. Scientific questions related to gas hydrates on the Hikurangi Margin include their relationship to "creeping" (slow moving) submarine slides observed in the study area of IODP proposal 781A (slow slip earthquakes), which may warrant an APL on the back of that proposed transect drilling. Energy-related drilling for purely scientific reasons may be difficult to justify, but one approach might be to share the costs through a CPP approach.

A drilling strategy might be to drill at least 2-3 holes, at a time when the *JOIDES Resolution* is operating in New Zealand (e.g., should 781A be drilled). These holes would also help with 'slow slip' faulting research, but would require a very specific hydrate-oriented approach. They could not simply be joined to another IODP leg. Ingo Pecher needs to gather more information in order to prepare a proposal to the New Zealand Government to support a CPP.

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