Workshop report

Australasian IODP Regional Planning Workshop Detailed Report: Developing community-based scientific priorities and new IODP proposals

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Overview

The importance of the Southern Hemisphere in the narratives of global plate tectonics and oceanography is well established, but regional questions are understudied. This is in large part due to the vastness of the regional oceans. Simply stated, the Australasia region is an ideal region to address many of the 14 science challenges in the 2013-2023 IODP Science Plan. The Australian and Indian continents have undergone the largest and most rapid paleo-latitudinal shifts – and studying this region is essential to address both paleoclimate and tectonic questions. The region boasts arguably the greatest diversity of subduction zones from fully seismically coupled to uncoupled; the greatest array of youthful subduction zones globally; an extensive set of shallow marine seas and submerged continents (especially Zealandia) with extraordinary stratigraphic records waiting to be studied; and not only the largest suite of massive hotspot-related features, but the largest mantle cold spot.

Without a doubt, another phase of IODP drilling within Australasia will dramatically improve our understanding of our planet's evolution. Sampling of plateaus and ridges will not only provide an enormous wealth of information about their origin, but will also provide key samples to address paleoceanographic and paleoclimate questions. Further drilling of the Antarctic margin will increase our understanding of global and regional questions related to Antarctic ice sheet and global climate evolution and past land and sea ice extent from the Cretaceous through the Cenozoic. Geomicrobiological questions can be addressed on many expeditions, including carefully targeted, dominantly microbiological expeditions to study the deep biosphere in a variety of tectonic settings. Petrological and geochemical studies of oceanic, back-arc, and arc crust, and of uplifted mantle remain a high priority, as do investigations of geological hazards. The geographic scope of this workshop was the eastern Indian Ocean, the southwest Pacific Ocean, and the Indian and Pacific sectors of the Southern Ocean.

The Australasian IODP Regional Planning Workshop was introduced with a plenary session of invited speakers outlining the broad IODP Science plans and capabilities, as well as more detailed keynote presentations reviewing each of the four themes in the 2013-2023 IODP Science Plan in the regional context. This was followed by overview talks of relevant regional research, including recent and upcoming expeditions in the region. The second day consisted of breakout sessions with 10-minute presentations from the workshop participants who had submitted abstracts outlining potential ideas for future drilling. In light of the abstracts received for the workshop, and with the ambition of promoting cross-disciplinary projects, the breakouts were divided into two groups focusing on:

1) Climate and Oceans/Biosphere Frontiers, chaired by Tina van de Flierdt, Tim Naish, Verena Heuer, and Yuki Morono
2) Earth Connections, chaired by Mike Coffin, Marguerite Godard, Laura Wallace, and Shuichi Kodaira.

Following these breakouts, strong research overlaps were clear between the Climate and Earth Connections themes which didn't necessarily relate to a distinct geographical region. Consequently, day three was divided up into breakout session to further nurture cross-disciplinary proposals, and these focused on distinct tectonic settings and their associated paleo-environmental history or biology.

The main breakout sessions included:

- Large Igneous Provinces and associated paleoceanography
- Subduction zones and associated paleoceanography
- Conjugate margin studies and associated paleoceanography

Participants interested in multiple topics/settings were encouraged to move between sessions to provide input. Short duration (~1 hour) subgroups met if additional ideas didn't relate to the above tectonic settings. These included:

- A Hikurangi subduction subgroup breakout to developing ideas building on the upcoming phase of drilling in this region.
- A Zealandia subgroup breakout to investigate possible targets on the Lord Howe Rise, building on the upcoming phase of drilling in this region.
- Biosphere Frontiers subgroup meeting to discuss ideas that didn't relate to the above tectonic settings.

Summary of workshop outcomes

The approach of the workshop was to combine local expertise with international experts, as well as to encourage early career researchers to become actively involved in developing proposals. A total of 97 participants included 10 students, 16 postdocs, 53 professional research scientists in a variety of roles (including university academics), 10 researchers/science managers with government institutions, and several IODP, ECORD, and ANZIC scientists in program management roles. ANZIC was represented by scientists from 17 institutions across Australia and New Zealand and the Office of the Chief Scientist of Australia. Participants represented 12 different countries, namely Australia, New Zealand, New Caledonia, Japan, India, Germany, United Kingdom, France, Denmark, Sweden, USA, and Canada.

A total of 24 proposal ideas were discussed, with 12 of these deemed to be mature enough for active proposal development to begin, with an aim for submission in late 2017 or 2018 (Figure 1). These are proposals with either existing sufficient site survey data or site survey cruises planned. Of the remaining 12 proposals, key regions were identified where key hypotheses are testable by drilling. However, these require either site survey proposals to be developed or the hypotheses require further scientific development. These refinements are anticipated to be made through integration of upcoming IODP drilling in the region during 2017/2018, or through analysis of recently collected (or soon to be collected) site survey data. The status of each project is outlined in the sections below.

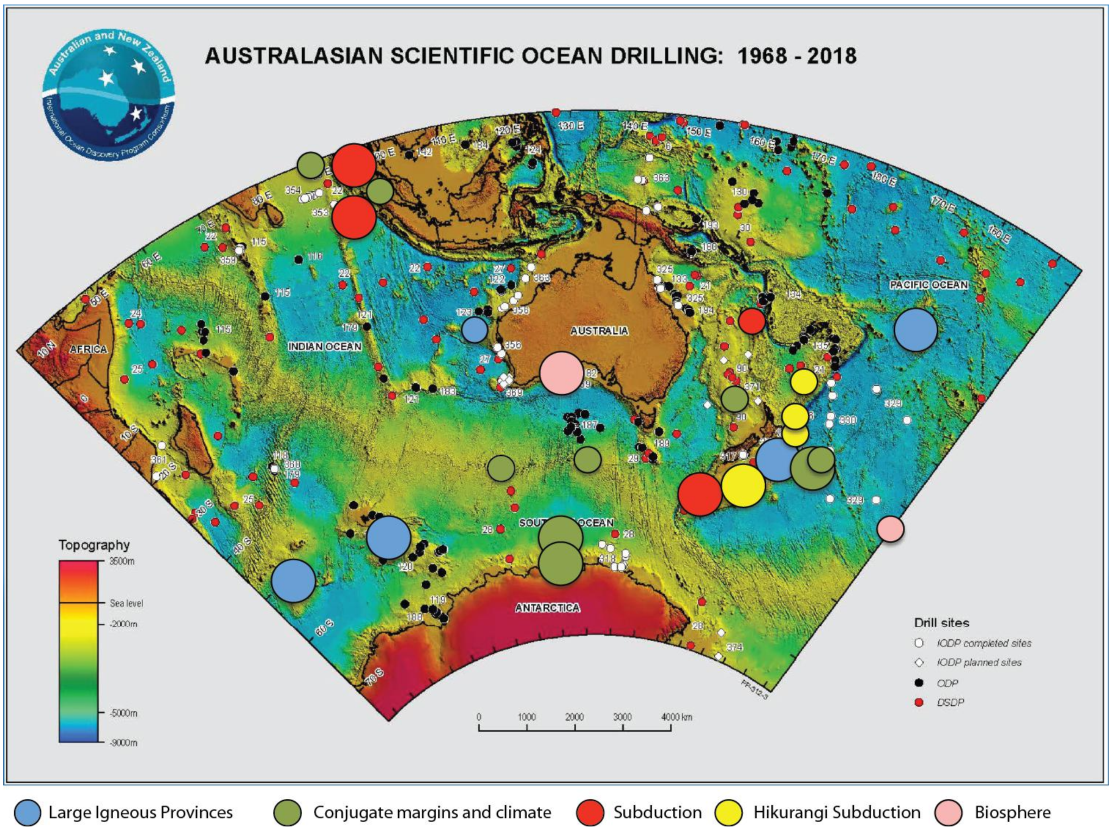


Figure 1: Location map of potential proposals discussed in the workshop, with color coded dots denoting the main theme for each proposal. Larger colored dots indicate proposals that appeared to be mature enough to develop pre-proposals. Smaller colored dots require site survey proposals to be developed – or await the results of upcoming drilling in the region to refine hypotheses (e.g. Hikurangi Subduction Zone and Lord Howe Rise regions).

Section 1. Large Igneous Provinces and associated paleoceanography

1.1 Manihiki-Plus: Ground zero for understanding large igneous provinces and their environmental impact

Science Lead - Gerald Dickens
Data Lead - Gabriele Uenzelmann-Neben
Other proponents – Mike Coffin, Bob Duncan, Elisabetta Erba, Karsten Gohl, Katharina Hochmuth, Kaj Hoernle, Fumio Inagaki, Junichiro Kuroda, Clive Neal, Nao Ohkouchi, Masao Nakanishi, Oliver Nebel, Don Penman, Christian Timm, Gabriele Uenzelmann-Neben, Jessica Whiteside.

Earth's evolution includes multiple geologically brief episodes when extraordinary volcanism and plutonism occurred across some regions. Documentation for this comes from large igneous provinces (LIPs), extensive areas of thick sections of mostly mafic material that was emplaced on a million-year time scale. While LIPs have been widely acknowledged and discussed by the geoscience community for at least two decades, major first-order questions remain regarding their origin and environmental impact.

Profound and rapid changes in biota and chemical cycling also have punctuated Earth's history. Many such "events" have been linked to the formation of LIPs. For example, massive volcanic outpouring may have been coupled to large increases in atmospheric pCO_2, which could have raised surface temperatures, amplified the hydrological cycle, and changed ocean circulation. Equally important is the concept that oceanic LIPs, typically lying above carbonate saturation horizons, provide the basement on which many of the outstanding records of Earth history accumulate.

Manihiki Plateau, in the southwest Pacific, is one of the "classic" LIPs discussed in numerous compilations. Much of this large (770,000 km^2) bathymetric high appears to have been emplaced about 125-120 Ma, although geophysical arguments suggest a more complex history, with at least two later stages of volcanism. For several reasons, Manihiki Plateau is ground zero for understanding LIP formation and impact. First, it may be the center of a much larger LIP that has been dispersed since the Cretaceous (other components include the Ontong Java and Hikurangi plateaus). Second, the core of Manihiki, where magmatism was most voluminous and the crust is thickest, can be located and drilled. Third, Manihiki Plateau lies in a wide range of water depths, and on the basis of available information, is characterized by mafic rocks with heterogeneous geochemistries. Fourth, environmental impacts of LIP extrusion can be monitored by syn-LIP sediments at proximal locations, especially Magellan Rise. Of course, other than targeting and understanding LIP formation, the sedimentary records on top of Manihiki Plateau and Magellan Rise hold the paleoceanographic history of the central Pacific from the Late Jurassic (Magellan) and Early Cretaceous (Manihiki) to the modern. The two locations lie beneath the eastern end of the Pacific warm pool.

For almost 45 years, much information concerning the magmatic composition of Manihiki Plateau igneous basement and all information on the overlying stratigraphic record has been ground truthed from only one location: DSDP Site 317 drilled in 1973 with poor recovery. The lone drill site on Magellan Rise (DSDP Site 167) was drilled in 1971, also with poor recovery.

We propose to drill five sites in total (Figure 2). One will be a re-drilling of Site 167 on Magellan Rise with modern technology and techniques. Four will be on Manihiki Plateau to understand the distribution of ages and compositions, and to collect the overlying sediment records.

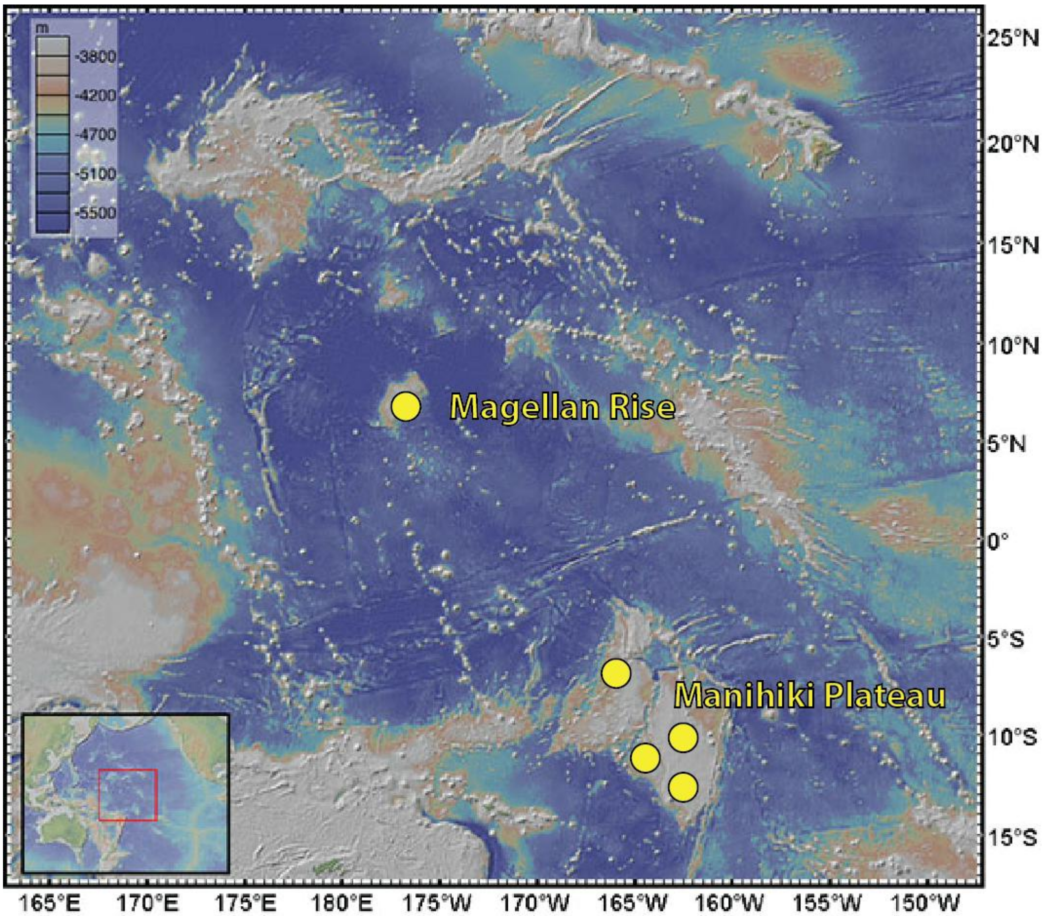


Figure 2: Location of Proposed sites on the Manihiki Plateau and Magellan Rise.

1.2 Hikurangi Plateau Large Igneous Province and Subduction Inputs

Science Lead: Christian Timm and/or Jörg Geldmacher
Data Lead: Dan Bassett
Other proponents: Mike Coffin, Brian Davy, Folkmar Hauff, Kaj Hoernle, Nick Mortimer, Martin Reyners

We will investigate the genesis of Large Igneous Provinces (LIP) by targeting the Cretaceous Hikurangi Plateau. Stratigraphically controlled sampling of the Hikurangi Plateau will yield insights into the mantle source and LIP emplacement rates, and help to constrain geodynamic models and environmental impacts of LIP emplacement. It will also enable testing of the hypothesis that Ontong Java, Manihiki, and Hikurangi were once part of a single super-LIP known as Ontong Java Nui.

We will also investigate the controls on subduction megathrust slip behavior. The Hikurangi margin of New Zealand displays strong along-strike variations in subduction interface slip behavior (locked versus creeping), and the nature of the material coming into the subduction zone on the subducting Pacific Plate likely exerts a strong control on these along-strike variations in slip behavior.

This proposal will acquire cores and logs sampling the incoming sedimentary section and underlying igneous basement at several locales along a north-south transect of the Hikurangi Plateau. These will resolve along-strike variations in the sedimentary section and igneous basement, and document variations in sediment lithology, fluid content, and igneous petrology, geochemistry, and geochronology. Petrologic, geochemical, and geochronological data will yield information on LIP genesis, and changes in sediment lithology and fluid may provide insights into locked versus creeping behavior at subduction megathrusts. We will target portions of the plateau where the sedimentary cover is thinner (less than several hundred meters), well east of the deformation front, to avoid the thick trench-fill sections near the Hikurangi Trough. We will also target sites where there are expanded sections of the portions of incoming stratigraphy that correlate with where the plate boundary decollement is forming.

We envision that the proponent group will combine researchers interested in processes associated with LIP emplacement and megathrust processes. Upcoming drilling on Expeditions 372 and 375 will provide critical information to underpin the development of such a proposal, as will multichannel seismic reflection and refraction lines to be acquired in November/December of this year. We suggest that the proponent group aim to develop a pre-proposal by October 2018, once all these information are available.

1.3 Kerguelen Plateau LIP and Paleoceanography

Lead/Data Lead: Gabriele Uenzelmann-Neben
Other proponents: Nick Arndt, Tiffany Barry, Irina Borissova, Mike Coffin, Elisabetta Erba, Karsten Gohl, German Leitchenkov, Dietmar Müller, Clive Neal, Kirsten Nicolaysen, Paul Renne, Marc Schaming, James Scoates, Thorvaldur Thordarson, Paul Wallace, Dominique Weis.

A multidisciplinary drilling expedition on the Kerguelen Plateau (Figure 3) will investigate large igneous province (LIP) formation and 120-0 Ma Southern Ocean paleoceanography. Our objectives address the Earth Connections and Climate & Ocean Change themes of the IODP Science Plan. The Kerguelen Plateau incorporates multiple microcontinents and has as unknown relationship to dipping reflection sequences on the nearby Antarctic margin. Tectonomagmatic questions include why the most voluminous magmatism (Figure 4) appears to have post-dated continental breakup (unlike other flood basalts associated temporally with breakup), and how continental fragments were isolated in the Plateau. Cretaceous and Cenozoic paleoceanographic records are well preserved in Plateau carbonates, and a transect will yield expanded sections of critical paleoceanographic intervals.

Located in a key region in the southern Indian Ocean, the complex topography of the Kerguelen Plateau exerts a strong influence on pathways of water masses within the Antarctic Circumpolar Current (ACC) and the Antarctic Bottom Water (AABW). Topographic highs such as William's Ridge reduce the flow of water masses leading to the deposition down-flow of thick sediment packages. Gaps and narrow passages in contrast lead to erosion and non-deposition. In the Cenozoic era, significant modifications in pathways and intensity of those water masses have been caused by the tectonic development of the Kerguelen Plateau as well as the openings of the Tasman Gateway and the Drake Passage, and major global climatic changes. In the Kerguelen Plateau region all these changes are explicitly well documented in the formation of sedimentary structures, e.g., sediment drifts, supposedly at very high resolution.

Specifically, this research will: 1) elucidate the temporal, volumetric, petrologic, and geochemical development of massive Early Cretaceous Kerguelen magmatism as well as associated uplift and subsidence, valuable for testing long-lived plume and other geodynamic models for flood volcanism, and for developing new geodynamic models; 2) define temporal, spatial, petrologic, and geochemical relationships among volcanic rocks on the Kerguelen Plateau and in the Princess Elizabeth Trough, and determine the uplift and subsidence histories of these features; 3) illuminate critical extreme environment events, including oceanic anoxia, mass extinction, thermal maxima, sea level change, and Antarctic ice sheet formation and dynamics; and 4) elucidate the evolution and dynamics of the ACC and AABW. We will accomplish our goals through drilling, coring, and logging multiple holes through the sediment section and, in some holes, from 250 to 500 m into igneous basement. We will then relate the magmatism and tectonism to continental breakup among Antarctica, India, and Australia, providing critical parameters for testing existing and developing new geodynamic models for continental breakup. New environmental data will provide critical Southern Ocean information on OAE-2, K-T boundary, PETM, mid-Oligocene sea level change, and Antarctic glaciation.

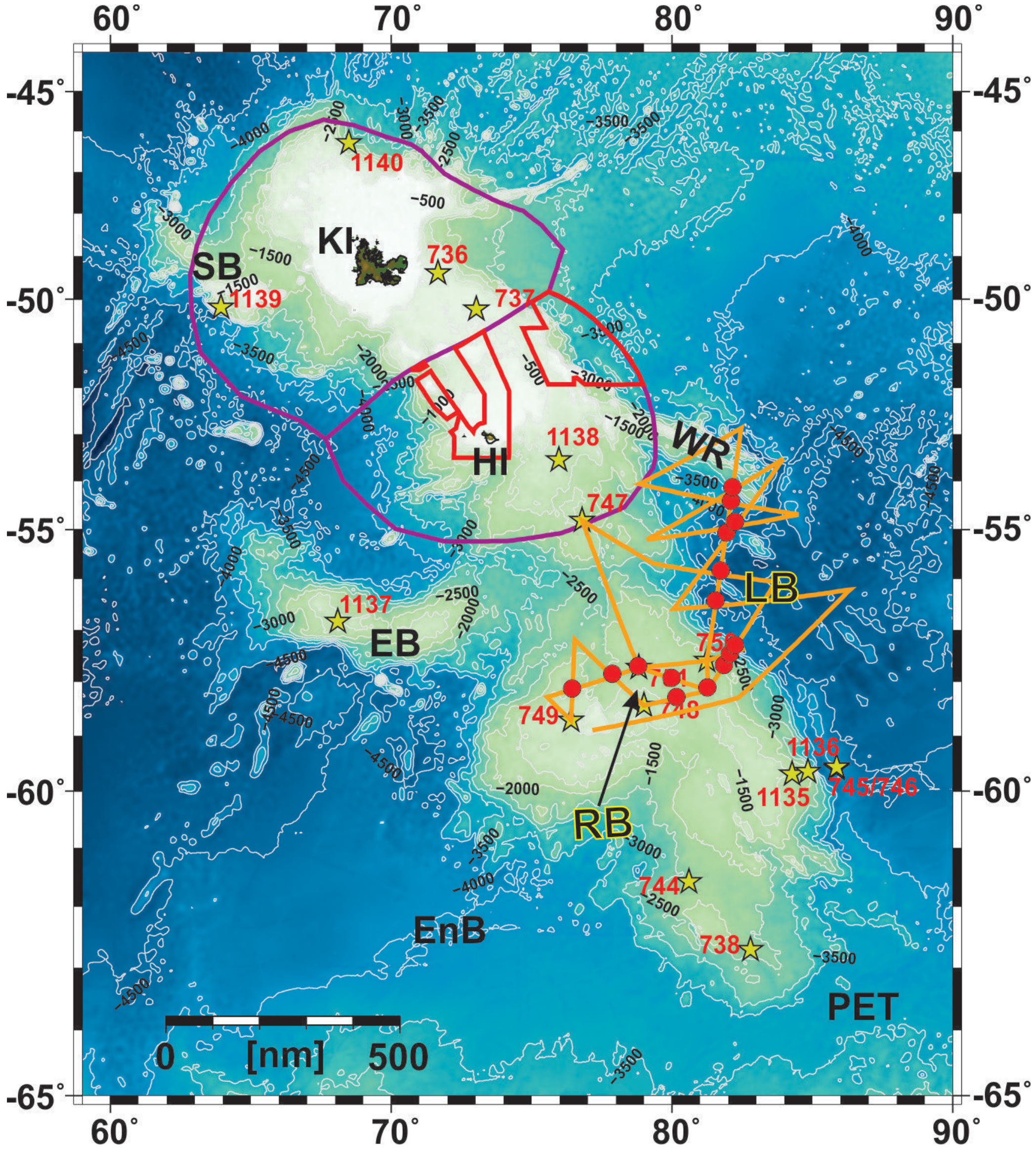


Figure 3: Location of existing seismic survey data and drill sites (stars) in the Kerguelen Plateau region, and location of upcoming seismic survey (orange lines). Red circles are planned geological sample stations for the site survey.

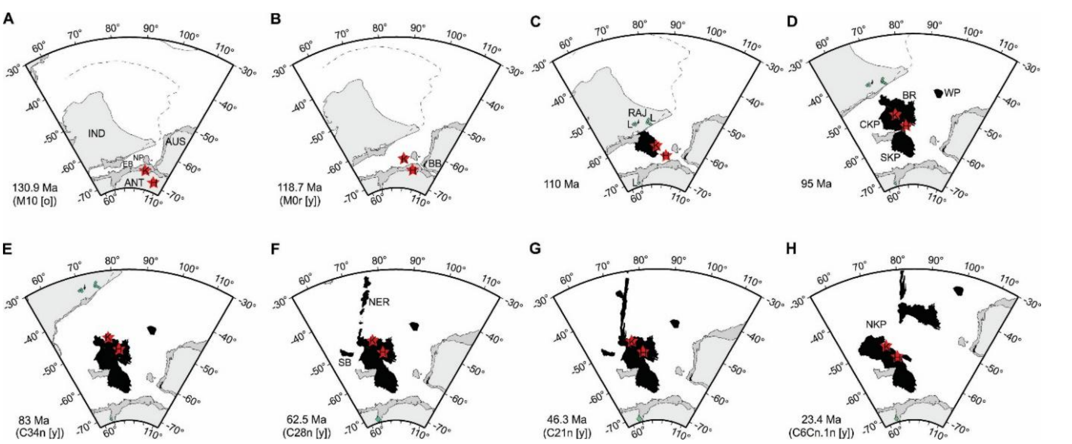


Figure 4: Tectonic evolution and emplacement of the Kerguelen Large Igneous Province

1.4 Plio-Pleistocene Paleoceanography of the Southwestern Indian Ocean sector of the Southern Ocean (PePSI-SO)

Science Lead: *Minoru Ikehara*
Data Lead: *Yasuyuki Nakamura*
Other proponents: Xavier Crosta, Samuel Jaccard, Tim Naish, Yoshifumi Nogi, Yusuke Suganuma, Gerhard Kuhn, Giuseppe Cortese, Boo-Keun Khim, Robert Dunbar, Richard Levy, Robert McKay, Thamban Meloth, Robert DeConto, Takuya Itaki, Elisabeth Michel, Alain Mazaud, Raja Ganeshram, Alfredo Martinez-Garcia

A preliminary proposal (918-Pre) in the Indian sector of the Southern Ocean was submitted to IODP for the April 2017 deadline. The main objectives of 918-pre are to drill at five high sediment accumulation sites located in the Southwestern Indian sector of the Southern Ocean (Del Caño Rise, Conrad Rise, Enderby Abyssal Plain) to document climate variability in the Southern Ocean and associated interactions and feedbacks between the atmosphere, ocean, and cryosphere on a variety of timescales spanning the Middle Miocene to Holocene. The targeted drill sites will fill an important gap in our knowledge providing Southern Ocean records covering the Middle Miocene cooling (~14 Ma), Late Miocene Carbon Shift (8-6 Ma), the Pliocene climate optimum (5.3-3.3 Ma), the Late Pliocene global cooling (3.3-2.6 Ma) culminating with the onset of northern hemisphere glaciations, the mid-Pleistocene transition (MPT: 1250-700 ka) and the mid-Bruhnes Transition (~0.43 Ma) when profound, large-scale climate changes have occurred. Glacial/Interglacial variability and ocean processes could be studied on millennial time scales here.

Within this framework, our investigations will contribute to further understanding of the following specific processes: Dynamic fluctuations of the ACC and associated meridional frontal migrations in relation to global circulation (Agulhas Leakage, Atlantic Meridional Overturning Circulation) and climate change; Changes in inter-ocean surface and deep water transport during periods of climate change; Variability in sea-ice extent in the Indian Ocean Sector and its implications for air-sea gas exchange and the partitioning of CO_2 between the atmosphere and the ocean interior; Changes in biological export productivity in relation to dust input, upwelling intensity, nutrient inventory, and sea ice extent. The target area of 918-pre is distal to the Australasian region, but is in an important location for upstream water masses directly feeding into the Southern Indian Ocean and Australo-Antarctic Basin, via the Agulhas retroflection and the Antarctic Circumpolar Current.

1.5 Wombat in the Greenhouse: Sampling rare regional records of Mesozoic Environmental Change

Science Lead: *Jessica Whiteside*
Data Lead: *TBD*
Other possible proponents/interested parties: Tim Bralower, Junichiro Kuroda, Mike Coffin, Dietmar Müller, Irina Borissova, Fumio Inagaki, Simon C. George, Neville Exon, Yasu Yamada, Yair Rosenthal, Ulrich Wortmann. Trevor Williams, Eun Young Lee, David de Vleeschouwer, Maija Raudsepp, Yuki Morono

Increasing ocean acidification, deoxygenation, and extinction are among the measurable consequences of current and 21st century projected trends in atmospheric CO_2 concentrations and climate change. Several mass extinction events in Earth's past occurred during global greenhouse (hothouse) climates, and these may serve as partial analogues from which we can infer the ecological consequences of anticipated future global climate scenarios. The warmest such interval in the last 300 million years – the early Mesozoic Era (252 to 66 million years ago, Triassic through Cretaceous) – witnessed pivotal biotic, climatic, and tectonic events against a backdrop that included generally elevated CO_2, conjoined and splitting continents, and nascent modern ecosystems. This time interval is punctuated by a number of sudden environmental changes, including possible transient icehouse intervals, the Carnian Pluvial Event, Large Igneous Province (LIP) emplacements, and at least two bolide impacts. This was also a period of large-scale continental dispersion, as the supercontinent Pangaea was slowly breaking apart to form the major plates we observe today.

Drilling of continuous marine sedimentary archives that document Earth's climate and tectonic history in Mesozoic time is a scientific and societal priority. Extensive early Mesozoic marine records from this region are rare, and when present they are difficult to precisely correlate with classic Tethyan and northern Panthalassan sections. This is primarily because the marine biozonation for this southern hemisphere region differs strikingly from the Laurasian index fossils used to define the GSSP chronostratigraphic boundaries. Thus, integrating a precise and accurate global picture of environmental and biotic changes during the early Mesozoic is impossible now.

We propose to drill Mesozoic sedimentary sequences on the northeastern side of the submerged Wombat Plateau, which is part of the northernmost continental margin of Australia. Here, previous work at four drill sites (759-761, 764) by ODP Leg 122 scientists reveals a thick succession of Late Triassic (Carnian-Rhaetian: ~236-201.6 million years ago) deltaic and shallow marine sediments unconformably overlain by Late Cretaceous (Cenomanian-Maastrichtian: 100.5-66 million years ago) pelagic sediments, including records of Oceanic Anoxic Event 2 across the Cenomanian-Turonian boundary (where black shale total organic carbon values rise to >25%) and the Cretaceous-Paleogene boundary. Though this previous drilling established a basic understanding of the sequence, core recovery was quite poor (≤30%), and existing cores are in poor condition, precluding the possibility of developing a well-preserved continuous record from them.

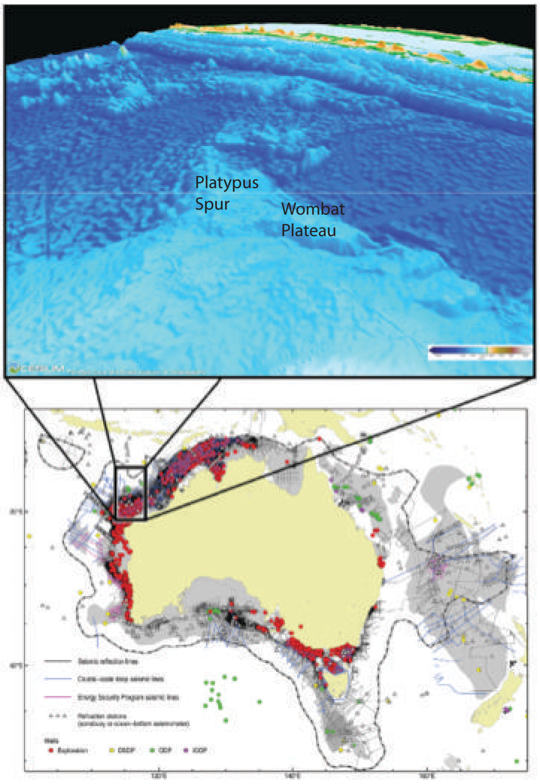


Figure 5: Top – bathymetric profile of Platypus Spur and Wombat Plateau on the northern Exmouth Plateau south of the Argo Abyssal Plain. Bottom - Map of the Australian region depicting offshore wells, seismic reflection lines and seismic refraction stations (either sonobuoys or ocean-bottom seismometers).

New core from the Wombat Plateau will provide a better understanding of the early Mesozoic in the region. These Triassic sediments were deposited at 20-30°S paleolatitude, which is particularly important because lower-latitude sediments from the Southern Hemisphere are rare. The magnetostratigraphic record recovered from this core will allow a precise correlation to Northern Hemisphere sections independent of biostratigraphy. At the same time, the biostratigraphic record for the core will allow correlation and integration of other South Pacific sections, and provide key Southern Hemisphere data for Late Triassic climate events (e.g., late Norian-Rhaetian increase in pCO_2, Carnian Pluvial Event, Manicouagan and Rochechuart impacts, and far-field effects of the Central Atlantic Magmatic Province). The regional versus global effect of these events is in debate, and thus a high-resolution southern record is critical for their understanding. Additionally, timing and environmental changes surrounding the Norian-Rhaetian boundary are poorly understood globally, and this drill site has high potential to recover a nearly complete shallow-marine record of this transition. Finally, the Late Cretaceous sediments that cap the Triassic sequence are an important deep-water record of the dynamic environmental changes during this time, just before the end-Cretaceous mass extinction event. Moreover, long sedimentary records from old rifted margins provide important information for reconstructing the pre-conditions and onset of rifting, continental breakup, and the formation of young ocean basins (and the many associated environmental changes), and the limits and evolutionary nature of the deep biosphere.

Section 2. Subduction/Zealandia

2.1 A proposal for deep ocean drilling in the Andaman Backarc Basin

<u>Science Lead</u>: *V. Yatheesh*
<u>Data Lead</u>: *D.K. Pandey*
<u>Other possible proponents/interested parties:</u> *K.A. Kamesh Raju, Nisha Nair, Anju Pandey, P. Dewangan, Sushant Naik, B. Nagender Nath, Satish Singh, A.V. Mudholkar, Sean Gulick, Eun Young Lee*

The Andaman-Sumatra Subduction Zone is a convergent plate boundary, formed by subduction of the Indo-Australian plate under the Burmese and Sunda plates. In this perspective, the northern sector of this subduction zone, i.e., the Andaman Subduction Zone, and the adjacent backarc basin, i.e., the Andaman Backarc Basin, were formed by subduction of the Indian plate under the Burmese plate. Detailed multibeam bathymetry data collected in the Andaman Basin and the adjacent regions map (Kamesh Raju et al., 2004) the well-defined rift valley of the presently active spreading centre as well as the seafloor image of the adjoining Alcock and Sewell seamounts. This spreading centre is connected to the West Andaman Fault in the west and the Sagaing Fault in the east. This high-resolution bathymetry image (Figure 6) suggests that the spreading centre is divided into three segments denoted as Segment A, Segment B, and Segment C.

Multichannel seismic reflection profiles (Figure 6) across the spreading centre in the segment C suggest that the Andaman Backarc spreading centre is a sedimented spreading centre filled with ~1.5 km thick sediments and its axial graben is bounded by normal faults and tilted fault blocks (Jourdain et al., 2016). Strong and discontinuous reflections within the sediment layers and underneath were interpreted to represent sub-horizontal sills injected within the sedimentary strata, without surface eruption. Magnetic anomaly profiles clearly show that the Andaman Backarc Basin contains prominent seafloor spreading type linear magnetic anomalies, which were interpreted to represent magnetic anomalies 1n (0 Ma) to 3n (4 Ma), and this inference indicate that seafloor spreading in the Andaman Basin commenced at ~4 Ma (Kamesh Raju et al., 2004; Curray, 2005). The interesting observation here is the absence of prominent magnetic anomalies in the segment C, where the spreading centre is filled with thick layers of sediments. This appears to be due to the different crustal accretion process in a sedimented spreading centre compared to the normal spreading along the mid-ocean ridges. Therefore, understanding the characteristics of a sedimented spreading centre has global importance since drilling in the rift valley of the Andaman Backarc Basin will provide important insights on the crustal accretion process and the reasons for absence of pronounced linear magnetic anomalies in a sedimented spreading centre. Drilling at the Alcock and Sewell seamounts and the inferred location of the oldest oceanic crust will help to address several geodynamic problems of regional interest such as the nature of the crust underlying the Alcock and Sewell seamounts and the timing of formation and evolution of the Andaman Backarc Basin. In addition, by analyzing the tephra layers from all these drilled sediment cores, the past volcanic history of the Andaman Sea can be deciphered.

All the proposed sites are also important locations for providing valuable insights on the paleo-circulation, provenance, and sediment slumping, through sedimentological and geochemical analyses. Coring, wire line logging, and *in situ* temperature and pore pressure measurements at these sites will constrain sediment deposition, diagenesis, and thermal and physical properties. The Central Andaman Trough in the vicinity of Alcock seamount complex has recently been found to record the silicate weathering changes related to late Quaternary climatic regime and monsoonal changes in the Indo-Burman ranges. Thus the proposed drilling will also help in the reconstruction of Neogene tectonics-climate linkage as well as the silicate weathering on tectonic timescales in Myanmar watersheds.

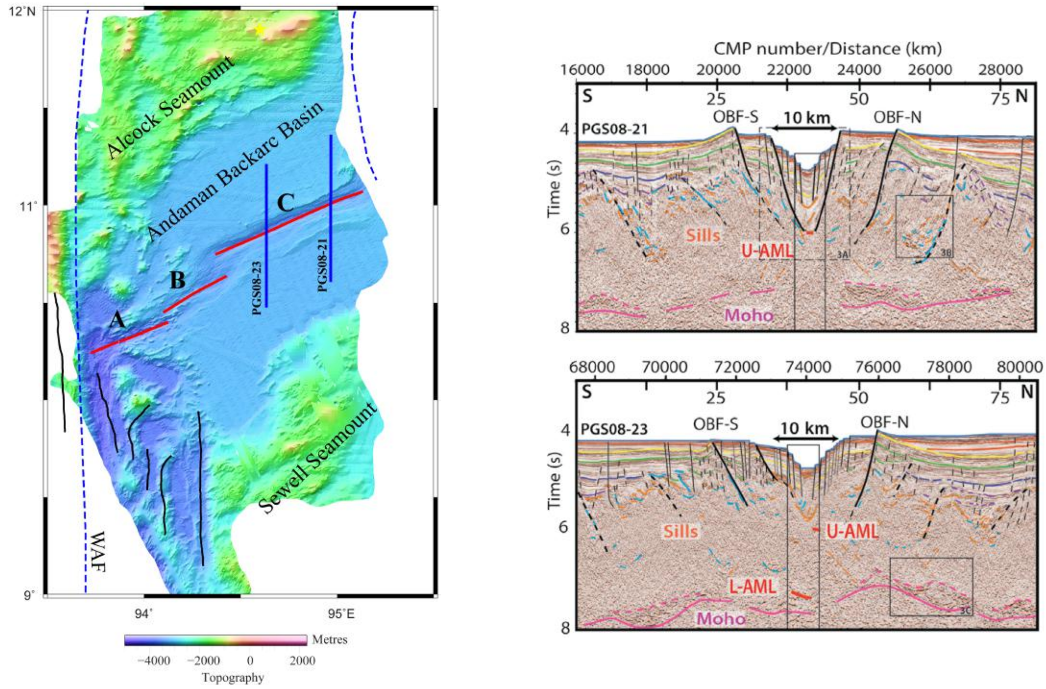


Figure 6. (left) Bathymetric map of the Andaman Backarc Basin [WAF = West Andaman Fault] and (right) seismic profiles PGS08-21 and PGS08-23.

2.2 Northern Zealandia: amphibious drilling approach to the New Caledonia peridotitic ophiolite

Science Lead: Julien Collot.
Data Lead: Julien Collot (offshore), Brice Sevin (onshore).
Other interested parties: M. Godard, J. Parr, B. Sevin, R. Sutherland, Y. Morono

Recent studies have reinvigorated the debate around the geodynamic evolution of the SW Pacific from Gondwana break-up during the Cretaceous to subduction-dominated tectonism in the Cenozoic. This geodynamic evolution led to the obduction of a string of peridotite ophiolites/massifs from the Anita Ophiolite in southern New Zealand to the Papuan Ultramafic Belt Ophiolite. Amongst these, the most extensively researched is the New Caledonian Ophiolite, which has been mined for mineral resources for more than a century.

Renewed interest in the evolution of the Tasman Frontier has resulted in a wealth of new marine geophysical data, which has brought new insights to our understanding the offshore structure and the geological setting of the region from the New Hebrides trench southwest to Lord Howe Rise and the Tasman Sea. At the same time, growing environmental concerns related to terrestrial mining on New Caledonia have led local institutions and mining companies to fund new research to develop tools to study the structure of the deeper parts of the ophiolite and the ultramafic hosted hydrothermal systems.

This research provided new insights to these questions, yet several fundamental questions relating to ophiolite emplacement and exchanges between solid Earth and external envelopes, and also to the nature of the deep biosphere, remain unresolved and could be addressed by drilling. The proposed program aims to tackle these questions through an Amphibious Drilling Proposal to allow a full understanding of an obducted deep geological system from a terrestrial setting to its marine extension as close (and therefore undisturbed) as possible from its unobducted mantle lithosphere source.

The New Caledonian Ophiolite is one of the largest obducted peridotitic masses in the world: it makes up a quarter of the 500 x 80 km island of Grande Terre and stretches off-shore south to the Norfolk Basin (Figure 8). This massive mantle nappe was tectonically emplaced during the Eocene onto the northeastern edge of the Zealandia continent. It is weakly deformed and structurally not imbricated/embedded within an orogenic belt (Figure 7). An Eocene High Pressure/Low Temperature (HP/LT) eclogitic metamorphic core complex is found to its northeast and Miocene to Quaternary reefs are observed around Grande Terre and surrounding islands.

South of New Caledonia, the offshore continuation of the allochthon has been identified in ca. 2000 m water depths as a linear body that is continuous for more than 400 km (Figure 8). These water depths allow effective 2D seismic imaging that reveals the present day structure and associated pre-, syn- and post-obduction sedimentary records. Seismic profiles (e.g., Figure 9) show that the nappe is flat-topped, capped by carbonate reefs, bounded by major normal faults, and lies within a 150 km wavelength depression. East of the peridotite nappe, Felicité Ridge is a 30 km wide, 350 km long, dome-shaped ridge, interpreted as being the southern extension of the LT/HP metamorphic core complex observed onshore. West of the nappe is the Norfolk Ridge along which compressional deformation is observed, and sedimentary nappes structurally underlie the peridotite nappe.

Extensive 2D seismic reflection data and geological dredging are available from the offshore part of the ophiolite and numerous onshore data are also available (exploration boreholes, electric tomography profiles, seismic reflection profiles). Four 150 to 200 m long cores were drilled onshore in the ophiolite and air-borne electromagnetic profiles imaging down to 500 m have been acquired. A permanent seismic network comprising eight broadband seismometers has been operational since 2010.

Drilling onshore and offshore along the New Caledonia ophiolite would address several outstanding science questions in relation to major challenges defined in the 2013-2023 IODP Science Plan, in particular, in themes Earth Connection, Earth in Motion, and Biosphere Frontiers:

Earth Connections: The emplacement mechanisms of mantle-dominated allochthons are still debated. These mechanisms could be addressed by deep drilling of the ultramafic sequence, its metamorphic sole, and underlying basement (IODP Challenge 8 & 11).

The Eocene contractional phase which led to obduction of the ophiolite is synchronous with the regional Tectonic Event of the Cenozoic in the Tasman Area (TECTA) interpreted to be related to subduction initiation of the Tonga-Kermadec subduction zone, which is the primary focus of upcoming expedition IODP 371. What are the relationships between these tectonic processes and are they linked into the regional dynamic tectonic framework? (IODP Challenge 11). The available geochemistry indicates that regionally the peridotites of New Caledonia have a highly-depleted chemistry. What causes this depletion? Is it related to subduction initiation or Gondwana breakup? (IODP Challenge 8)

Earth in Motion and Biosphere Frontiers: Several HT and LT alteration processes are observed onshore throughout the massifs and are associated with serpentinization, fracturing, flow, and transport in fractured ophiolitic basement acquifers namely in peridotites. They involve carbon trapping, methane and hydrogen-rich fluid production, volatile and metal fluxes (IODP Challenges 11, 13, 14), and abiotic vs biotic processes. Archaeal and eubacterial communities are known to develop in these alkaline systems, which could have several similarities with hydrothermal environments at the beginning of life on Earth (IODP Challenge 5, 6, 7).

Climate and Ocean Change: Miocene to Quaternary carbonate reefs, which overlie the allochthon, are part of the world's second largest rimmed platform. What is the age of their formation and their relation to the Great Barrier Reef and other Pacific reefs? Was their initiation associated with climate changes or the result of interaction between ultramafic alteration-derived fluids and carbonate reef developments? (IODP Challenges 1, 2)

Finally, significant discrepancies exist between geological records and phylogenetic analysis of evolution and biogeography. Indeed, endemism of New Caledonia and New Zealand biota is thought to be inherited from Gondwana which implies the existence of land throughout the Cenozoic, whereas current studies of geological records indicate deep sea environments were prevalent during the Paleocene and Eocene. Thus, identifying possible land gateways and paleogeography would help resolve this major issue.

Developing an Amphibious Drilling Proposal will require engagement of the scientific communities associated with the International Ocean Discovery Program (IODP) and the International Continental Scientific Drilling Program (ICDP), as well as colleagues from the mining related industries and with policy makers. A workshop will be organized in New Caledonia to raise the profile of research on ophiolitic basements along Zealandia's eastern frontiers and their economic impact. The role of scientific research, and particularly drilling, in research and development will be explored. The workshop goal will be to define the main science questions to be addressed by drilling the New Caledonia ophiolite on-shore and/or off-shore, and to propose coordinated drilling strategies.

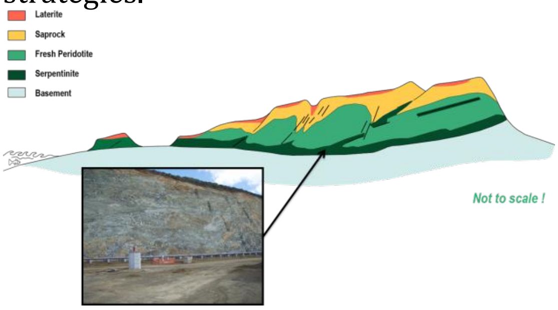


Figure 7: Schematic structural cross-section of a peridotite klippe onshore New Caledonia (unpublished data, Iseppi, Sevin et al., 2017)

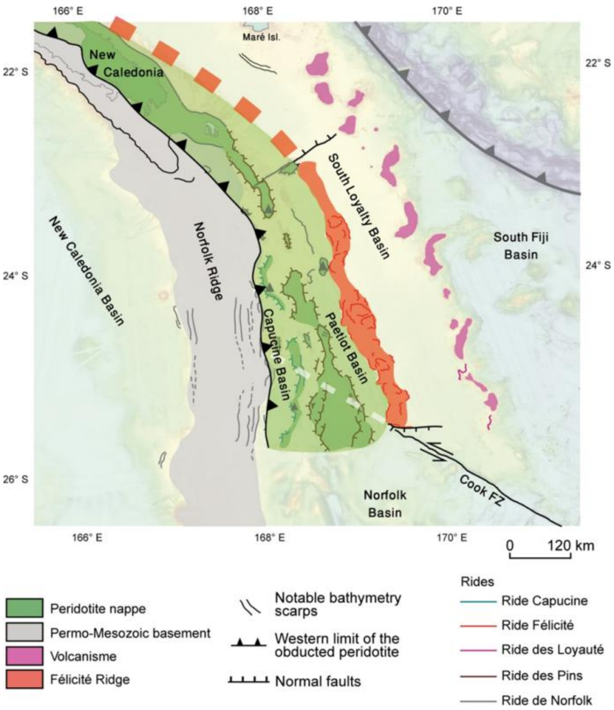


Figure 8: Map of the southern offshore extent of the New Caledonian Peridotite Nappe (Patriat, Collot et al., submitted 2017)

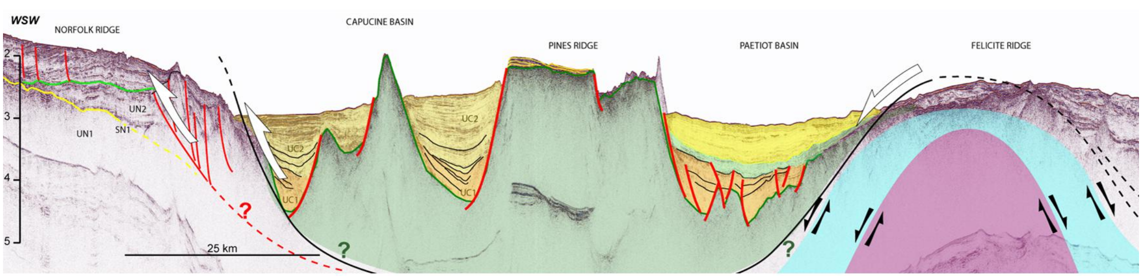


Figure 9: Seismic cross-section of the offshore part of the New Caledonian ophiolite (unpublished data from the VESPA voyage onboard RV L'Atalante, Patriat, Collot et al., 2015)

2.3 Testing Geodynamic models for subduction initiation, mega-thrust development, and deep biosphere development through ocean drilling at the Puysegur Trench, south of New Zealand

Science Lead: M. Gurnis
Data Lead: S. Gulick
Other possible proponents/interested parties: J. Stock, H. Van Avendonk, R. Sutherland, V. Toy, L. Strachan, M. Rowe, B. Dugan, K. Martin, Y. Morono, S. Gallagher, M. Kendrick, R. McKay, Y. Yamada, M. Godard, H. Bostok.

Subduction initiation is a vital phase of the plate tectonic cycle. New subduction zones must form as long-lived and well-developed ones disappear through closing of ocean basins, fundamentally altering the global force balance on tectonic plates. Subduction fluxes water into the overlying mantle wedge, lowering the melting point of the solid mantle while greatly increasing mantle melting ultimately leading to arc volcanism. Newly subducted oceanic crust is subjected to high-pressure metamorphism while releasing water, further altering the driving and resisting forces of plate tectonics. Thus, two of the great unknowns in solid earth sciences – subduction initiation and the deep water cycle – may be intimately linked in ways that we do not yet fully understand. Although studies have examined the initiation of subduction, the dynamics and geochemistry of this process remain obscure. There remain substantial disagreement and uncertainty about the significance of diverse processes operating at subduction zones, the material properties of tectonic plates, and even whether it is possible to initiate a totally new subduction zone in isolation from an existing one. Theoretical studies, and interpretation of the Mesozoic and later plate tectonic history of the Pacific, suggest that subduction initiation alters the force balance on plates. To make fundamental advances in understanding the forces driving and resisting plate motions, a detailed picture of the early evolution of a subduction zone is required.

The key evidence to answer these questions can be found through study of a subduction zone that is intermediate in its evolution, that is, one that has *partially proceeded* through the nucleation stage. This would allow accurate plate motions along with detailed knowledge of antecedent tectonics and subsequent history to constrain the geodynamic process. The Puysegur incipient subduction zone south of New Zealand (Figure 10A) is an ideal location to constrain the key geodynamic unknowns. Precise plate tectonic constraints along with a high level of seismicity reveal the transition from south to north of strike-slip motion along the Macquarie Ridge to the south, to a clear Benioff zone and active subduction beneath Fiordland, southwestern South Island, in the north (Figure 10A). It is likely that the Puysegur subduction zone is currently in the process of making a transition from a forced to a self-sustaining state.

IODP drilling around Puysegur will allow testing and refinement of three topics fundamental to the IODP Science Plan 2013-2023: (1) the forces associated with subduction initiation (Challenge 11); (2) the origin of subseafloor communities in the deep biosphere (Challenge 5); and (3) the development of fault properties in a mega-thrust environment (Challenge 12). For questions associated with the initiation of subduction, drilling would constrain the timing associated with vertical motions along the Puysegur Ridge, in-plane changes in stress indicated by a basin inversion within the Solander Basin, and the composition of the basement rocks composing the Puysegur Ridge. All of these will provide key observations to further geodynamic models. Drilling at the base of the inner trench wall in order to sample the plate interface would allow constraints to be placed on the nature of the plate interface and the state-of-stress. This is a unique data set as the trench is primarily sediment free with a simple variation in total convergence from essentially zero in the south to about 150 km in the North.

At Puysegur, we have the development of an entirely new fault interface that could provide key constraints on how fault and megathrust rock properties change with increasing cumulative fault slip. Such data sets could provide a globally unique data set bounding different small-scale processes associated with plastic failure and rock damage. *In situ* bounds could be placed on the orientation and magnitude of stress along the fault and overlaying basement. Important compositional variations could be discovered, including the placement of peridotite (and its alteration into serpentine) compared to basalt and gabbros and other igneous rocks. Since observations on fault properties could be made at two (or more) "times" in the development of the plate interface (using total plate convergence as a proxy for time) the rates of all of these processes (such as, rates of gouge formation, grain size reduction, serpentinization) could be discovered. All told, such observations are critical observations bounding the role that mechanically weak structures play in the initiation and evolution of a nucleating megathrust and subduction zone.

Subduction provides a means by which ocean floor and sub-sea floor communities are transported to depth. The juvenile nature of the plate interface and the simple variation in cumulative displacement from south to north could place important bounds on the time-dependence of this process. One could envision a drilling plan in which the fault zone is sampled from the same holes used for rock physics and the state of stress. However, the ocean floor at shallow depth would need to be sampled on the downgoing (Australian) plate adjacent to the plate interface to constrain the subsea communities before being transported to depth in the fault zone.

Key site surveys are needed to effectively target a campaign of drilling. Most of the site survey data at Puysegur will be acquired by the *R/V Marcus Langseth* February to March 2018 through the South Island Subduction Initiation Experiment (SISIE). The centerpiece of the survey (Figure 10) comprises two wide-angle refraction lines running perpendicular to the strike of the trench, one across the Snares zone and the other in an even more juvenile setting further south. The *Langseth* will deploy and recover 23 OBSs along the northern line and 20 OBSs along the southern line. The OBS lines will constrain the crustal thickness, the nature of the plate interface, including its dip, and the seismic wave speeds in the crust and upper mantle across the plate boundary. Roughly 1730 km of MCS lines will constrain the upper basement, image upper plate faulting, and map the stratigraphy of the Solander Basin. The MCS and refraction lines will provide the firm basis for ocean drilling in the region.

During the initiation of subduction, the plate boundary may have evolved from the merging of earlier fracture zones and spreading centers. Consequently, segments of the nucleating margin have some peridotite or altered peridotite (serpentine). The occurrence of such serpentine, which is generally much weaker than basalt and gabbro, could play a fundamental role in the dynamics of subduction initiation.

Numerous associated paleoceanographic objectives may be addressed by drilling in this region. Previous cores suggest that the overlying sediment cover is Pleistocene in age, but sediment >500 m thick in the Solander Trough extends down to a unconformity, below which more chaotic sediment reflectors are thought to be deposited during the Eocene-Miocene rifting. Most of the terrigenous sediment in the trough is thought to be from the rapid uplift of the Southern Alps since the Miocene – thus potentially providing an associated record of glaciation/terrestrial paleoclimatic changes since the Miocene. Limited cores have been recovered from the deeper section of these deposits. DSDP Site 279 drilled through most of the Pleistocene without coring (upper ~100 m), and only cored a lower Miocene sequence. DSDP Site 278 is farther south in the Emerald Basin, and also did not core in the upper 100 m and thus lacks the late Pleistocene record that is present in the uppermost strata at this site. A complete sedimentary record from the Miocene to present would provide not only a record of terrestrial runoff from New Zealand as the convergent plate boundary evolved, but also a record of pelagic sedimentation in this location documenting sea surface conditions and paleoproductivity within the Antarctic Circumpolar Current (ACC). Paleocurrent proxies in this location could provide a record of changing intensity of this current through the Late Neogene and Quaternary. Paleooceanographic objectives at these site would link strongly into the records of ice volume and sea ice change from the Antarctic margin directly south of the region (e.g., IODP Expedition 318 and 374), as well as "upstream" records of the eastward flowing ACC - including the proposed Conrad Rise proposal discussed at this workshop (IODP 918-Pre) and ODP Leg 177.

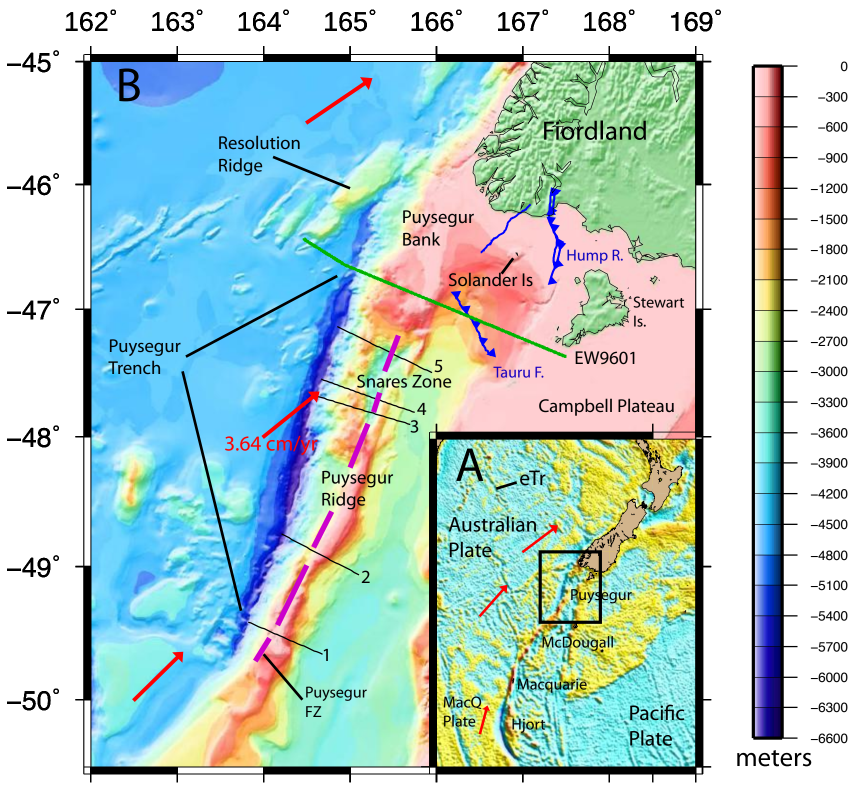


Figure 10: A. Puysegur study region (black rectangle). Four sectors of Macquarie Ridge Complex, each defined by a different margin trend & morphology are shown. Extinct Tasman Ridge = eTR. Base map is free-air gravity. MacQ = Macquarie Plate. B. Bathymetry of Puysegur Ridge and Trench region. The sector denoted Puysegur Trench has experienced active subduction. The Puysegur Fault Zone is shown as a dashed mauve line; not indicated is the splaying of the PFZ into multiple faults in the Snares Zone. Previously acquired MCS line EW9601 and lower quality lines 1-5 . In A and B, red arrows are the modern relative plate motion of AUS (or MacQ) with respect to PAC.

2.4 Stress state in the upper oceanic crust in a region of great intraplate earthquakes

Science Lead: Lisa McNeill,
Data Lead: Brandon Dugan

The world's largest known intraplate earthquakes have occurred in the subducting Indian Plate offshore Sumatra, and have raised many questions about the genesis of such events. Expedition 362 had two sites (Figure 11) approved for drilling (SUMA-22A and SUMA-23A) located to the north and south of the epicenter of one of these major intraplate earthquakes (within 10-20 km of the earthquake). Although approved for drilling, these sites were never drilled due to time constraints exacerbated by some equipment problems on the *JOIDES Resolution* that required Expedition 362 to return to port in Singapore in the middle of the expedition. However, these already approved sites offer a unique opportunity to investigate the stress state in the region of these great intraplate earthquakes, and also to further extend understanding of the sedimentary sequence entering the Sumatra subduction zone further north (building on the goals of Exp. 362). The proponents of Expedition 362 (L. McNeill, B. Dugan, and others) plan to submit either an APL or a full proposal (depending on the scope) to follow up on the Expedition 362 objectives and extend these to investigate the state of stress state in upper oceanic crust near these highly seismogenic transform faults. These sites are mature (they have already been approved by EPSP), and advancing this effort would require development and submission of the proposal.

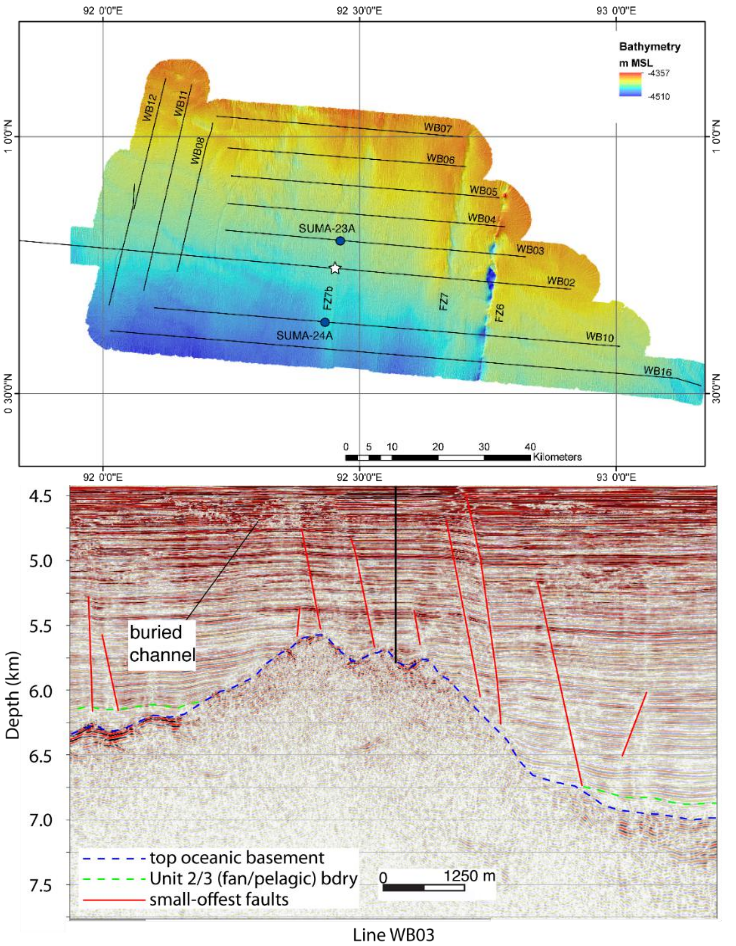


Figure 11: Top: Map of sites approved for Expedition 362 that could be used to address the state of stress in the upper oceanic crust in a region of great intraplate earthquakes. Bottom: Seismic line showing one of these proposed sites sites. Figures from Exp. 362 Scientific Prospectus. Data provided by S. Singh.

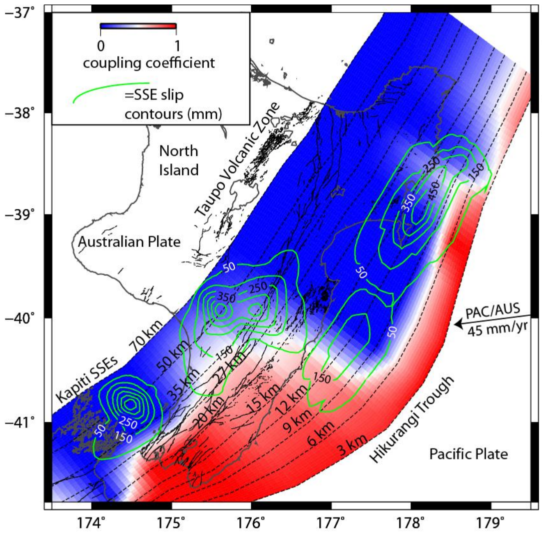
Section 3. New Zealand region: Hikurangi Subduction and Plateau, Canterbury fresh water, and related paleoenvironmental targets eruptive processes on Kermadec Ridge

3.1 Hikurangi subduction inputs proposal

Scientific Lead: *Ake Fagereng (Univ. Cardiff),*
Other interested proponents include Philip Barnes (NIWA), Mike Underwood (New Mexico Tech), Shuichi Kodaira (JAMSTEC), Laura Wallace (GNS Science), Mike Coffin (Univ. Tasmania), Clive Neal (Notre Dame), and Christian Timm (GNS Science).

A major outstanding question relevant to the Earth in Motion theme involves resolving the controls on subduction megathrust slip behavior. The Hikurangi margin of New Zealand is arguably one of the best locales on the planet to address this question due to the strong along-strike variations in subduction interface slip behavior (locked vs. creeping) observed there (Figure 12, left). The nature of the material coming into the subduction zone on the subducting Pacific Plate likely exerts a strong control on these along-strike variations in slip behavior (Figure 12, right). This proposal will acquire cores and logs sampling the incoming sedimentary section and underlying Hikurangi Plateau at several locales along the Hikurangi Plateau (from north to south). These will resolve along-strike variations in the sedimentary section and underlying Hikurangi Plateau, and how these variations in lithology and fluid content may influence locked versus creeping behavior at subduction megathrusts. We will target portions of the plateau where the sedimentary cover is thinner (less than several hundred meters), well east of the deformation front, to avoid the thick trench fill sections near the Hikurangi Trough (e.g., Figure 12, right). We will also target sites where expanded sections of the portions of incoming stratigraphy correlate with where the plate boundary decollement is forming.

This proposal also dovetails well with the scientific aims of groups investigating the genesis of Large Igneous Provinces (LIP), as we will be targeting the Hikurangi Plateau itself, which is a Cretaceous LIP. Samples of the Hikurangi Plateau will yield insights into LIP emplacement rates, reveal the plume composition, and help to constrain geodynamic models and environmental impacts of LIP emplacement. It will also enable testing of the hypothesis that Ontong Java, Manihiki, and Hikurangi were once part of a single giant LIP. We envision that the proponent group will combine researchers interested in megathrust processes and processes behind LIP emplacement. Upcoming drilling on Expeditions 372 and 375 will provide critical information to underpin the development of such a proposal, as will multichannel seismic reflection and refraction lines to be acquired in November/December 2017. We suggest that the proponent group aim to develop a pre-proposal by October 2018, once all of these information are available.



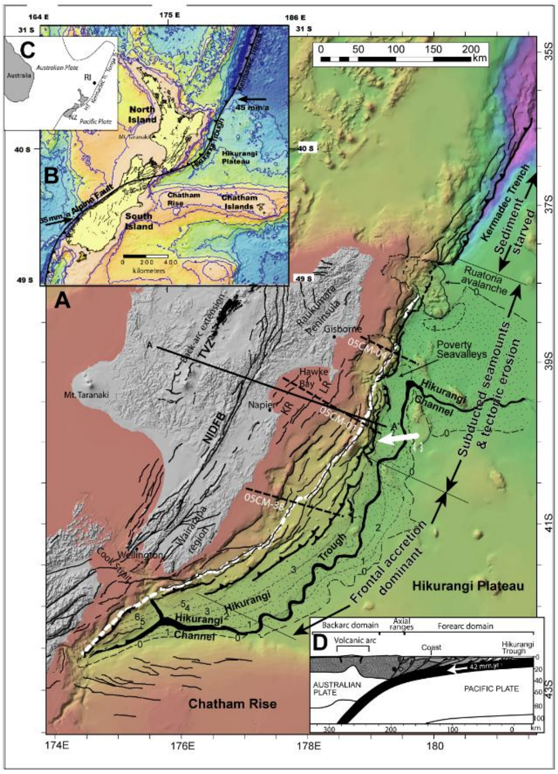


Figure 12: Above: Interseismic coupling and slow slip event distribution from Wallace et al. (2012). Right: Tectonic and physiographic setting of the Hikurangi margin, including dashed contours (in km) for thickness of trench fill turbidites on the subducting plate (after Barnes et al., 2009).

3.2 Episodic Hikurangi fluid flow driven by slow slip and its impact on gas hydrate systems

<u>Science Lead:</u> Ingo Pecher (Univ. of Auckland).
<u>Data Lead:</u> Gareth Crutchley (GNS Science)

Some interesting and unique characteristics of Bottom Simulating Reflectors (BSRs) observed at the Hikurangi subduction margin and their relationship to heat flow changes suggest that Hikurangi gas hydrate systems may be strongly influenced by episodic fluid flow processes. Episodic fluid flow at the Hikurangi margin may be driven by large strain transients that occur during episodic slow slip events observed to occur at the offshore Hikurangi subduction zone. This proposal would seek to install sub-seafloor observatories (most likely simple observatories, such as SCIMPI, or genius or smart plugs) to monitor pore pressure and temperature changes throughout the slow slip cycle. If Genius plugs were used, we could use osmotic samplers to undertake time series sampling of fluids to evaluate changes in geochemistry with time. These observatories would enable evaluation of the impact of fluid pulsing on gas hydrate systems, and also quantify the degree of overpressure that builds up beneath hydrate systems during and between fluid pulsing potentially driven by slow slip events. The latter could also play a role in submarine slope stability processes. Installation of a denser network of simple observatories would also enable more detailed spatiotemporal investigation of the distribution of offshore slow slip events, allowing many questions about shallow slow slip distribution and its impact on hydrogeology in the upper plate to be addressed. A couple of candidate locations for such a proposal were discussed, including (1) the

Porangahau ridge area of the central Hikurangi margin, or (2) an area approximately 20 km north of the Expedition 372/375 drilling transect. Similar to the Hikurangi inputs proposal, development of such a proposal should build on information acquired during Expeditions 372 and 375. Development of this proposal would also require acquisition of additional heatflow data and additional modeling of the possible impact of episodic fluid flow on gas hydrate systems.

In terms of other Earth in Motion targets in the Indian Ocean region, there was also interest from the group in subduction systems offshore Java and Andaman, although these would need substantial data collection efforts and better characterization of these systems before drilling proposals would be tractable in those areas.

3.3 Offshore Freshwater Resources (Canterbury Basin)

Science Lead: Aaron Micallief
Data Lead: Joshu Mountjoy or Brandon Dugan

Drilling at Site U1353 during Canterbury Basin Expedition 317 drilling showed a freshening signature at ~50 m depth, while nearby Site U1354 showed near-seawater salinity (Figure 13). This transition from a freshwater charged zone to a non-freshwater zone would make an interesting and well-characterized target to investigate dynamics of and interactions between freshwater and seawater sub-seafloor hydrological systems. Abundant site survey data exist in this area, stemming from the Expedition 317 efforts, as well as a more recent voyage to acquire seismic and controlled source electromagnetic data to investigate the freshwater system beneath the offshore Canterbury Basin. A drilling proposal would also include well as some active pumping tests and potentially an observatory component to look at transients in these systems. Such an effort could also be of great interest to the biological community as the communities of freshwater and saline systems will be very different, and evaluating the communities in the transition between these systems could provide insights on microbiology and nutrient availability. All required site survey data exist for this effort, and development of a workshop next year and a proposal by 1 October 2018 is planned.

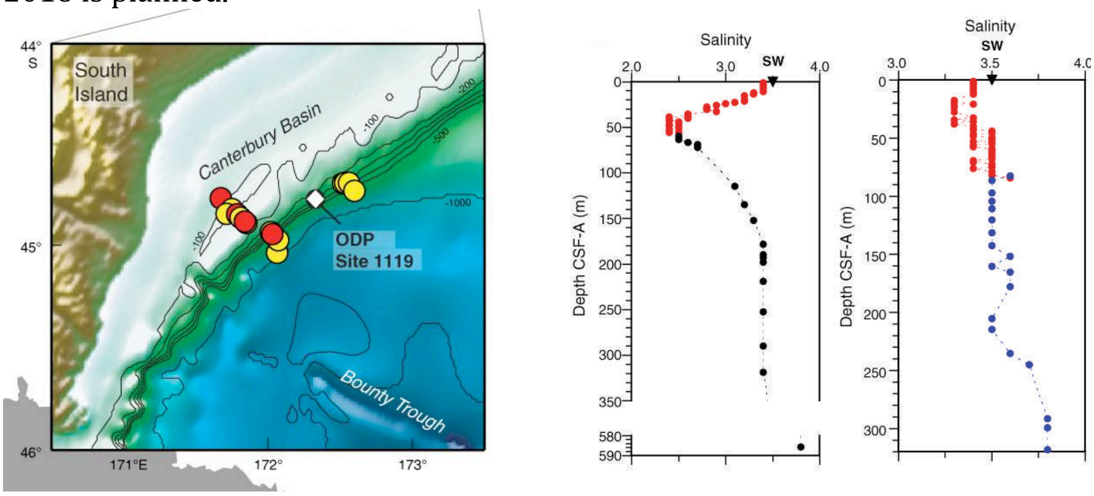


Figure 13: Location of Expedition 317 drilling (left). Salinity profile at Site U1353 (center). Salinity profile at Site U1354 (right)

3.4 Eruptive processes and transport in submarine volcanic environments

Science/Data Lead: Martin Jutzeler.

Submarine volcanic eruptive processes and transport and deposition of the eruptive products is a poorly understand problem to which IODP drilling can contribute greatly. A related issue is the transport and depositional processes of pyroclastic flows as they transition from onshore to offshore environments. In some historical cases (such as the Krakatoa eruption), large tsunami have resulted from this, so understanding the underlying mechanisms of pyroclastic flow into the sea has important geohazards implications. Recent drilling in the IBM uncovered 20-100 m thick units, but drilling on the flanks of submarine volcanoes is what is really needed to investigate this. The Kermadec arc is a highly attractive location for such an effort, because (a) several submarine volcanoes have always been submarine and also have produced eruptions with significant volume, and (b) Macauley Island would be an excellent locale to investigate pyroclastic transport and depositional processes into the sea (arcuate sediment waves are observed there on the order of 100 m high and 1 km wavelength; Figure 14). Key questions include: (1) what are the physics and processes behind submarine volcanic eruptions and subsequent deposition of products, (2) are the eruptive products emplaced all at once, or do they occur in multiple episodes? Overall, the group felt that addressing submarine volcanic processes with IODP drilling is an interesting idea. However, an international workshop would help greatly to flesh out the key hypotheses to address, identify community priorities, and to zero in on the best locations to address the questions. Once the focus areas are decided on, additional site survey data will be needed to mature a proposal.

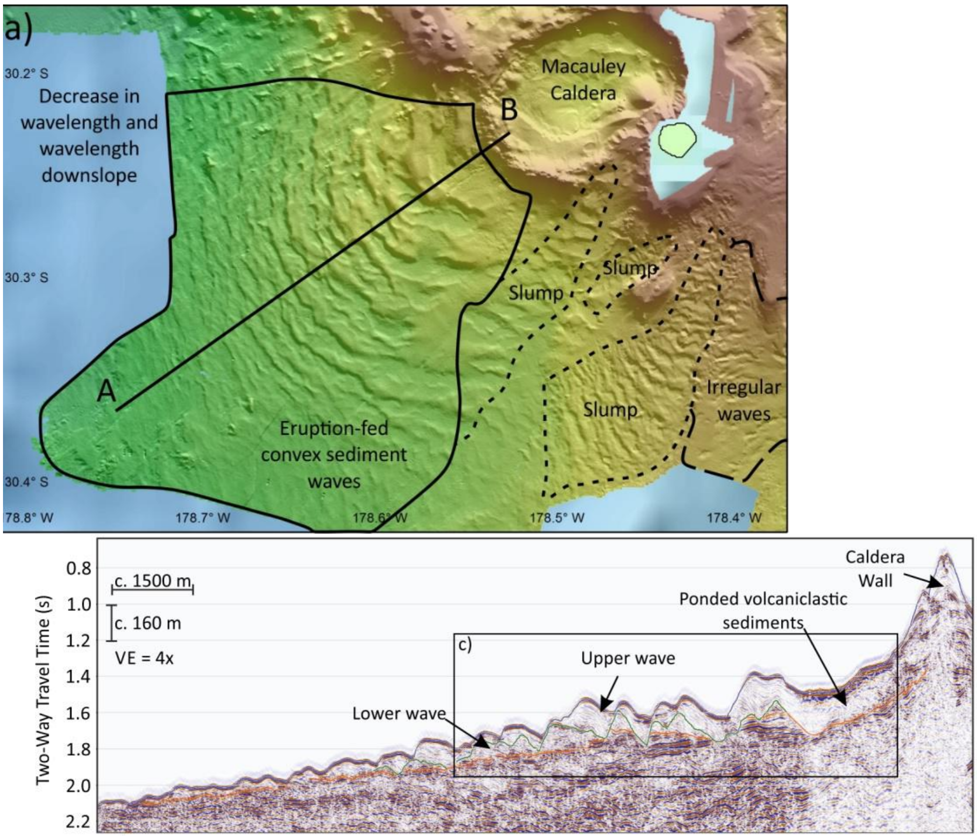


Figure 14: Bathymetric map surrounding Macauley Caldera showing eruption-fed sediment waves (top). Seismic image along line A-B (bottom). From Pope, Jutzeler, et al., in prep.

Section 4. Conjugate Margins and Climate

4.1 Accumulation and release of Carbon Dioxide from geologic sources in the South Pacific contributed to glacial/interglacial pCO_2 variability and caused the formation of seafloor pockmarks on the Chatham Rise, New Zealand

Science Lead: Lowell Stott.
Data Lead: Ingo Pecher
Other proponents/interested parties: Richard Coffin, Bryan Davy, Helen Neil, Joerg Bialas, Jess Hillman, Fumio Inagaki, Molly Patterson, Chris Turney, Linda Armbrecht, Agathe Lise-Provonost, Christina Riesselman, Verena Heuer, Yuki Morono, Mike Coffin.

One of the grand challenges in ocean and climate science is to learn what mechanisms operating within the Earth System regulated the concentration of atmospheric CO_2 systematically between 280 ppm and ~180 ppm during each glacial cycle of the late Pleistocene. After more than three decades of effort there is no scientific consensus on what those mechanisms are. One hypothesis calls for sequestration of marine metabolic carbon into an 'isolated abyssal water mass' during glaciations and then ventilation of that accumulated carbon during deglaciations. To date, there is no compelling evidence to support the existence of an isolated water mass during the last glacial cycle. New observations, however, highlight geologic processes that can regulate the flux of geologic carbon to the ocean and in doing so, affect the concentration of atmospheric pCO_2 on glacial/interglacial timescales. Our proposal seeks to investigate and test whether geologic reservoirs released large volumes of CO_2 to the ocean during each glacial termination in the late Pleistocene.

Recent discoveries have identified accumulations of both liquid and hydrate (~solid) CO_2 in the oceans at a variety of tectonic settings. Liquid and hydrate phases of CO_2 are stable and accumulate in the ocean below ~400m water depth and at temperatures below ~9°C. Where this CO_2 accumulates in the ocean it can undergo phase changes as temperature and pressure changes. Temperature and pressure changes that accompanied glacial/interglacial cycles would have affected the stability and, hence, the flux of this carbon to the ocean. This led Stott and Timmermann (2011) to hypothesize that the accumulation of geologic carbon in the form of CO_2 and the release of this carbon would have contributed to glacial/interglacial pCO_2 variations. In this sense, these geologic carbon reservoirs act as 'capacitors' that accumulate carbon during glaciations and then leak carbon to the ocean and atmosphere during glacial terminations.

The evidence that supports a release of geologic CO_2 to the oceans during the last glacial cycle has come from radiocarbon measurements of marine benthic foraminifera that document large negative excursions near the end of the last glacial cycle and during the glacial termination (Figure 15). The magnitude and duration of these ^{14}C excursions cannot be explained without calling upon a large flux of ^{14}C-dead carbon to the ocean. And, to date, the largest excursions have been documented in the South Pacific on Chatham Rise and on the East Pacific Rise. These ^{14}C excursions coincided with the formation of large pockmarks on the southern margin of the Chatham Rise (Davy et al., 2010). The pockmarks extend over an area of >20,000 km^2. We argue that the close temporal relationship between the late glacial ^{14}C excursions and the formation of pockmarks points to a causal relationship whereby gas released from geologic reservoirs on Chatham Rise during glacial-interglacial transitions produced the pockmarks (Davy et al., 2010). We propose to investigate and test this hypothesis. A verification that geologic carbon was released during each glacial cycle from Chatham Rise would constitute a transformative discovery that would potentially solve one of the grand scientific challenges in climate science, the regulatory mechanism responsible for the systematic variations in atmospheric pCO_2.

This proposal builds upon our previous research that has sought to find the causal mechanism for the large pockmarks on Chatham Rise. When we began this investigation, we anticipated finding evidence for deep-seated methane that may have destabilized and produced these anomalous features on the seafloor. We carried out expeditions on the Hikurangi Margin and Chatham Rise that incorporated seismic, heat flow, controlled-source electromagnetic, and piston coring geochemistry data to assess spatial variation in gas hydrate within each region. Our geochemical and isotope data from a suite of cores across the margin cores found low methane fluxes. We did find anomalously old radiocarbon ages for the sediments, consistent with the documented excursions shown in Figure 15.

Importantly, associates at Anadarko have observed Dawsonite in sediments that would be associated with the formation of pockmarks. This mineral requires an active CO_2 flux rather than methane. These observations now point to a linkage between geologic CO_2 release from hydrate or sub-seafloor CO_2-rich fluids and the formation of large pockmarks on the Chatham Rise. The CO_2 responsible for the geochemical anomalies and the pockmarks may be sourced from a limestone sequence on the Hikurangi Plateau, which was subducted beneath the study area. Alternative mechanisms that have been set forth to explain the formation of pockmarks, including involvement of deep-water currents, cannot account for the geochemical signatures we find, and thus we see a strategic and urgent need to use the IODP capabilities to test the hypothesis that recurrent flux of geologic carbon to the seafloor from geologic reservoirs was responsible for the development of pockmarks that accompanied each glacial cycle during the late Pleistocene (Davy et al., 2010). Evaluating how this source of carbon affected the flux of carbon to the ocean and atmosphere on glacial/interglacial timescales constitutes a critically important contribution to the Earth sciences.

We seek to propose to the IODP a series of coring sites on the Chatham Rise that can provide sediment records spanning each of the glacial cycles of the late Pleistocene and to calibrate 3D seismic data from the study area. A coring, logging and post-cruise analysis plan is presented to test our primary hypothesis and other alternative mechanisms that have been proposed to account for pockmark formation.

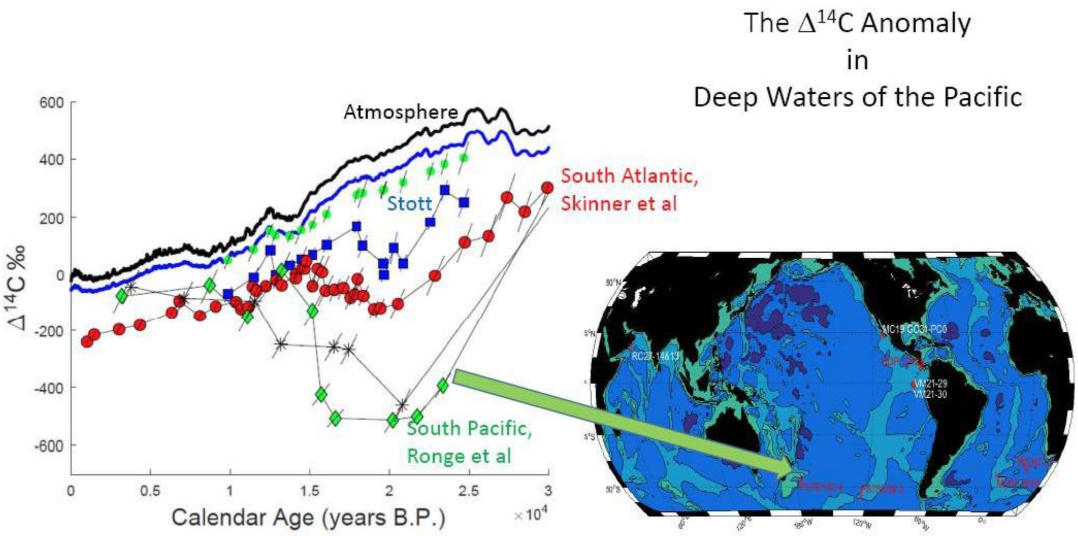


Figure 15: Radiocarbon(^{14}C) excursions in the South Pacific at the end of the last glacial cycle.

4.2 Southeast Chatham Rise margin: tectonics, dynamics and paleooceanography

Science/Data Lead: Karsten Gohl.

The southeastern continental margin of Chatham Rise is conjugate to the Amundsen Sea margin of West Antarctica. Deep crustal seismic data, gravity and magnetic data, and analysis of dredged samples from seamounts reveal a complex transition from continental to oceanic crust on both conjugate margin segments. In particular, the area of SE Chatham Terrace is underlain by a broad zone of thinned and fragmented transitional crust with presumed continental blocks separated by zones of presumed oceanic crust. The nature of this type of transitional crust and the processes of its generation during Cretaceous rifting and breakup is little understood. The SE Chatham Rise margin would be an ideal location for testing various hypotheses on crustal fragmentation during continental breakup by drilling into the different crustal zones. Such a drilling campaign can be perfectly combined with drilling into the well-imaged sediment drifts to address questions and hypotheses on development and changes in the SW Pacific ocean circulation (e.g., Deep Western Boundary Current DWBC and ACC).

Most site survey data exist from earlier surveys and from RV *Sonne* cruise SO246 in 2016 (Figure 16). The possibilities of an IODP proposal for a combined paleoceanographic and tectonic/geodynamic drilling campaign on the SE Chatham margin was discussed during a workshop at GNS Science (Lower Hutt, NZ) on 22-24 August 2017, which focused on the tectonic, geodynamic, magmatic and paleoclimate/paleoceanographic evolution of the Chatham Rise region.

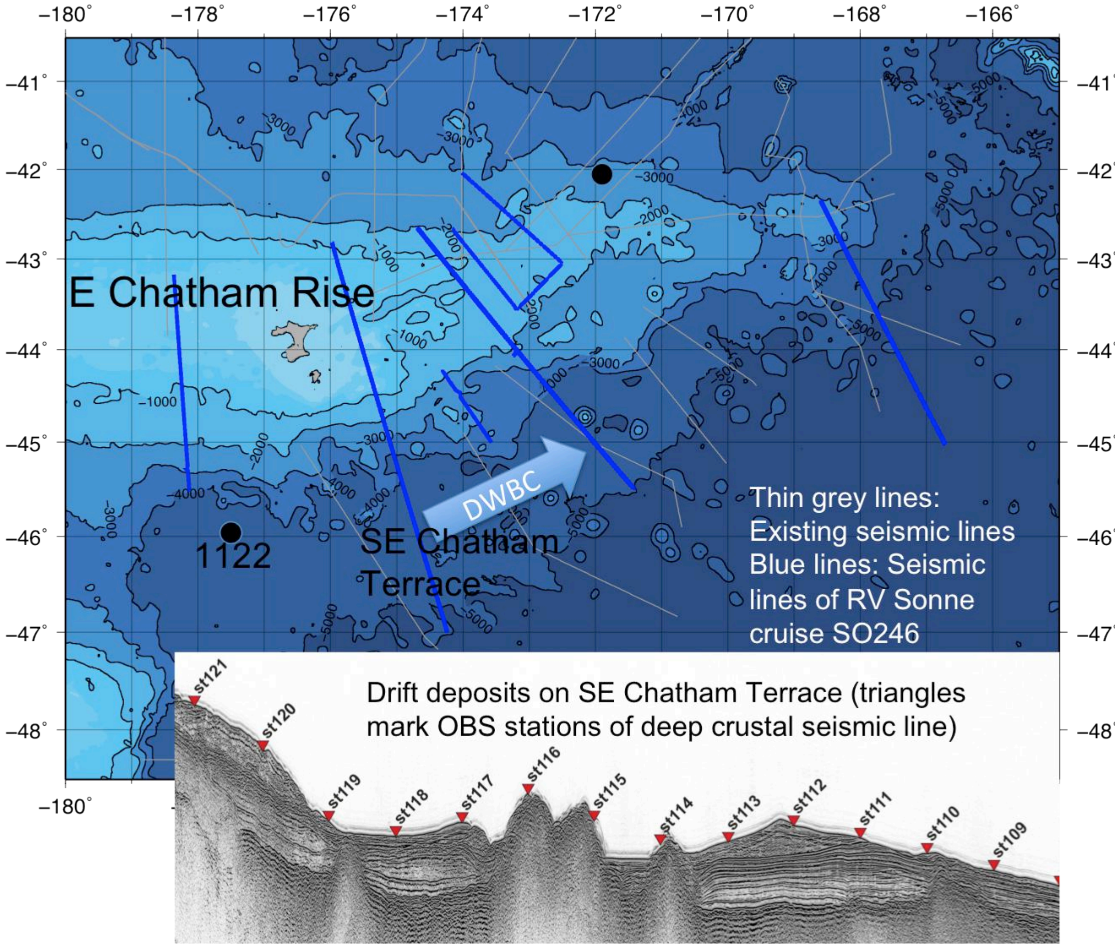


Figure 16: Location map of recent seismic surveys in the Chatham Rise region, and example cross section of drift deposits.

4.3 Totten Glacier Cenozoic ice sheet evolution

Science Lead: Amelia Shevenell
Data Lead: Sean Gulick
Other proponents/interested parties: Denise Kulhanek, Molly Patterson, Lara Perez, Taryn Noble, Chris Turney, Trevor Williams, Leanne Armand, Chris Fogwill, David de Vleeschouwer, Linda Armbrecht, Howie Scher, Tina Van de Flierdt, Rob Mckay

The vulnerability of the East Antarctic Ice Sheet (EAIS), which contains 19 meters of sea-level equivalent ice in its marine-based catchments, is uncertain (Fretwell et al., 2013). To improve predictions of future EAIS response to anthropogenic warming and contribution to global sea-level rise, knowledge of past EAIS behavior in climatically sensitive catchments is critical. While models illuminate climatically sensitive locations, ice-proximal marine geologic and geochemical records are required to assess the timing, rates, spatial heterogeneity, and mechanisms of past ice sheet behavior within these catchments.

The Aurora Subglacial Basin (ASB) drains ice from the Gamburtsev Mountains to the Sabrina Coast (~1/8 of the EAIS) via the fast-flowing Totten Glacier, which is influenced by warm ocean waters (Rintoul et al., 2016) and experiencing the largest mass loss in East Antarctica (Li et al., 2015). The ASB is a glacially sculpted low-lying catchment (~3.5-7 m sea level equivalent ice) with over-deepened topography susceptible to progressive glacial instability and contains an extensive subglacial hydrologic system (Young et al., 2011; Wright et al., 2012; Fretwell et al., 2013; Li et al., 2015; Aitken et al., 2016). Model simulations suggest significant ice mass loss from the ASB catchment with climate conditions expected under all IPCC Representative Concentration Pathways (Golledge et al., 2015; DeConto and Pollard, 2016).

Ice-proximal high-resolution seismic reflection profiles and marine sedimentary data from the Sabrina Coast continental shelf (Figure 17 and Figure 18) reveals a sedimentary record of glacial evolution in the ASB since the Paleocene (Gulick et al., in revision). Records indicate enhanced sedimentation to the Sabrina Coast in the latest Paleocene and tidewater glaciers at the coast in the early to middle Eocene, before the establishment of continental-scale Antarctic ice sheets. Initial ice advance across the shelf is indicated in the seismic data, but is currently undated. Above this surface, ten glacial erosion surfaces indicate that glaciers advanced and retreated across the shelf at least 11 times before the late Miocene. Five of these surfaces include tunnel valleys, which indicate the presence of substantial subglacial meltwater (Figure 18). A widespread regional unconformity of late Miocene age occurs across the shelf. Above the unconformity, late Miocene to recent glacial sediments of variable thickness are preserved. Inter-till reflectors suggest continued glacial variability in the catchment since the late Miocene, a time of global atmospheric and oceanic cooling. However, features indicative of substantial subglacial meltwater are absent (Figure 18).

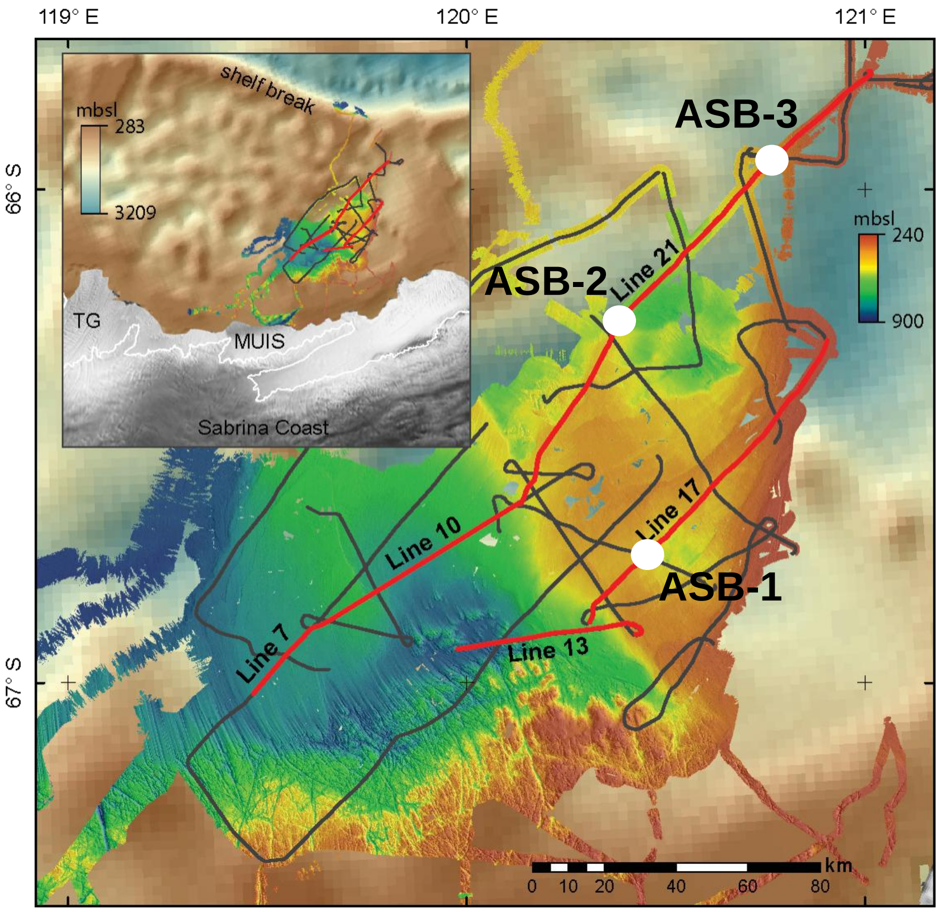


Figure 17: Study area (North up) showing NBP14-02 seismic and bathymetric data; seismic profiles (red) and proposed drilling targets (white). Inset: BEDMAP2 (Fretwell et al., 2013) bathymetry with Sabrina Coastline, Moscow University Ice Shelf (MUIS), Totten Glacier (TG) and shelf break indicated (Gulick et al., in revision).

Our new data highlight the potential of the Sabrina Coast for future IODP drilling to examine an ice proximal record of ice sheet evolution in a major EAIS catchment from the Paleocene to the Pleistocene. Unlike the deep-sea, continental shelf records are inherently discontinuous; this discontinuity is essential for understanding past ice sheet evolution. Drilling the Sabrina Coast Shelf will enable us to test fundamental hypotheses related to Cenozoic climate and East Antarctic Ice Sheet evolution, including:

1. PETM warming was driven, at least in part, by methane release from East Antarctic permafrost (e.g. Deconto et al., 2012);
2. Tidewater glaciers were present at the Sabrina Coast by the early to middle Eocene;
3. In this catchment, ice first expanded across the shelf in the middle to late Eocene, earlier than indicated by deep-sea $\delta^{18}O$ records;
4. The glacial system in the ASB was wet-based and sensitive to astronomically paced climate change from its inception to the late Miocene;
5. The regional unconformity and shift to a less meltwater rich system occurred in the late Miocene and not middle Miocene; and

6. In the ASB catchment, there was minimal retreat of the EAIS during Pliocene warmth.

Drilling the Sabrina Coast Shelf will be technologically challenging. We envision drilling either a series of longer (~400 m) holes using a DOSEC or ANDRILL-type rig deployed through the moonpool of an icebreaker (ASB-1, -2, -3; Figure 17) or shorter (~100 m) sequences using a seabed drilling system deployed from an icebreaker. Although the platform will ultimately dictate the drilling strategy, our drilling targets will be designed to recover pre-glacial strata, the sequence of Eocene to Miocene strata including ice proximal and ice distal sequences, and the timing of the not necessarily unidirectional transitions between non-glacial, pro-glacial, to glacial climates as recorded on the Sabrina Coast continental shelf (e.g., Figure 18). This drilling will complement Expedition 373 (George V Coast; Williams and Escutia) objectives as well as off-shelf objectives from the Sabrina Coast proposal discussed below.

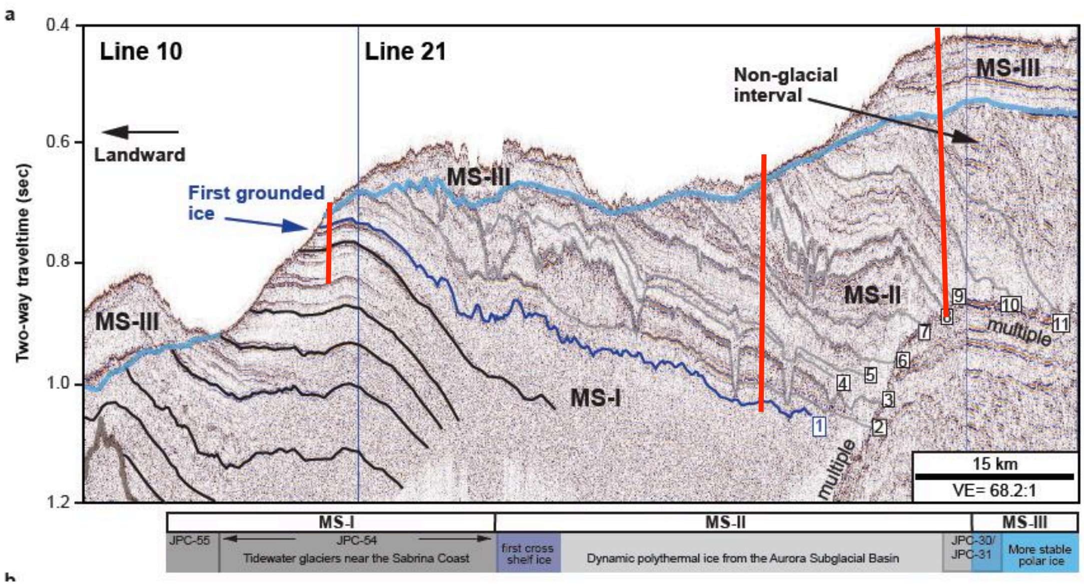


Figure 18: Composite Sabrina Coast seismic line with non-glacial to pro-glacial Megasequence I (MS- I) (black horizons), dark blue horizon first glacial (MS-I/MS-II contact), gray horizons as glacial advances within MS-II (including meltwater-rich conditions associated with horizons 3-5, 8, 9) overlain by a non-glacial interval, and light blue as an unconformity marking onset of less meltwater-rich conditions (MS-III) (Gulick et al., in revision). Red lines indicate locations of preliminary drilling targets ASB-1, -2, and -3 (inner to outer shelf).

4.4 Sabrina Coast Slope deposits: Miocene to Pleistocene ice sheet and ocean interactions

Science Lead: Brad Opdyke

Data lead. P. O'Brien

Other proponents/interested parties: L. Armand, T. Noble, A. Carbolotta, M. Ikehara, Y. Rosenthal, S. Bova, S. George, L. Perez, X. Crosta, P. Cortese, S. Sugisaki, F. Donda, L. De Santis, T. Naish, R. McKay, D.Kolcheck, C. Reisselman, L. Holder, W. Howard, T van de Flierdt, S. George, T. Williams, M. Patterson, S. Gulick, A. Shevenell, V.Heuer

This project aims to obtain high latitude paleoclimate records from the Miocene to Pleistocene of ice sheet and ocean interactions at the East Antarctic margin to understand the history of Totten Glacier mobility and melting. It will also seek to obtain pre-Miocene records in relation to Australian conjugate margin and correlation to Totten shelf records

Extensive seismic lines cross the area with more than 28 crossing lines for multiple potential drill site selection (Figure 19). Average sedimentation rates are 7-8 cm/kyr in the turbidite overbank deposits. Standard *JOIDES Resolution* riserless drilling is feasible on the slope. Experience from an RV *Investigator* voyage (January to March 2017) showed good weather and microclimate for coring in this area.

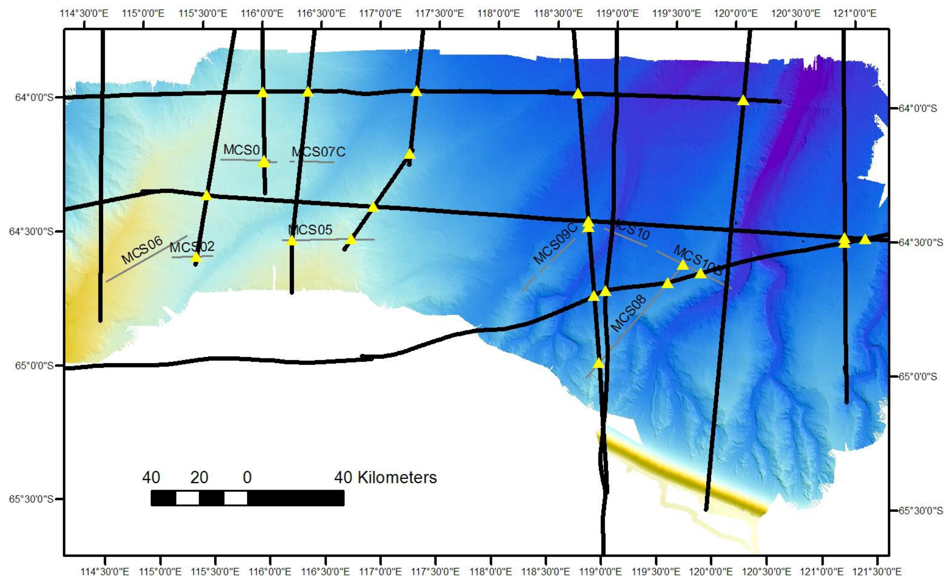


Figure 19: The seismic surveys, that were included for the Sabrina continental slope include the following; TH83, TH94 – Japanese National Oil Company/Geological Survey of Japan 1983, 1994, RAE50, RAE51 – Russian Antarctic Expeditions 2008, GA227, GA228, GA229 – Geoscience Australia 2001, 2002. MCS – Sabrina Sea Floor Survey Australia/Italy 2017. Surveys TH83, TH94, GA227, GA228, GA229, RAE50 and RAE51 are available to download from the SCAR Seismic Data Library System (sdls.ogs.trieste.it). The yellow triangles mark potential drilling targets.

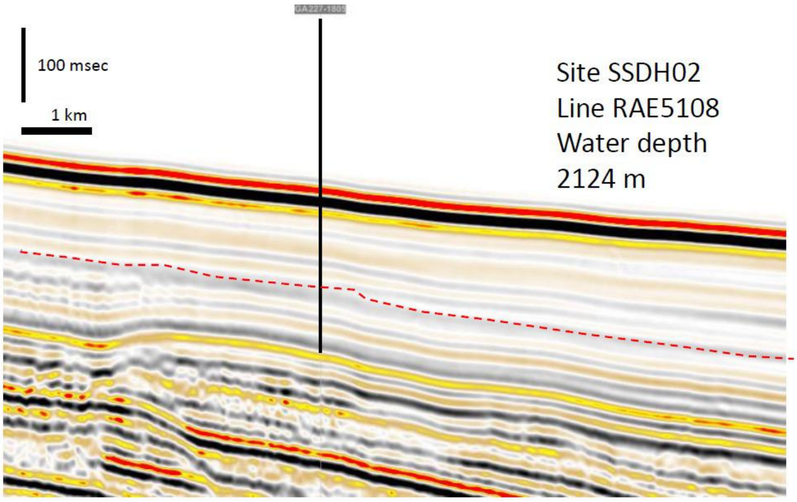


Figure 20: An example of a Sabrina slope seismic section on a crossing of lines RAE5108 and GA227-1805.

4.5 Southeast Indian Ocean deep circulation and sediment drift history, basement depth, and mantle chemistry anomalies

Science Lead: Dietmar Müller
Data lead. Taryn Noble, Oliver Nebel

Other proponents/interested parties: Rob McKay, Yair Rosenthal, Molly Patterson, Karsten Gohl, Lara Perez, Leanne Armand, Adriana Dutkiewicz, Chris Fogwill, Christina Riesselman, Agathe Lise-Provonost, Ivano Aiello, Amelia Shevenell, Tina van de Flierdt, Mark Kendrick, Will Howard, Mike Gurnis, Samuel Jaccard

Paleoceanography Objectives

Unlike its northern hemisphere counterpart, the interplay between ocean circulation, deep-sea sedimentation patterns, glaciation, and climate in the Southern Hemisphere remains decidedly understudied (Brackenridge et al., 2011). The Southern Ocean encircles a highly dynamic glaciated Antarctic margin and accommodates the amalgamation of several major water masses: Antarctic Bottom Water (AABW), North Atlantic Deep Water (NADW), Antarctic Intermediate Water (AAIW), and the Antarctic Circumpolar Current (ACC; Johnson, 2008), thus complicating reconstructions of paleoceanographic change at high Southern Hemisphere latitudes. Evidence from sub-bottom profiling data, seismic reflection data, and cores suggest that bottom water production and ACC flow fluctuates in intensity and orientation in response to climatic and tectonic drivers, both on glacial-interglacial (Prell et al., 1980; Pudsey & Howe, 1998) and longer geologic timescales alike (Maldonado et al., 2003; Uenzelmann-Neben, 2006). However, such evidence often appears to be prone to conflicting interpretations. This is particularly true for the Pliocene, a dynamic period marked by elevated global temperatures (i.e., the mid-Pliocene warm period) followed closely by Northern Hemisphere glaciation and the advancement of ice sheets in Antarctica (McKay et al., 2012). Some authors argue for enhanced regional circulation and bottom current activity into the Pliocene (Maldonado et al., 2003; McKay et al., 2012; Pérez et al., 2015). Others argue that the opposite took place (Joseph et al., 2002), or argue that bottom current intensity fluctuated minimally during this time (Hassold et al., 2009). Such quandaries are typically further elucidated or resolved by procuring thick sediment sequences from undersampled regions of the deep sea through ocean drilling expeditions.

As rapidly-deposited signatures of bottom current activity, contourite drifts are often deliberately targeted in paleoceanographic and paleoclimatic studies due to their ability to provide high-resolution records of paleoceanographic change (Faugères et al., 1984; Jansen et al., 1996). Several lines of evidence suggest that the Southeast Indian Ridge (SEIR) is covered extensively by a succession of drifts, possibly as old as 3-5 m.y. (Dutkiewicz et al., 2016). Firstly, several sedimentological markers support the presence of such features, where long-term sedimentation rates exceed 5.5 cm/kyr and focusing factors suggest extensive sediment winnowing by lateral advection of bottom currents (Dutkiewicz et al., 2016). Further, drilling results from DSDP Leg 28 Site 265 on the Southeast Indian Ridge indicate "extremely high" sedimentation rates in the Quaternary, and it is estimated that ~370 m of diatom ooze has accumulated at the site since the early Pliocene (Shipboard Scientific Party, 1975), which is quite sufficient for drift formation (Stow et al., 2002; Rebesco et al., 2014). This initial drilling report also states that "thick sediment patches" in excess of $1x10^5$ km^2 in area are speculated to coat the ridge, citing seismic evidence. Finally, recent ocean circulation numerical modelling (Dutkiewicz et al., 2016) also supports the accumulation of sediment drifts in this environment. This potential SEIR contourite drift succession represents a major potential extension of the much smaller contourite east of Kerguelen proposed by Dezileau et al., (2000), though they are likely to be more patchy than depicted on the long-term sedimentation rate map below, and areas with extremely thin or no sediments naturally lend themselves for petrological sampling.

These potential drifts are ideally situated as Pliocene/Quaternary paleoceanographic drilling targets for several reasons. For context, the SEIR is similar to more exhaustively investigated regions of the Southern Ocean (e.g. the Scotia Sea, Antarctic Peninsula, Weddell Sea, Kerguelen Plateau, etc.) in that 1) it has been subjected to anomalously high sedimentation rates during the Pliocene/Quaternary and 2) it is situated beneath the trajectories of several major Southern Ocean water masses (e.g. the ACC, AAIW, and AABW), lending itself to be a credible candidate for recording significant changes in ocean circulation. However, unlike any of the aformentioned regions, the SEIR lies far from any downslope terrigenous sources that could mask or otherwise contaminate any signals of bottom current intensity that manifest themselves within these sediment drifts. This is particularly critical in the Southern Ocean; areas that lie in close proximity to the Antarctic margin are heavily influenced by ice-rafted debris, which complicates grain-size analyses often used to reconstruct relative paleocurrent intensity (Rebesco et al., 1997; Masson et al., 2010; Mulder et al., 2013). Furthermore, the tectonic/subsidence history is well-constrained for the SEIR (Geli et al., 2007), thus removing the potentially confounding variable of fluctuating degrees of flow obstruction on drift accumulation rates (Livermore et al., 2000). Additionally, if confirmed, these drifts would comprise the first open-ocean biosiliceous (and perhaps the first entirely biogenic) contourite drifts ever described, as virtually all other reported drifts have experienced at least some degree of terrigenous input (Stow & Holbrook, 1984; Rebesco et al., 2014). Finally, within the larger framework of the field, targeting the Indian Ocean will provide invaluable insight into a currently lopsided perspective of the paleoceanographic and paleoclimatic history of the Southern Hemisphere, as most of our current knowledge predominantly stems from drilling sites in the South Atlantic. This rationale, in addition to the multiple branches of evidence that point to the existence of these sediment drifts, demonstrates that the SEIR is a remarkably low-risk, high-return prospective drilling target from a paleoceanographic perspective.

Tectonic/Geodynamic Objectives

It is straightforward to combine this goal with petrological sampling of the AAD and the eastern SEIR, aimed at testing alternative hypotheses about the origin of geochemical and depth anomalies along the SEIR (westward plume/asthenospheric flow along eastern SEIR towards the AAD versus MOR migration over ancient slab burial ground). The two issues are connected in that anomalously elevated ridge segments act as potential obstacles along which contourites are deposited, while anomalously deep troughs and segments of the ridge may allow deep water to pass from one ridge flank to the other (a high-resolution bottom water circulation model suggests this is the case).

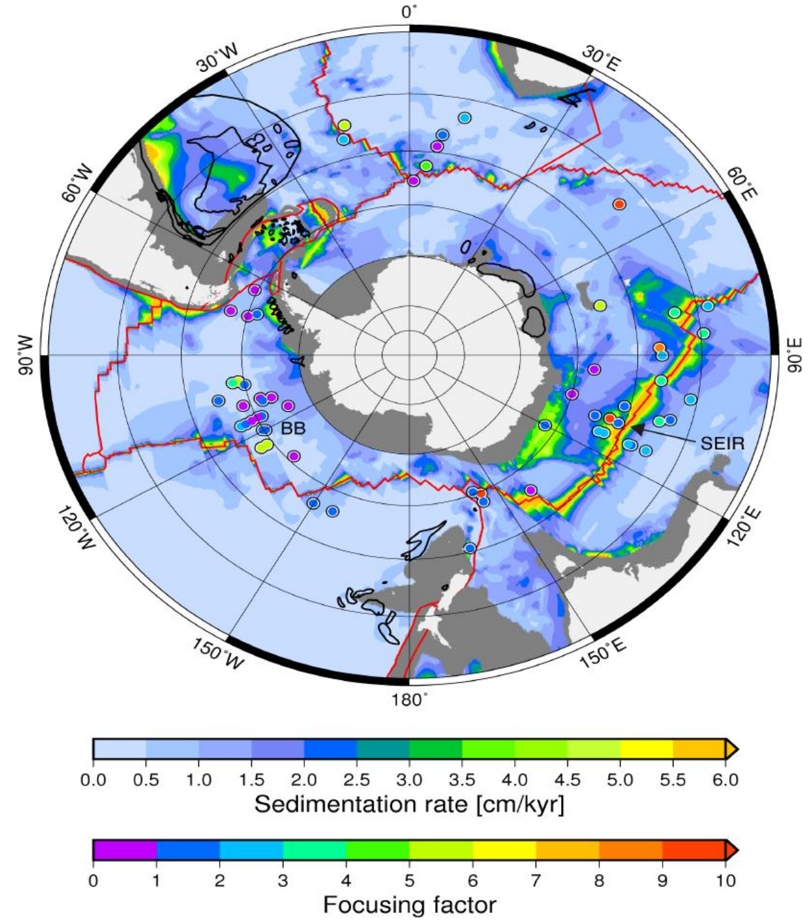


Figure 21: Focusing factors along the Southeast Indian Ridge (SEIR) are consistently and significantly greater than 1, indicating lateral advection of sediment as the dominant mechanism for anomalously high sedimentation rates. In contrast, in the Bellingshausen Basin (BB) the majority of focusing factors range between 0.5 and 1.5 with only 3 values > 5, while data in other parts of the Southern Ocean are relatively sparse. Black outlines indicate known large contourite deposits from Rebesco et al. (2014). From (Dutkiewicz et al. 2016).

The anomalously deep AAD may result from the sampling of both an ancient mantle wedge, depleted by prolonged melting, and/or mantle cooled by the subduction system (Gurnis & Müller 2003). Along the trace of the residual depth anomaly, a fundamental change may have occurred in the dominant mechanism causing the topography – first by sampling of refractory mantle from the old wedge and later by the sampling of cold mantle (Figure 22).

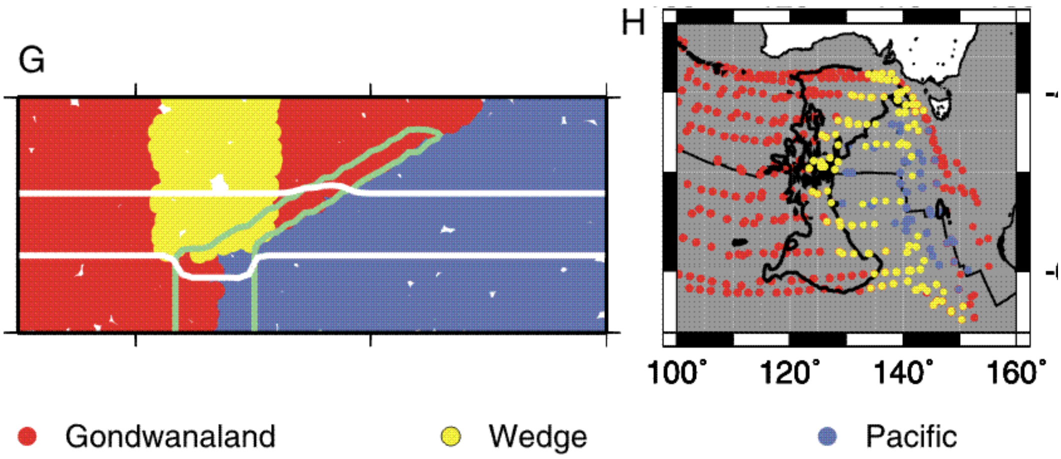


Figure 22: Left: Initial configuration of three passive reservoirs, sub-Gondwanaland (red), mantle wedge (yellow), and sub-Pacific (blue). The heavy green line is the outline of a thermal subducting slab while the white lines are the phase transitions at 410 km and 670 km depth. Right: Modelled positions of mantle tracers sampled by the SEIR and shown in their present position after incorporation into the Australian and Antarctic oceanic plates; the heavy black line is the observed residual depth anomaly contoured at -800 meters. A sampling radius of 200 km below the ridge was assumed. From Gurnis & Müller (2003).

Hypothesis 1: Origin of AAD depth anomaly may have changed from initial sampling of refractory mantle wedge to sampling of cool mantle since 20 Ma. In both cases, melting of mantle wedge or cold mantle is difficult and both give rise to thinner crust.

Hypothesis 2: Increase in westward asthenospheric flow of Pacific mantle plays a major role in driving geochemical boundary between Indian (Dupal) and Pacific mantle westward.

Question: What is the origin of "Dupal anomaly" and its relation to the ancient eastern active Gondwana margin mantle chemical overprint – Dupal is the largest chemical/isotopic anomaly in the mantle and we still don't know how it forms or what it is. Its boundary coincides with the AAD.

The recent STORM survey of the SEIR (Boulart et al. 2017) revealed that ridge elevation and magma temperature regulate the type and vigour of hydrothermal activity along the SEIR, modulating biochemical cycles via the input of micronutrients into the water column. The time dependence of these processes is currently unknown.

Opportunities for Site Surveys

There are no modern seismic profiles anywhere in the region (neither west nor east of the AAD). There is a need to acquire high-resolution seismic data, dredges, and piston cores (Investigator, Thompson?). RV *Investigator* services the IMOS Southern Ocean Time Series (SOTS) mooring every March – see http://mnf.csiro.au/Voyages/Investigator-schedules.aspx for ship schedules in 2018 and 2019. SOTS is located at 140ºE, 47ºS. MNF granted voyages fall into three categories: primary, supplementary, and piggyback. See http://mnf.csiro.au/Applying-for-sea-time/MNF-Granted-Voyages.aspx for more details. Pre-proposals are prerequisites for primary proposals; the next available opportunity for a primary proposal is May 2018 for a 2020/2021 voyage. May 2017 also applies for 2018/2019 and 2019/2020 supplementary proposals. Piggyback proposals are more flexible – see http://mnf.csiro.au/Applying-for-sea-time/MNF-Granted-Voyages/Piggyback-projects.aspx.

4.6 The Indian Ocean Dipole and Monsoon

Lead Proponents: Sushant S. Naik, P. Divakar Naidu, Dhananjai K. Pandey, Brandon Dugan

The Indian Ocean Dipole (IOD) involves reversal of the sea surface temperature (SST) gradient and winds across the equatorial Indian Ocean from their climatological state. This proposal aims to recover sequences of sediments from Miocene to recent from the eastern equatorial Indian Ocean primarily to study the history of the IOD on annual to geologic timescales. The objectives of the drilling are to understand 1) the evolution of SSTs in the eastern Indian Ocean since the Miocene; 2) the long-term relation between eastern Indian Ocean SSTs and strengthening/weakening of the Indian monsoon; 3) the response of the eastern Indian Ocean SSTs/IOD to atmospheric CO_2 forcing; and 4) the influence of constricted Indonesian Throughflow gateway at ~3-4 Ma on the IOD. We propose drilling a latitudinal transect ~5°S (~90-110°E) to obtain longer timescale records (going back to the early Miocene), in order to understand the evolution of SSTs and the effect of Indonesian Throughflow gateway closure on the IOD. Secondly, we propose drilling off the west coast of Sumatra (or high sedimentation rate sites in international waters) which would be helpful in obtaining high-resolution sediment cores to understand variations in IOD at decadal to centennial time-scales. This proposal will be amalgamated with an earlier plan which aims to understand Nicobar fan evolution, its relation to monsoon intensity and Himalayan uplift, and the stress state in oceanic crust and relation to seismicity. Site survey data are available off Sumatra, but we need site surveys farther south, in the core region of the IOD to identify high-sedimentation sites.

4.7 Future IODP Drilling in Northern Zealandia/Lord Howe Rise

Break-out participants: *Ron Hackney, Yasu Yamada, Sanny Saito, Lena Maede, Simon Williams, Neville Exon*
Additional comments: *Julien Collot, Jerry Dickens, Rupert Sutherland and others*

Northern Zealandia and the Lord Howe Rise were drilled during IODP Expedition 371 using *JOIDES Resolution* from July to September 2017, and will be drilled during a SEP/CIB-approved *DV Chikyu* expedition that, subject to funding, is scheduled for the second half of 2020 (Complementary Project Proposal 871).

New opportunities for drilling in northern Zealandia will undoubtedly emerge from the core and data collected during Expedition 371. In addition, as is typically the case, not all of the proposed sites are able to be drilled during the expedition. Some combination of these previously-proposed sites, together with new sites selected post-drilling, could readily form the basis for future Zealandia/LHR drilling proposals.

In the case of Proposal 871-CPP for deep riser drilling, several proposed alternate sites are suitable for riserless drilling using *JOIDES Resolution*. A separate proposal for riserless drilling of these shallow basement sites and additional riserless sites that target Cretaceous sediments at shallow depths would provide an additional opportunity to address the objectives of Proposal 871-CPP.

New site survey data obtained in support of these scheduled and planned expeditions (see figure) provide modern seismic coverage of the entire width of Northern Zealandia from the Norfolk Ridge to the Tasman Sea oceanic basin. These data undoubtedly reveal many additional drill sites, most of which have not yet been considered in detail.

Another possible long-term objective in the region is to target seamounts and submerged plateaus within and to the north of northern Zealandia where drilling could address important geodynamic questions surrounding changes in Pacific Plate motion, and the connections among deep mantle plumes and large igneous provinces. The area is the target of a proposed *RV Investigator* voyage, to take place in 2019–2020, which would focus on the formation of the Louisiade Plateau and the seamount chain tracking from this feature. Subject to the availability of seismic equipment from MNF, the proposed voyage would present an opportunity to collect site survey data that could form the basis of future drilling expeditions.

The combination of already-proposed but undrilled alternate sites, extensive new site survey data, results from Expedition 371 and ideas yet to be fully developed will form the basis for viable new IODP proposals in northern Zealandia that address challenges in global tectonic, climate and biosphere evolution. However, it was agreed at the workshop that future plans for IODP drilling in northern Zealandia should be revisited in mid-2018 after results from Expedition 371 begin to emerge and the status of funding and logistics for Proposal 871-CPP becomes clearer.

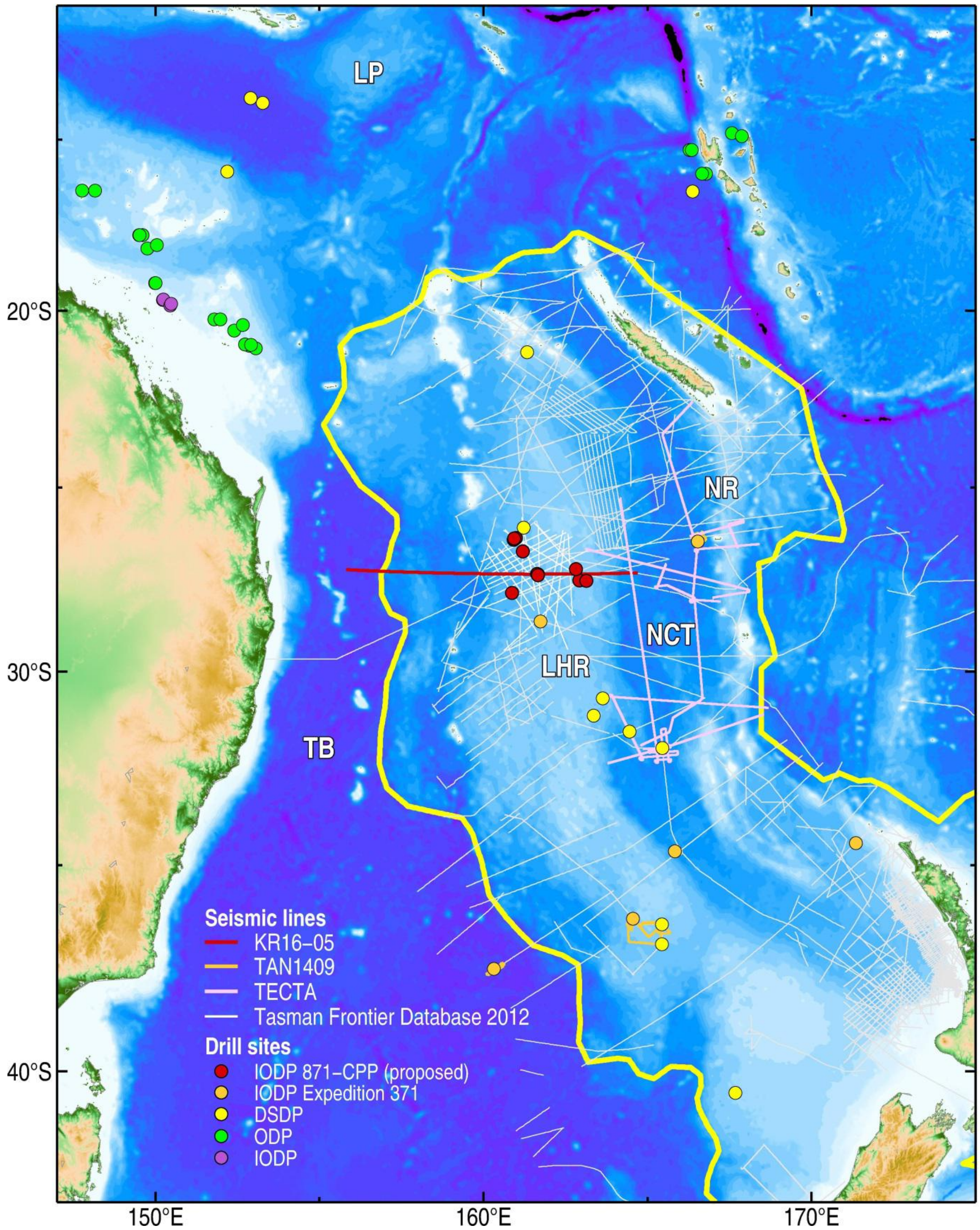


Figure 23: Map showing past and future IODP drill sites in northern Zealandia (yellow outline), together with existing and recently-acquired seismic lines. TB, Tasman Basin; LHR, Lord Howe Rise; NCT, New Caledonia Trough; NR, Norfolk Ridge; LP, Louisiade Plateau.

4.8 Completing the Australian-Antarctic transect

Lead: Peter K. Bijl,
Interested parties: Isabel Sauermilch, Jo Whittaker, Francesca Sangiorgi
Note this was presented by Rob McKay on behalf of Peter Bijl, and was not discussed in detail during the breakouts, but interested parties are encourage to contact Peter Bijl (P.K.Bijl@uu.nl) to further develop this idea.

Our proposal idea is to complete the transect of sedimentary archives between Australia and Antarctica to elucidate:

1) Lithosphere thinning history during continental breakup
Rationale: Lithosphere thinning during continental rifting and the transition between rift and oceanic crust formation is not well-understood. The Australo-Antarctic rift system provides an opportunity because the peridotite ridge, representing the boundary between continental and oceanic crust, has risen high enough to be reached with riserless drilling

2) Post-rift continental shelf subsidence history of both Australian and Antarctic margins
Rationale: The timing, nature and consequences of post-rift subsidence of the outer continental shelf of both the Australian and Antarctic margins is poorly understood. It is expected that post-rift subsidence was minimal, because continental migration is compensated for by formation of oceanic crust. Also, both margins should be completely independent in terms of subsidence history as soon as oceanic crust formation commences. However, we have reconstructed from the Antarctic margin profound collapse of the outer continental shelf long after oceanic crust started forming in the rift system. Moreover, and surprisingly, we see from seismic profiles along the Australian Margin a largely symmetrical pattern to that of Antarctica. However, from the Australian side, we lack sedimentary records that recover allow dating the sediments from the outer end of the continental margin.

3) The deep-sea expression of Eocene-Oligocene circum-Antarctic erosion
Rationale: Late Eocene sedimentary records dispersed around the Antarctic Margin shows evidence of severe winnowing, glauconite formation and erosion, all of which were interpreted to result from spun up ocean currents. While this profound erosion on the continental shelf should have eroded a huge amount of sediment, the fate of this sediment, the nature of ocean current invigoration and the expression of these currents in the deeper parts of the Southern Ocean are not well resolved.

4) History of the development of the Antarctic Circumpolar Current and spatial migration of Southern Ocean frontal systems
Rationale: The Antarctic Circumpolar Current is a major oceanographic feature and represents the most vigorous ocean current on our planet. It has profound impact on high-latitude Southern Hemisphere climate, and has been related to the thermal isolation of Antarctica, deep-ocean circulation and ventilation and carbon drawdown. However, despite numerous efforts from all kinds of

disciplines, we still lack understanding of when and how the ACC came to be, whether the tectonic setting (unobstructed oceanic gateways) or atmospheric circulation (high pressure over the south pole, low pressure over the latitudes of ~60S) determined its installation. Also, major glacial-interglacial variations in ocean circulation and climate have been related to shifts in the Southern Ocean frontal systems. The poor spatial coverage of sedimentary records across a transect of the Southern Ocean prevent to understanding of the various stages of development of the ACC, including recent glacial-interglacial migration of the ocean frontal systems.

We propose to develop a plan to drill a transect which connects the Otway/Ceduna basins with the Antarctic margin. We propose to investigate the optimal site to drill the peridotite margin, for which we already have seismic data in place. We propose to investigate the ideal site to drill one conjugant site to U1356 on the edge of the Australian continental plate, in order to investigate the post-rift subsidence history of the Australian continental margin. For this we also have seismic data in place. We further propose to investigate the possibility to drill a transect on both conjugant oceanic crusts between Australia and Antarctica to investigate the deep-sea expression of the late Eocene erosion on the abyssal plain sedimentation, (equivalent to DSDP Site 269) as well as the onset and developments of the Antarctic circumpolar current (equivalents to DSDP Site 265-268, but then also on the Australian continental crust), including the recent migration patterns of ocean frontal systems. For proposing these sites, additional seismic data will be necessary.

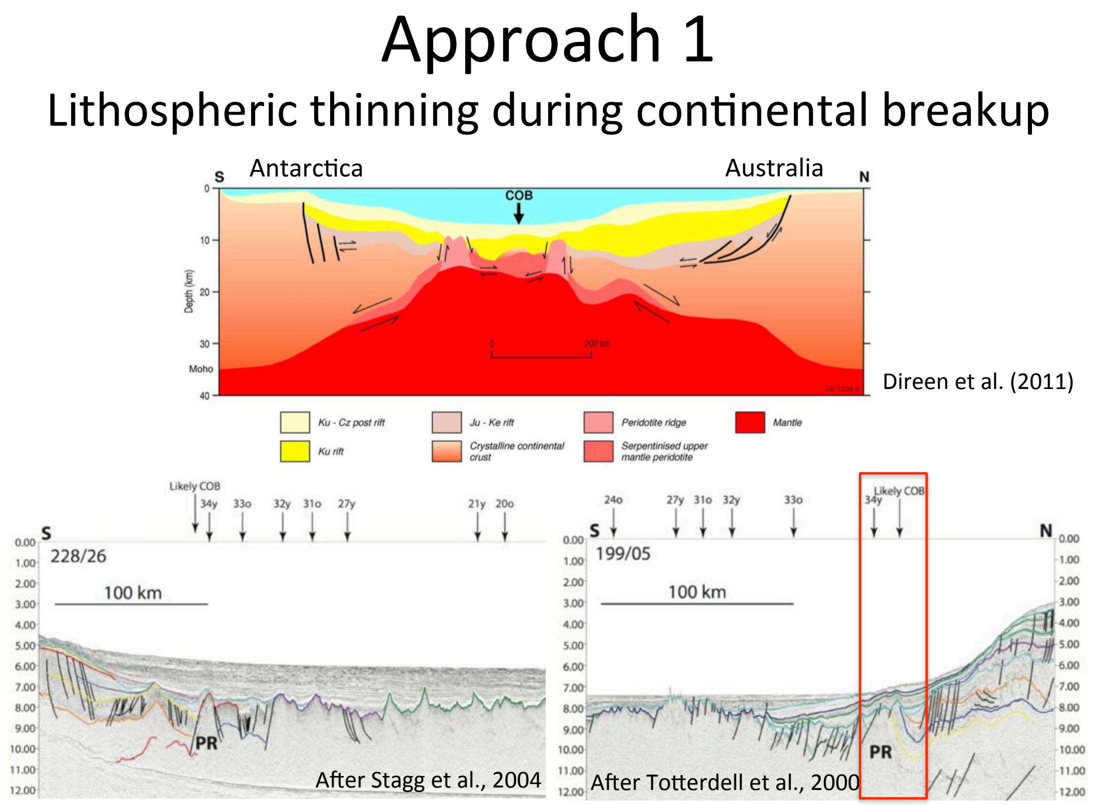


Figure 24: Seismic profiles across the Australo-Antarctic Gulf, highlighting lithosphere structure and possible targets to investigate continental breakup.

Available seismic data

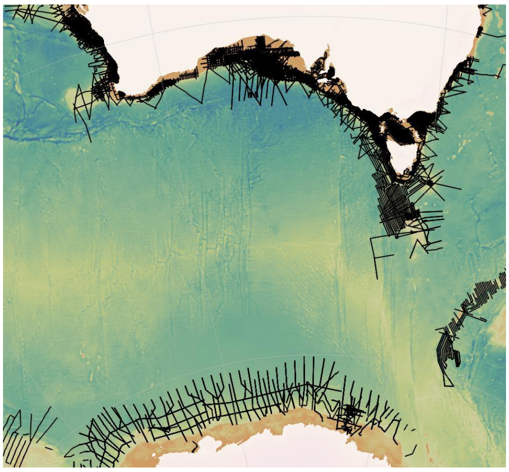
Multi-channel seismic data:

- Antarctica: Seismic Data Library System (SDLS) free access, sonobuoy velocity information
- Southern Australia: data exist, request Geoscience Australia, mostly stacking velocity information

Single-channel seismic data:

- Across Australo-Antarctic basin
- Low penetration, free access (JPG, navigation)

http://www.marine-geo.org/ (06/2017)



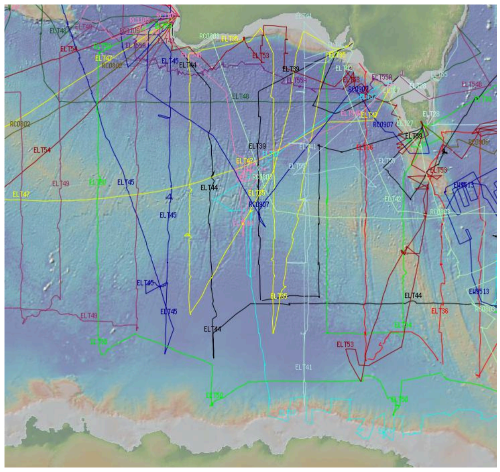


Figure 25: Available multi-channel (left) and singe-channel (right) seismic lines in the region

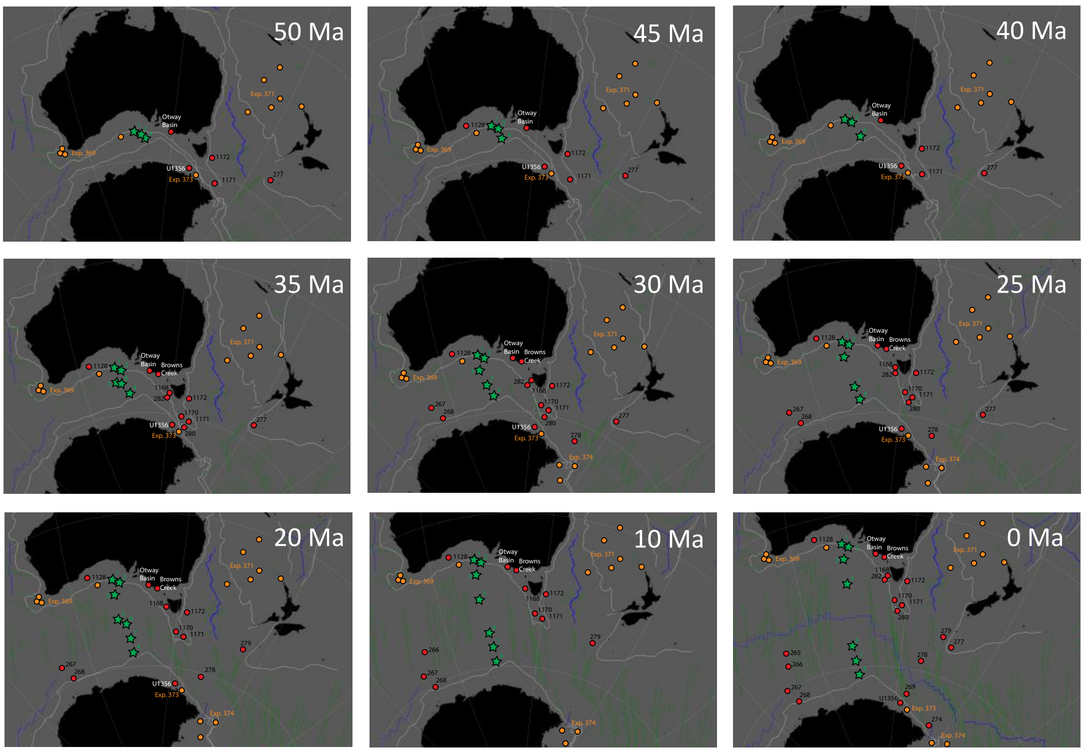


Figure 26: Proposed idealized position of sites in order to meet objectives 1-4.

Section 5. Biosphere

5.1 Investigating unusual fluids and their influence in the Cenozoic continental margin of the Great Australian Bight

Science Lead: Ulrich G. Wortmann
Data lead. Mads Huuse
Other proponents: Alica Wilson (Hydrology lead), Maija Raudsepp (Microbiology lead), Vincent Post, Simon George, Gordon Southam, Gene Tyson, Talitha Santini, Jessica Whiteside, Peter Swart, Fumio Inagaki, Stephen Gallagher, Yuki Morono, Paul Evans, Brice Loose, Gene Tyson

The role of mass transport in continental margin environments has historically been underappreciated. Recent oceanographic tracer studies indicate that discharge of saline groundwater from passive continental margins occurs at rates equal to (or exceeding) river discharge. This implies large-scale migration of saline groundwater through continental shelf sediments and is consistent with decades of research in carbonate diagenesis, where the importance of groundwater mass transport has long been recognized. We propose to assess coupled groundwater flow, geochemical reactions and microbial metabolic processes in the Great Australian Bight (GAB), a subtropical carbonate passive margin where prior drilling suggests that we will be able to access an actively discharging brine system.

The work of Jones et al. (2002) suggests that sea-level pumped reflux brines (brines formed by evaporation of seawater on the exposed shelf during sea-level minima) should be common in subtropical passive margin sequences. If so, they would provide the hitherto missing mechanism to explain the large-scale dolomitization and mineralization processes observed throughout Earth's history. These shelf-scale hydrological systems can be likened to enormous flow-through reactors which not only control diagenetic reactions (and by extension, seawater chemistry), but also support abundant deep microbial life on the upper shelf slope. Results from ODP-Leg 182 suggest that these brine-supported microbial ecosystems thrive under hyperalkaline and hyper-sulfidic conditions, which are profoundly distinct from most other known deep-biosphere environments.

Surprisingly, of all the DSDP/ODP/IODP cruises conducted over the years, less than ten expeditions cored locations where such brines were encountered. None of the cruises that intercepted high-salinity groundwater systems, had scientific objectives geared toward groundwater research, and the science teams were not prepared to conduct the type of research/sampling necessary to advance our knowledge of reflux brines and their associated deep-biosphere ecosystems.

Here we propose to revisit the outer shelf and upper shelf slope of the GAB, which was previously investigated by ODP Leg 182. We choose this location so that we can build on the already existing geochemical data from Leg 182, and because the GAB is considered a modern analogue of Mesozoic carbonate systems, not only in geometry but also in its microbial ecology. The tantalizing possibility is that we will gain an unprecedented glimpse into the microbial and organic geochemical processes that are responsible for the formation of a large portion of the world's hydrocarbon resources, as well as determine the role of saline groundwater flow in carbonate diagenesis in continental margin environments.

This proposal aims to A) Elucidate the age and formation mechanism of the hypersaline groundwaters on the shelf margin of the Great Australian Bight (challenge 14 in the IODP Science Plan 2013-2023); B) Establish the extent and the flow rates of the GAB brine system, and evaluate its effect on seawater chemistry and mineralization potential (challenge 14); C) Explore how water and energy supply from terrestrial hydrogeological systems affect the dispersal, transportation and adaptation of microbes to the subseafloor deep biosphere (challenges 5, 13, 14); D) Explore how the GAB microbial ecosystem flourished under hypersaline and hyperalkaline condition (challenge 6) ; E) Explore how the GAB deep biosphere sustains methanogenesis in the presence of sulfate reduction, processes which are generally considered to be exclusive (challenge 6); F) Investigate how substrate changes across the Quaternary/Neogene boundary affect microbial ecology (challenge 7). Note, that our exploration of the effect of brine cycling on seawater chemistry also expands upon challenge #10, specifically suggesting that chemical exchange with continental shelf sediments should be considered as a control on the major ion chemistry of seawater.

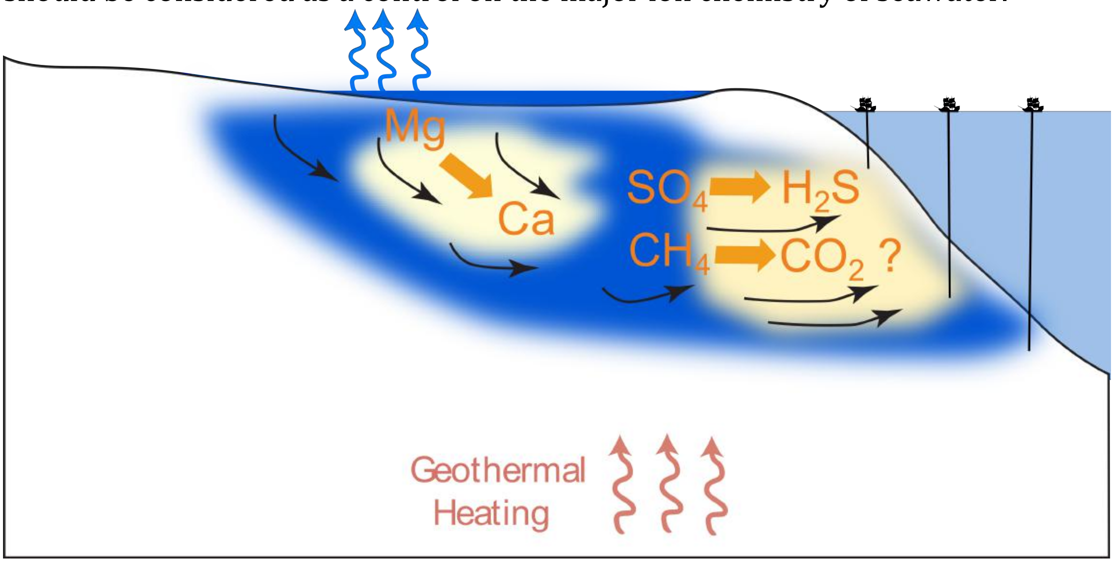


Figure 27: Theoretical considerations suggests that hypersaline fluids which form in brine pools during sea-level lowstands will migrate outwards toward the shelf. Repeated sea-level fluctuations will recharge this system on a continuing basis (Jones et al. 2002). Note that the above model is based on the OPD Leg 182 porewater geochemistry, whereas Rivers et al. 2012 observe dolomitization processes within the outer shelf deep biosphere.

5.2 The edge of the gyre: Biological and oceanographic transitions from the South Pacific Gyre into the Southern Ocean through the Cenozoic.

Break-out participants: *A.G. Dunlea, Y. Morono, F. Inagaki*

We discussed proposing to drill a transect of sites with oxic and suboxic deep-sea sediment from the South Pacific Gyre into the Southern Ocean for microbiological, geochemical, and paleoceanographic-focused research. The transect of sites under consideration for the transect are all of similar ages (~75

Ma), but record a north-south gradient of different biogeochemical and oceanographic regimes through the Cenozoic. Microbiological research would be addressing questions honed from the results of IODP Expedition 329 to the South Pacific Gyre. One of the most southern sites (Site U1371) included a shift from pelagic clay sedimentation to siliceous accumulation ~8 Ma and the microbial communities of these two lithological units are unique. Drilling additional sites on the southernmost edge of the South Pacific Gyre that focus on acquiring these types of depositional and biogeochemical transitions would allow the examination of how microbial ecosystems are established and respond to changing environments. The following research questions would be targeted.

What are the dispersal and evolutionary processes that shape and force the diversity and function of microbial ecosystems over millions of years? What are the environmental factors that constrain microbial population size and diversity of deep subseafloor microbial communities in the open ocean? How does the deeply buried microbial community persist in oxic sediments and sensitively respond to environmental changes? Does activity of the sedimentary community impact on the underlying crustal biosphere? And more generally, where did the deep subseafloor sedimentary microbes come from? Do adaptation and evolution of the deep biosphere occur? And if so, what mechanisms in the deep biosphere are distinct from Darwin's theory on Earth's surface biosphere? What are strategies of deep life for the long-term survival in oxic sediments over millions of years? What is the difference of microbial activity and its biogeochemical consequences occurring in the aerobic and anaerobic biosphere?

The position of these sites on the southernmost edge of the South Pacific Gyre would also be interesting for paleoceanography and paleoclimatology research. For the pelagic clay sequences, an age model could be developed using osmium isotope stratigraphy with other biostratigraphic constraints when available. Given the slow sedimentation rates of pelagic clays, paleoceanographic questions would be focused on timescales of millions of years. In any siliceous- or carbonate-rich sediment sequences, traditional biostratigraphy could be used and higher temporal records may be achieved. Possible avenues of research include the following: (1) Tracking the spatial and temporal deposition of dust and volcanic ash to trace the aridification of Australia and wind patterns in the Southern Hemisphere (2) Examine relict hydrothermal systems and deposition (3) Assess the sources and cycling of metals/micronutrients in seawater and how they have changed over time. (4) Characterize authigenic clay minerals and ash alteration and their effect on seawater chemistry. (5) Tracking high-latitude water masses and circulation changes (6) Trace the onset and the northern extent of biogenic siliceous deposition in the Pacific sector of the Southern Ocean.

Consensus statement regarding the critical importance of site characterization data for IODP scientific drilling proposals

The 97 scientists gathered at the 2017 Australasian IODP Workshop in Sydney, tasked with planning scientific ocean drilling expeditions in the Eastern Indian, Southern and Southwest Pacific Oceans, emphasise the critical importance of geoscientific site characterisation to the future success of IODP and its successors. Site characterisation data, most importantly seismic reflection data, are essential for the identification of suitable primary and alternate drill sites in every full drilling proposal submitted to the IODP Science Support Office, and subsequently carefully considered by the program's Science Evaluation Panel (SEP) and the three Facility Boards.

Without this type of information, the scientific exploration of the deep subseafloor and our understanding of its role in tectonic, climatic, oceanographic, biological and geochemical processes in the Earth System cannot advance. Providing suitably capable vessels for that purpose is essential for the advancement of scientific ocean drilling as it addresses ever-evolving global scientific questions, particularly in under-explored parts of the world ocean like the Australasian region.

Accordingly, we emphasize that blue water research vessels with the necessary seismic reflection systems should continue to be available to researchers in all IODP member countries on reasonable fiscal conditions, and with suitable advance (national and international) planning mechanisms.

Submitted by Professor Neville Exon (ANZIC Program Scientist) on behalf of the workshop participants (Neville.Exon@anu.edu.au).

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