International Ocean Discovery Program (IODP): The Latest Incarnation of Almost Five Decades of Scientific Ocean Drilling Excellence

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IODP (2013-2023) represents the latest phase of the longest running, most successful scientific collaboration in the history of the Earth sciences. IODP follows on from three earlier phases, the Deep-Sea Drilling Project (DSDP, 968-1983), the Ocean Drilling Program (ODP, 1983-2003) and the Integrated Ocean Drilling Program (IODP, 2003-2013). IODP is now a collaborative program, in which member countries (currently 25) provide a broad variety of drilling/coring/sampling capabilities to explore changes in the Earth system through geologic time. The United States (U.S.) supplies IODP's flagship - the leased commercial drillship *JOIDES Resolution*. The "JR", as she is affectionately known by the thousands of scientists and students who have sailed aboard her on more than 100 drilling expeditions around the world, has been serving the scientific drilling community since 1984. To address deep objectives within sedimented continental margins and in the crust, where overpressured fluids may create a hazard to drilling safety, Japan contributes the riser-equipped *Chikyu;* that vessel has completed a number of important expeditions along the Japanese/Nankai margin, and has also investigated the zone of slip associated with the 2011 Tohoku earthquake. Finally, the European Consortium for Ocean Research Drilling (ECORD) contributes "mission-specific platforms" (MSPs), e.g., lift-boats, jack-ups, special purpose drilling vessels, to address targets not suitable for the other platforms - those in shallow water, like reefs and continental margins, and in ice-covered high latitudes.

IODP is entirely motivated by competitively reviewed proposals from the international community. These proposals respond to a decadal Science Plan, "Illuminating Earth's Past, Present and Future" (see iodp.org), developed and written in response to extensive discussions among the world's best Earth scientists. The vast majority of proposals are written by scientific teams from member countries and consortia, but IODP proposals often include scientists from non-member countries interested in scientific ocean drilling. IODP is also presently especially interested in adding countries bounding the South Atlantic to its membership ranks, as the JR will be there within the next 4-5 years; efforts have recently been underway to engage South Africa and Namibia. The Japanese are presently negotiating with Australia to bring *Chikyu* to the Lord Howe Rise for both deep and shallow drilling there. ECORD has plans to use MSP technologies to drill both in the Arctic (on the Lomonosov Ridge) and in the Gulf of Corinth (within a complex rift system there) between now and the end of the current phase of IODP in ~2018.

All IODP expeditions are staffed by technicians and scientific "parties" derived from member country/consortia communities. Those parties always represent a spectrum of appropriate disciplines, and include graduate students and educators. Members are expected to provide funding (e.g., salary, fellowships) for that participation, along with post-expedition support for scientific research, education and outreach, synthesis workshops, and other activities that showcase the program's world-class scientific results, e.g., lectures at academic institutions and museums. Cores are stored in perpetuity, in repositories in Japan, Germany, and in the U.S., as the ultimate legacy of scientific ocean drilling.

Keywords: scientific ocean drilling, international collaboration, global emphasis, climate and crustal objectives

Towards a Cenozoic "Megasplice" of climate history: Hemispheric climate response to astronomical forcing during the past 35 m.y.

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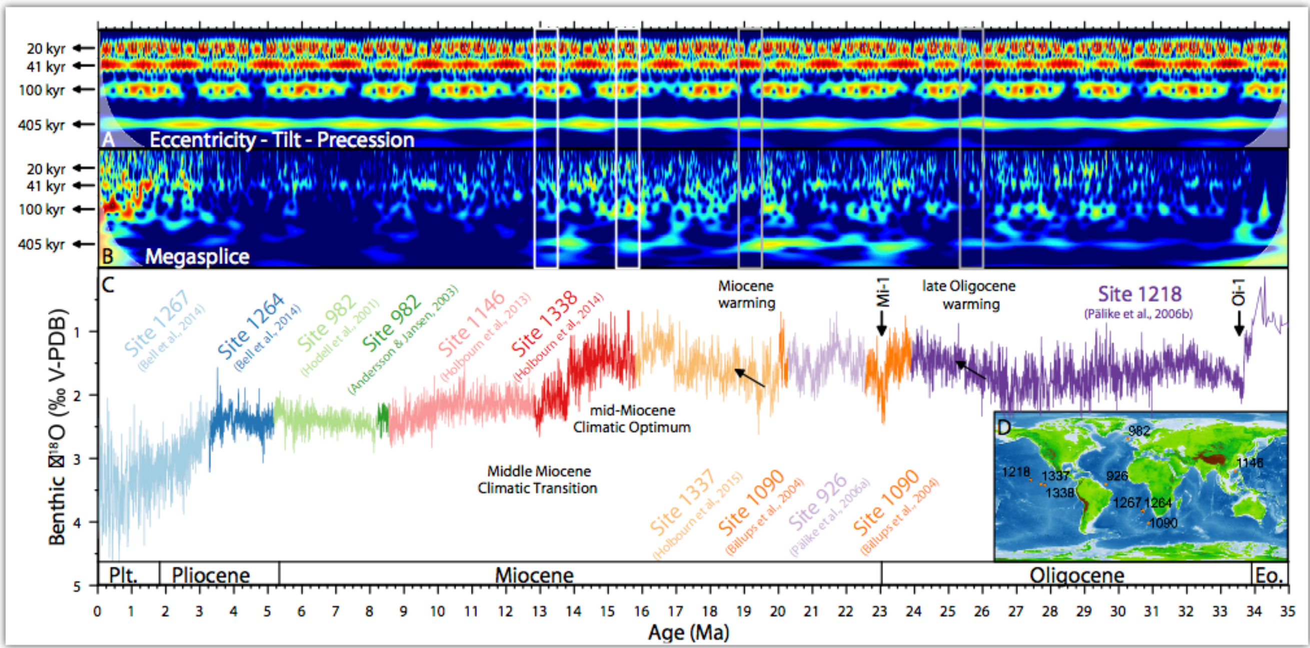
Earth's climate has undergone different intervals of gradual change as well as abrupt shifts between climate states. Here we aim to characterize the corresponding changes in climate response to astronomical forcing in the icehouse portion of the Cenozoic, from the latest Eocene to the present. As a tool, we use a 35-m.y.-long delta$^{18}O_{benthic}$ record compiled from different high-resolution isotope records spliced together (what we refer to as a megasplice).We analyze the climate response to astronomical forcing during four 800-k.y.-long time windows. During the mid-Miocene Climatic Optimum (ca. 15.5 Ma), global climate variability was mainly dependent on Southern Hemisphere summer insolation, amplified by a dynamic Antarctic ice sheet; 2.5 m.y. later, relatively warm global climate states occurred during maxima in both Southern Hemisphere and Northern Hemisphere summer insolation. At that point, the Antarctic ice sheet grew too big to pulse on the beat of precession, and the Southern Hemisphere lost its overwhelming influence on the global climate state. Likewise, we juxtapose response regimes of the Miocene (ca. 19 Ma) and Oligocene (ca. 25.5 Ma) warming periods. Despite the similarity in delta$^{18}O_{benthic}$ values and variability, we find different responses to precession forcing. While Miocene warmth occurs during summer insolation maxima in both hemispheres, Oligocene global warmth is consistently triggered when Earth reaches perihelion in the Northern Hemisphere summer. This pattern is in accordance with previously published paleoclimate modeling results, and suggests an amplifying role for Northern Hemisphere sea ice.

Keywords: Cenozoic paleoclimate, Milankovitch, benthic oxygen isotopes



Six million years of Leeuwin Current history using changes in water column stratification and productivity

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The Leeuwin Current (LC) is a warm ocean current that flows southwards along the western Australian coast. Changes in the dynamics of this current can have a significant impact on the continental climate in SW Australia. Yet, there is a limited understanding of the timing of the onset of the LC, as well as of its variability. Furthermore, the relationship between LC variability and SW Australian climate is poorly constrained. Expedition 356 drilled a series of sites off the western margin of Australia to evaluate the evolution of the LC. These long, generally continuous records provide the opportunity to reconstruct LC dynamics over the last 6 million years. Moreover, these records provide a unique archive of continental climate change, recorded changing fluxes of wind-blown dust and fluvial transport. Here, we present paleoceanographic and paleoclimate interpretations of oxygen isotopes and scanning XRF from IODP Sites U1459 (28.67°N) and U1460 (27.34°N) off SW Australia.

Previous work on the NW Australian shelf (Site U1463, 18.97°N) revealed a rapid onset of humid conditions at 5.5 Ma, and a transition at 3.3 Ma to the onset of arid conditions and the development of the modern NW dust pathway by 2.4 Ma. The longer- scale changes at Sites 1459 and U1460 are generally in accord with the timing identified for Site U1463. At 5.5 Ma, when Australia becomes more humid as it is surrounded by warmer waters associated with the expansion of the WPWP, the Western Australia Current is dominant off SW Australia. The onset of a proto-Leeuwin Current south of the NW Cape as suggested by indicators for reduced productivity (e.g., Ba/Al) at 4 Ma, is coeval with the restriction of the Indonesian Throughflow (ITF) as the Maritime Continent emerged. Atmospheric conditions may also place a role in the development of the LC. Today, the LC is strongest during Austral winter, when the opposing northward blowing winds are weaker (e.g., Feng et al, 2003). In Austral summer, when the ITCZ straddles Australia, the alongshore pressure gradient and the northward blowing winds are maximum, counterworking the LC. The increase in stratification observed in the mid-Pliocene (~4.0 Ma) suggests an increase in the influence of the LC at Site U1459. Using the modern-day circulation pattern as an analogue, this implies a weaker alongshore pressure gradient during summer, and thus a more northerly position of the ITCZ. At ~3.3 Ma, we observe a short-lived event, likely M2, characterized by cooler surface waters and an increase in productivity. The timing is consistent with the transition interval identified at Site U1463 and indicates a strengthening of the WAC. It is unlikely to be related to reduced trade wind strength associated with a more southerly ICTZ, but instead is attributed to a combination of reduced sea level and continued restriction of the ITF.

Our hypotheses about ocean circulation and productivity should align with the records of terrestrial input. Intervals during which the ITCZ reaches more southerly latitudes during Austral summer were characterized by more summer precipitation, and thus should be associated with higher Fe. Indeed, for the late Pleistocene, Fe seems to be elevated during interglacial periods indicating continental material

was transported offshore by strong trades when the LC was stronger. Conversely, Ni/Cl, a likely productivity indicator, is generally higher during glacial periods, and potentially when the WAC dominates. On a longer timescale, Ni/Cl tracks the natural gamma radiation elemental ratio, U/Th, recording Pleistocene variations in productivity, and Fe inversely covaries, indicating periods with high delivery of continental sediments to the study area.

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Keywords: IODP, Leeuwin Current, Southwest Australia shelf, Neogene, NGR

Exploring multi-spheres interactions through scientific ocean drilling: A perspective from the deep biosphere

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Over the past decades, scientific ocean drilling has explored subseafloor environments at various oceanographic and geological settings, which resulted in numerous discoveries on Earth’ s planetary sub-systems —the atmosphere, hydrosphere, geosphere, and biosphere. The dynamism fostering the co-evolution of life and the Earth system is principally constrained by extra- and intra-terrestrial energy sources. The lithosphere consisting of sediments, crusts and upper mantle plays a significant role as an interface between the Earth’ s asthenosphere and the overlying hydrosphere and atmosphere. Drilling deep into the Earth’ s lithosphere has significantly expanded our understanding of Earth’ s sub-systems and will continue to do so in the future. To date, only little is known about how Earth’ s various spheres interact, despite the awareness that such spheres connect and interact with each other. Building this knowledge will provide useful insights at various levels into the past, present and future of our Earth and human society.

With respect to the deep biosphere, accumulating evidence from ocean margin sites indicates that remarkable numbers of anaerobic microbial cells are present at least down to at least ~2.5 km below the ocean floor[1]. In open ocean sites, the occurrence of microbial communities and oxygen was observed in the entire sediment column of the ultra-oligotrophic South Pacific Gyre, qualifying up to ~37% of the global oceanic sediment as aerobic biosphere[2]. These recent findings through scientific ocean drilling have characterized the deep biosphere as one of the important Earth’ s sub-systems, where microbial life inhabiting the vast oceanic lithosphere influences whether several important elements are sequestered for millions of years or returned to the ocean as active agents with an impact on life and climate[3].

Only a better understanding of the Earth’ s multi-spheres interactions through scientific ocean drilling will enable informed conclusions regarding the origins and evolution of life, oceans and Earth—the characterization and monitoring of multi-spheres boundaries, including the limits to the deep biosphere, will highlight the organization and interactions of Earth’ s sub-systems and provide critical information enabling the discovery and utilization of new functions of Earth’ s multi-spheres deep beneath the ocean.

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Keywords: Deep subseafloor biosphere, Multi-spheres interaction, Chikyu

Insights into earthquake processes from borehole temperature monitoring within the Japan Trench plate boundary fault zone

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Sub-seafloor temperature monitoring within the Japan Trench plate boundary fault zone has revealed great insight into hydrologic, thermal, and stress conditions, and dynamic earthquake processes. These observations come from a sub-seafloor temperature observatory installed across the main plate boundary fault as part of the Integrated Ocean Drilling Program's Japan Trench Fast Drilling Project (JFAST): Expeditions 343/343T. The observatory was installed following the March 2011 Mw 9.0 Tohoku-oki earthquake and was operation from July 2012 through April 2013 during which time nearby a Mw 7.3 earthquake doublet and a large number of aftershocks occurred.

Key discoveries from the JFAST temperature observatory include:
1) Direct measurements of the frictional heat signature of the March 2011 Mw 9.0 Tohoku-oki earthquake that constrains the co-seismic plate boundary frictional stress to very low values.
2) A deep robust measure of heat flow in the near-trench area that is consistent with low long-term frictional resistance during slip along the shallow fault zone interface.
3) Characterization of the hydrogeologic structure and fault zone architecture suggesting a low-permeability fault core surrounded by a ~100 m wide more permeable damage zone above.
4) In situ observations indicative of transient fluid flow out of discrete faults and fractures in response to earthquakes.
5) Observations suggestive of damage and healing processes within the damage zone during a major aftershock sequence.

The observatory data form one component of the JFAST project that also includes logging-while-drilling data and geologic and experimental analyses on core samples from above, below, and within the plate boundary fault itself. The design of the JFAST temperature observatory builds upon thermal monitoring programs in other IODP observatories largely focused on large-scale sub-seafloor hydrogeology. The JFAST observations highlight the utility of using high-resolution (~mK accuracy), closely-spaced (m-scale) temperature sensors to characterize processes and conditions within an active fault zone. Whereas the JFAST observatory was a temporary deployment consisting only of temperature measurements, we hope to someday return to the Japan Trench and install a long-term observatory consisting of both thermal and pore pressure measurements to characterize long-term healing processes and continued transient behavior. Observations and analysis techniques gained from the JFAST observatory have provided guidance for thermal monitoring efforts in the Hikurangi Margin where observatories that integrate temperature, pore pressure, and geochemical monitoring are scheduled to be installed in areas of known shallow slow slip.

Keywords: Japan Trench, IODP Expedition 343, JFAST, temperature, observatory, fault

Seafloor and subseafloor experiments at the Hikurangi subduction margin to investigate the causes and consequences of slow slip events

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Slow slip events (SSEs) involve transient aseismic slip on a fault (lasting weeks to months) at a rate intermediate between plate boundary displacement rates and that required to generate seismic waves. Only since the advent of dense, plate boundary–scale geodetic networks in the last decade has the importance of these events as a significant mode of fault slip been recognized. The northern Hikurangi subduction margin, New Zealand is the site of the shallowest well-documented slow slip events (SSEs) on Earth. Due to the close proximity of the SSE source area to the seafloor at the offshore Hikurangi margin (<2-15 km), it has become an important international target for a variety of geophysical studies to understand the offshore physical mechanisms that lead to slow slip. A recent seafloor geodetic study using Absolute Pressure Gauges measured 1.5-5.5 cm of vertical deformation of the seafloor during large slow slip. These data demonstrate for the first time that slow slip continues to within at least 2-3 km of the seafloor, and it is possible that it occurs all the way to the trench (Wallace et al., 2016). We also show that using realistic elastic properties in the geodetic inversions greatly increases the amount of shallow slip needed to fit the data.

The centerpiece of efforts to understand slow slip at the Hikurangi margin is a series of IODP proposals (781A-Full and 781B-Full) to undertake riserless (Joides Resolution) and riser (Chikyu) drilling, and CORK observatory installation on a transect spanning the shallow Hikurangi SSEs. Joides Resolution drilling is scheduled at the Hikurangi margin for November-December 2017 and March-May 2018 on Expeditions 372 and 375. These two expeditions aim to investigate the processes and in situ conditions that underlie subduction zone SSEs at northern Hikurangi through coring and logging of the frontal thrust, upper plate, and incoming sedimentary succession, and by installation of borehole observatories in the frontal thrust and upper plate above the slow slip source area. The LWD data will be acquired on Expedition 372, while coring and installation of the CORK observatories will take place on Expedition 375. We will also discuss the plans and scientific objectives for the upcoming JOIDES Resolution drilling.

Keywords: subduction, scientific drilling, slow slip events

A new perspective of the subduction zone derived from the Ocean Drilling Program for the Nankai Trough Seismogenic Zone Experiments (NanTroSEIZE)

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The NanTroSEIZE project has been one of the most complex and challenging scientific ocean drilling projects in history, and a milestone for the Integrated Ocean Drilling Program (2005-2013) and the current International Ocean Discovery Program (2013-present). The ambitious goal of investigating the fault mechanics and seismogenesis of the Nankai Trough, and studying the in situ fault slip, strain accumulation, formation composition, fault architecture and install advanced sub seafloor observatories for real-time investigations and analysis is now nearing its final stages: directly sampling and measuring the plate boundary fault system, believed to be the primary pathway for the historically recurring mega-earthquakes and associated tsunami. The study area is located South-Southeast of the Kii Peninsula, off the Kii Peninsula, and comprises a transect of drill sites beginning in the Kumano Basin, extending across the Nankai Trough and to the incoming Philippine Sea plate. As a result of the drilling campaign since 2007, many scientific results broke through the previously accepted common concepts in the Nankai seimogenic subduction zone.
1)The Nankai forearc has been punctuated grown since ~6Ma and ~2Ma due to the rapid sediment supply from the land area and the hanging wall wedge for the great earthquakes has been set up as a result. 2)Slips along the plate boundary megathrust and its splay fault once run away to the trench and ocean floor. 3)The fault composed of sedimentary gouge is absolutely weak whichever in static or dynamic behavior. 4)In-situ stress conditions of the accretionary wedge and the outboard Philippine Sea Plate are well measured and tectonically loaded status suggests the build up of the stress for the next Nankai great earthquake. 5)Borehole observatories combined with ocean floor network documented the 2016, Aril 1 earthquake, tsunami and slow slips along the megathrust and presented an innovatively new science and technology in ocean floor science.

Repeating and triggered slow slip events in the near-trench region of the Nankai Trough detected by borehole observatories

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Slow slip events (SSE), non-volcanic tremor, and very low-frequency earthquakes (VLFE) are well documented down-dip of the seismogenic zone of major faults, yet similar observations for the shallowest reaches of subduction megathrusts are rare. Here, we document a family of repeating strain transients in the outermost Nankai subduction zone, updip of the region that ruptures in great (M8-class) earthquakes. We report on data from two borehole observatories: IODP Site C0002, which penetrates the accretionary prism and monitors a zone 931-980 m below seafloor (mbsf) at a location 36 km landward of the trench; and Site C0010, 25 km landward, which penetrates the prism and monitors a zone spanning 389-407 mbsf. We focus on a time window from Dec. 2010 - Apr. 2016, for which we recovered records of formation pore pressure at both sites.

After filtering oceanographic noise using a local hydrostatic reference at each site, the pressure records reveal seven transient signals that are synchronous at the two holes. Of these, five arise spontaneously, and occur at ~1 yr intervals with durations of ~7-21 days. All are positive in sign at C0010, with consistent magnitudes of ~0.3-0.9 kPa; at Site C0002 three are negative in sign and two are positive, with magnitudes of ~0.3-0.7 kPa. The remaining two events are larger (1.7-2.7 kPa), exhibit a negative sign at both sites, and occur immediately following: (1) the Mar. 2011 M9 Tohoku earthquake; and (2) a sequence including an Apr. 1 M6 thrust event on the plate interface nearby and the Apr. 16 M7 Kumamoto event. In most cases, the pressure transients are accompanied by swarms of VLFE on the shallow plate interface. We interpret the pressure signals to reflect volumetric strain in response to SSEs. Simple dislocation models illustrate that the data at both sites are well fit by slip of ~1-2 cm on a patch at the plate interface that extends 20-40 km in the down-dip direction, and is centered beneath Site C0002 (spontaneous events) or slightly updip (triggered events). This coincides with a region of the megathrust characterized in previous studies by anomalously low V_p, and elevated pore fluid pressure. The repeating nature of the events, taken together with apparent triggering by regional earthquakes, indicates that the outermost reaches of the subduction megathrust are highly sensitive to perturbation and are perched near a state of failure.

Initial findings of post-cruise research on IODP Expedition 352 hard-rock cores I: Petrology and geochronology

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IODP Expedition 352 drilled a nearly complete volcanic sequence in the Ogasawara/ Bonin fore-arc associated with subduction initiation in the western Pacific. Four sites were cored. The two deepest sites, U1440 and U1441, sampled fore-arc basalt (FAB), and the two shallower sites, U1439 and U1442, sampled a wide variety of boninites. Preliminary $^{40}Ar/^{39}Ar$ ages for FAB from Site U1440 stretch back to about 52 Ma, with several younger ages that we attribute to alteration. Major element data for FAB resemble those of highly depleted mid-ocean ridge basalts (MORB). Incompatible trace element concentrations are exceedingly depleted. Exceptions are variable enrichments in fluid-soluble elements such as Rb, K, and U in FAB whole rocks. However, these enrichments are absent or weakly expressed in FAB glasses, and thus are most likely the result of sea-floor alteration. FAB glass compositions are noteworthy in their unusually high Cl concentrations and H_2O/Ce compared with MORB glasses. Parental magmas for FAB thus appear to have been generated by melting of a highly depleted mantle source in the presence of fluids driven off the newly subducting plate. Rare andesite glasses in Hole U1440B appear to be the products of FAB differentiation involving assimilation of altered basaltic crust.

All lavas from Sites U1439 and U1442 are boninitic with considerable enrichments in fluid-soluble elements, presumably from the newly subducting Pacific plate. Preliminary $^{40}Ar/^{39}Ar$ ages of the boninites range from ~52-50 Ma from sites U1439 and U1442, respectively. The lowermost cores of Hole U1439C consist of fine-grained dolerites with rare chilled margins, suggesting they could represent the feeder system for the overlying lavas and tephras.[1] However, trace element concentrations in clinopyroxene phenocrysts from this basal section suggest that they represent a compositionally transitional unit between boninite and FAB. The sheet flows, pillow lavas, and hyaloclastites that make up the majority of cores from these sites are low-Si boninites. The oldest boninite age from Site U1439 indicates that boninites began erupting within the same time frame as FAB. This age is significantly older than the ages of boninites found on the nearby Ogasawara Ridge[2], which lengthens the duration of boninite magma generation in the nascent IBM system to at least 7 million years. High-Si boninites cap the stratigraphy at both sites. One high-Si boninite from Site U1442 was dated at ~50 Ma, indicating that volcanism persisted at our boninite sites for ~2 million years. Overall, REE concentrations in boninites generally decrease up-section, and change from LREE-depleted to LREE-enriched, reflecting an increase in subduction flux with time. Zr/Sm ratios increase up section, which we attribute to Zr mobility. Major element data imply melting depths shallowed over time. These data are consistent with initial production of basaltic crust during rapid sea-floor spreading immediately after subduction initiation at about 52 Ma with minimal involvement of fluids from the subducting Pacific plate. Within about 10^5 years, fluids from subducting Pacific lithosphere became involved in mantle melting to generate first low-, then high-Si boninites. The

persistence of boninitic volcanism at Sites U1439 and U1442 suggests that the dynamics of magma genesis transitioned from sea-floor spreading towards central-vent volcanism about the time boninites began erupting.

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Keywords: Subduction initiation, Basalt, Boninite, Ogasawara

IODP deep riser stratigraphic drilling in the southwest Pacific: tectonics, climate and ancient life on the Lord Howe Rise continental ribbon

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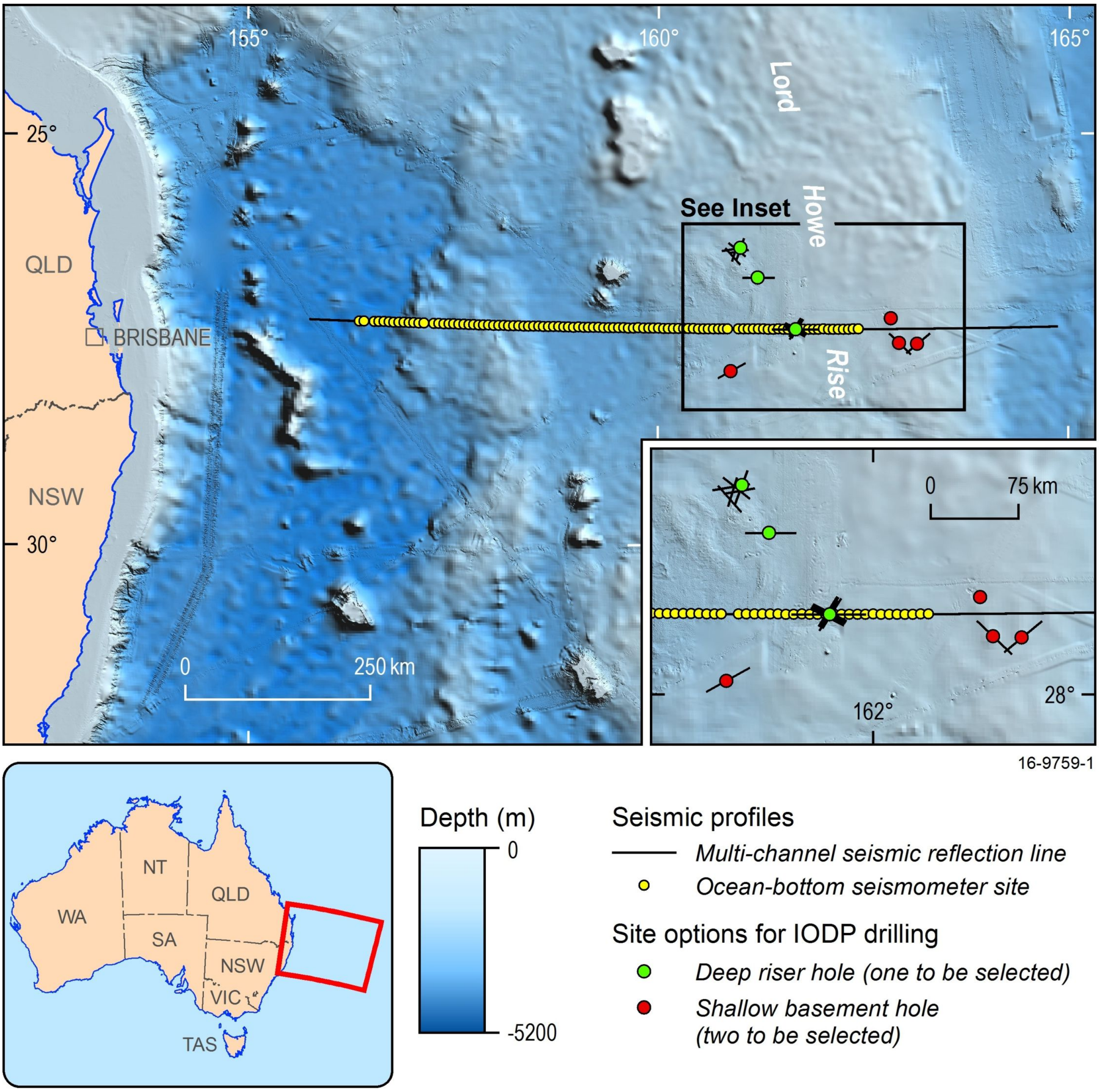
The Lord Howe Rise is a ribbon of submerged and extended continental crust that separated from Australia during the Late Cretaceous. The Lord Howe Rise is remote and concealed beneath the Tasman Sea in water depths of 1000–3000 m, therefore current knowledge of Lord Howe Rise geology is based on sparse shallow (<600 m below-seafloor) DSDP drilling into Cenozoic pelagic sediments, isolated dredge samples and regional-scale marine and satellite geophysical data.

Existing data provide a limited understanding of the Lord Howe Rise’s crustal structure, sedimentary basin architecture and resource potential. However, building knowledge of Lord Howe Rise geology, and the geological evolution of the southwest Pacific more broadly, requires drilling into rocks that record the >100-million-year geological, tectonic and climatic history of the region. To this end, Geoscience Australia and JAMSTEC are leading an international effort to drill a deep stratigraphic well through a Lord Howe Rise rift basin that will core Cretaceous and older sediments and potentially basement rocks. This deep riser drilling will extend to a depth of up to about 2500 m below the seafloor. Two shallow, non-riser holes may also be drilled up to ~500 m below the seafloor into basement horst blocks.

A proposal for drilling using the JAMSTEC drilling vessel CHIKYU was submitted to the International Ocean Discovery Program (IODP) in October 2015 (Proposal 871-CPP) and was rated “excellent” by the IODP Science Evaluation Panel in January 2017. The objectives outlined in this IODP proposal are to: 1) define the role and importance of continental crustal ribbons, like the Lord Howe Rise, in plate tectonic cycles and continental evolution; 2) recover new high-latitude biomarker and micropaleontology data in the southwest Pacific to better constrain Cretaceous paleoclimate and linked changes in ocean biogeochemistry; and 3) test fundamental evolutionary concepts for sub-seafloor microbial life over a 100-million-year timeframe.

The deep stratigraphic drilling is planned for 2019 or 2020, subject to funding approval. Preparations for drilling include a seismic survey conducted in the first half of 2016 that acquired 2D seismic reflection and refraction data along an east–west transect across the Lord Howe Rise to map regional crustal structure and 2D seismic reflection data at the prospective drill sites. Results from this survey helped to better constrain depth to and character of the basement beneath the proposed drill sites and suggest that the crust beneath the Lord Howe Rise is about 20 km thick. Initial velocity models also provide evidence of crustal segmentation linked to lineaments that align with fracture zones in the Tasman Sea oceanic crust. A second survey in late 2017 will acquire the geotechnical data necessary to successfully drill a deep stratigraphic well. This detailed site survey will also acquire high-resolution seabed and shallow sub-seafloor data, shallow sediment cores (up to 20 m below-seafloor) and underwater video.

Keywords: continental ribbon, southwest Pacific, Gondwana, Chikyu, IODP, Lord Howe Rise



Mantle Drilling Projects: M2M, Fore Arc M2M and ICDP OmanDP

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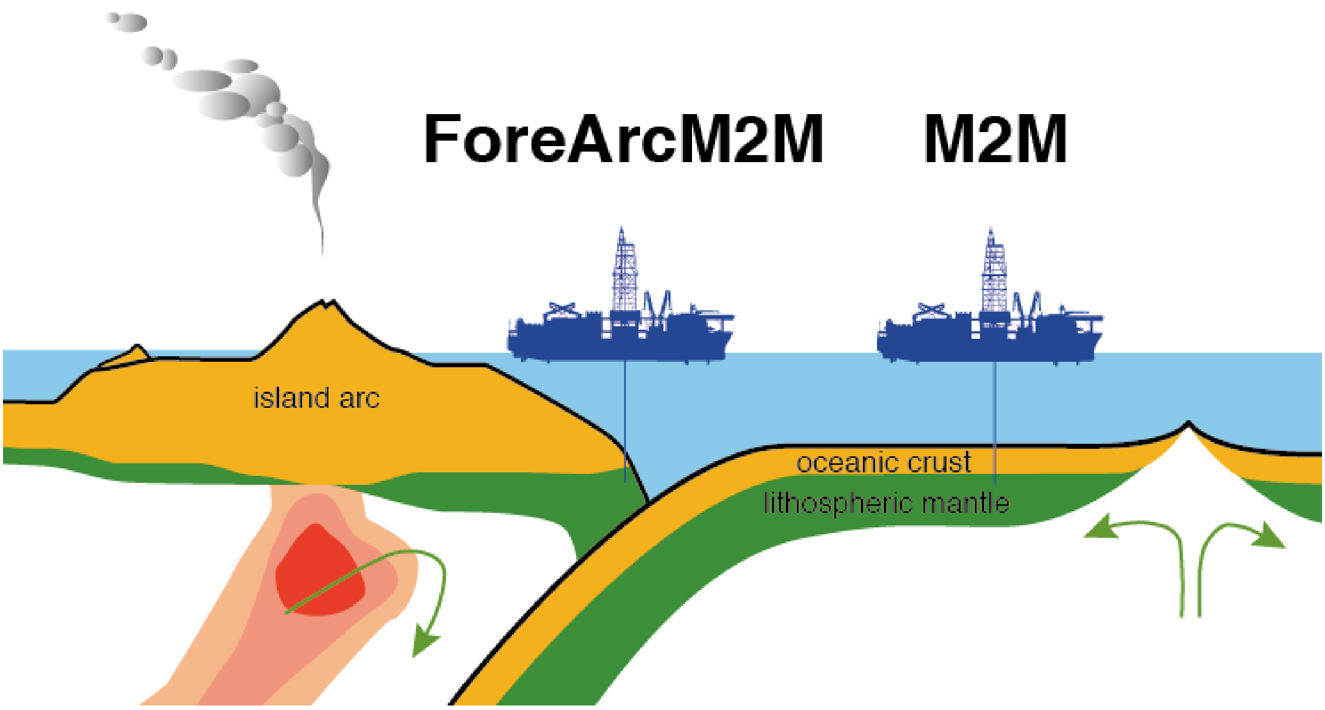
Drilling into mantle has been a long-time aspiration since the first Mohole project in 1961. The (Moho-to-Mantle) M2M project, submitted to IODP in 2012, addressed the reachable goals of sampling the *in situ* upper mantle peridotite and investigating the nature of the Mohorovicic seismic discontinuity (Moho) with the drilling vessel *Chikyu*. The growing technology can accomplish the proposed drilling through ~6,000 m of igneous oceanic crust formed from a fast-spreading ridge, and an additional ~500 m into the ocean lithosphere mantle. Fore Arc M2M project has been submitted to IODP in April 2016 for sample relatively young oceanic mantle. The target site of Fore Arc M2M is the fore-arc mantle/crust section exposed on the landward slope of the Bonin Trench, near the drill sites for the recently completed IODP Expedition 352 and will sample the fresh lower igneous crust and the uppermost mantle peridotite, including the intervening boundary layer, that were accreted during the tectonism and magmatism associated with initiation of subduction at ~52-48 Ma. The Samail Ophiolite, in Oman and the United Arab Emirates, is the largest, best-exposed section of oceanic lithosphere in the World. The Oman Drilling Project (OmanDP) is a comprehensive ICDP drilling program that will sample the whole ophiolite sequence, from crust through to upper mantle, in a series of diamond- and rotary-drilled boreholes. The OmanDP in Phase I has already been achieved in early December 2016, through April 2017. Phase II is scheduled for autumn/winter 2017/2018. Moreover, drilling cores in Phase I will be sent to the IODP research drilling vessel *Chikyu* in Japan for core description by its dedicated core logging facilities in mid-July to mid-September 2017.

Keywords: Mantle Drilling, Oman Ophiolite, Ogasawara/Bonin Trench, Peridotite



Project SloMo - Drilling through the lower crust to Moho at the SW Indian Ridge

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Project SloMo is a complex two-phase program to drill through the lower crust to Moho at the SW Indian Ridge at Atlantis Bank on a wave-cut platform flanking the Atlantis II Transform at 32°42′S, 57°17′E on ~11 Ma crust. The ~24 km^2 platform sits in 700-m of water at the center of a ~400-m^2 gabbro massif. A sub horizontal contact between the gabbro massif and mantle peridotite is exposed along the transform wall for 30 km at 4,200 m depth below the platform, and ~4 km above seismically determined Moho. IODP Hole 735B was drilled to 1508 m during Legs 118 in 1987 and 176 in 1997 ending with an engineering accident that permanently blocked the hole. The drilling conditions and recovery (ave. 87%), however, were the best ever encountered in a hard rock hole in the oceans. Thus, with the upper ocean crust removed by tectonics and erosion and its shallow depth, it is the optimal location for a deep drill hole to Moho on any slow or ultraslow spreading ridge. Phase 1 of the project plan is to use the JOIDES Resolution to drill to 3 km. Based on the geology, it is believed that the crust-mantle boundary beneath Atlantis Bank lies 2-3 km above Moho, which may be a serpentinization front in the mantle. If this is the case, then there may be an entirely new planetary biosphere beneath slow and ultraslow spreading crust as serpentinization is a methanogenic process that would provide food for life. This project, then, not only seeks to recover the full section of the lower crust and the crust-mantle transition, to determine the true nature of Moho at an ultraslow spreading ridge, but also to see if life on earth extends to greater depths than previously believed. SloMo consists of two phases: Phase 1 will use the JOIDES Resolution to drill to 3-km, while Phase 2 will bring Chikyu to the site to drill to 500-m below seismically determined Moho. Phase 1 of the SloMo project began with Expedition 360 in December and January 2015-2016 establishing Hole U1473A. Expedition 360 drilled to 790 meters below seafloor, with total recovery of 59%. Subsequently, Expedition 362T deepened the Hole to 809.4 m while doing remediation work. The Hole is currently in good condition and suitable for reentry to drill to the crust-mantle boundary, believed to lie at ~2500 mbsf. The cores and logs show that the basic stratigraphy of Hole 735B is continuous across the Bank to Hole U1473A ~2 km to the north, which is critical as the SloMo Project seeks to create a seismic laboratory where in-situ velocity measurements can be made hole-to-hole to directly determine seismic velocities in the lower crust in situ, and for placing receivers down hole to avoid surface bounce and the complications presented by the extreme topography of slower spreading ridges. It is anticipated that the site will be reoccupied in three to four years once the Resolution re-enters the Atlantic. Due to long transit times for Expedition 360, and an emergency port call in the middle of the expedition it will require two additional expeditions to reach the target depth of 3,000 m.

Keywords: Moho, gabbro, peridotite