IODP
INTEGRATED OCEAN DRILLING PROGRAM

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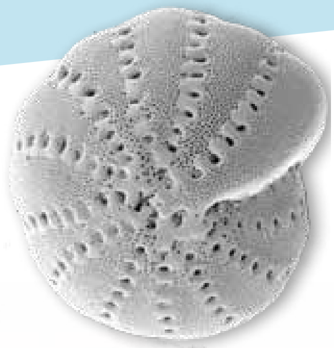

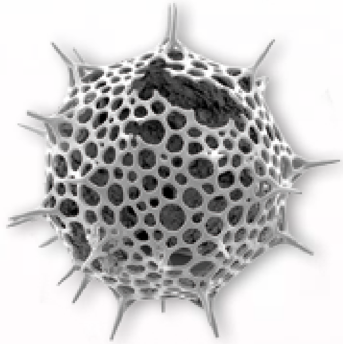

NATURAL ENVIRONMENT RESEARCH COUNCIL

ECORD
European Consortium for Ocean Research Drilling

IODP Highlights

- UK scientists on 7 expeditions in 2009
- Grants: UKIODP held 2 grant rounds in last year with approximately £2.5m in funding awarded

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Front cover: The *Joides Resolution* leaving Hawaii for Expedition 321 © Bill Crawford, TAMU; Microfossils from Expedition 323 in the Bering sea
Back cover: The *Greatship Maya* © D. Smith, ECORD IODP; Microfossils from Expedition 323 in the Bering sea

Foreword

Dayton Dove (UK–IODP Science Programme Coordinator), Mike Webb (UK–IODP Programme Manager),
Mike Bickle (UK–IODP Science Advisory Panel Chairman)

2009 was a very active year for IODP, with UK scientists participating in 7 expeditions, and over 20 peer–reviewed papers published as a direct result of UK–IODP funded research. This activity has persisted into 2010 with UK scientists sailing on the first 2 expeditions of the year.

JOIDES Resolution resumed drilling after her refit in March 2009 with the two Pacific Equatorial Age Transect Expeditions followed by Shatsky Rise, Canterbury Basin and Wilkes Land and is due to resume drilling in July with Juan de Fuca Hydrogeology, Cascadia CORK, South Pacific Gyre Microbiology, Louisville Seamount Trail in 2010 and Costa Rica Seismogenesis Project (CRISP) and Superfast Spreading Rate Crust 4 in the first part of 2011. ECORD completed two mission specific platform expeditions in the last year with New Jersey Shallow Shelf from April to July, 2009 and Great Barrier Reef Environmental Changes from February to April, 2010. The Chikyu completed NanTroSEIZE Stage 2 Expeditions: Riser/Riserless Observatory 1 and Subduction Input in 2009 and will commence NanTroSEIZE Stage 3: Plate Boundary Deep Riser 1 in July 2010 followed by Deep Hot Biosphere, NanTroSEIZE Stage 2: Riserless Observatory 2 and NanTroSEIZE Stage 2: Inputs Coring 2 and Heat Flow in 2010.

In 2009 the UK–IODP funded the grant round: "Ice sheets and sea level reconstructions and sensitivity'. Another, £1.5 m directed small and standard grants round has only just closed with excellent proposal pressure on topics ranging from plate–boundary geodynamics to microbiology and biogeochemical impacts, and feedbacks of the marine biosystem. Grant round science meetings will be held this year for the 2008 'Forcings and Feedbacks' and 'Ice–sheets/sea–level' rounds. The latter is set to be held in conjunction with the international PALSEA meeting this coming fall, an excellent opportunity for awardees to share their research with international colleagues, and to increase the visibility of IODP science in the UK.

For the UK–IODP management, the past year has also been a year of transition as Dayton Dove replaced Heather Stewart as the Science Programme Coordinator, and Mike Webb replaced Chris Franklin as Programme Manager.

The team has now set its sights on UK–IODP programme Renewal post–2013, when the current programme will expire. This process is being conducted concurrent to, and interactively with the international effort to shape the post–2013 ocean drilling programme.

In the past year, the process has begun in earnest to outline what a new ocean drilling programme will look like post–2013. To concentrate the priorities of the international community, the INVEST conference was held in September 2009 to define the scientific goals and technology requirements for a new program. The UK–IODP funded over 20 scientists to attend the meeting with 4 session chairs, underlining the prominence of UK scientists within the IODP.

For the UK–IODP, the first step in this process is to compile a body of evidence which describes the achievements and value of the current programme, but also gathering information/advice that will actuate greater effectiveness in a future program. Outside of the internal evidence gathering, we strongly encourage external input, from the UK–IODP community to the wider academic and user communities. To achieve this, we distributed questionnaires in the UK and internationally to solicit feedback on the UK programme: www.nerc.ac.uk/research/programmes/ukiodp/events/review/. We have had an excellent response which will ensure that we build a fully informed assessment of the benefits and impacts of the UK's involvement within IODP.

What started as the UK Industrial Liaison Panel (ILP) has now evolved into the ECORD ILP. This group has focussed its attention on encouraging industry support of Arctic scientific drilling. With significant input from the UK, they will soon release a brochure on the subject, and a workshop will be organized in the coming year.

Ongoing expeditions

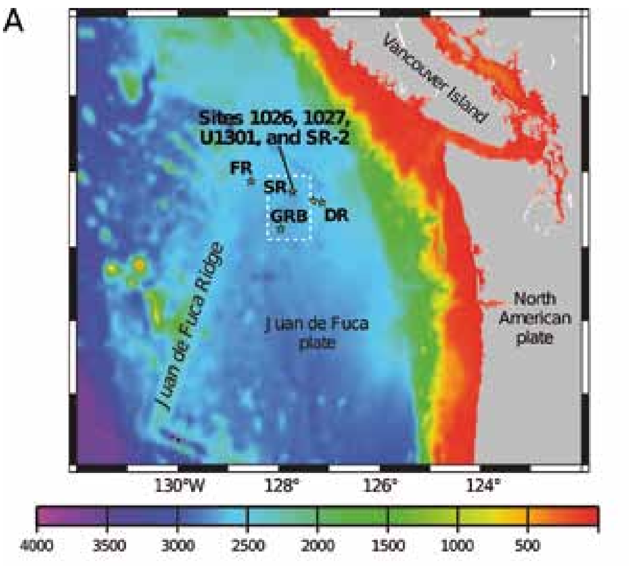
IODP Expedition 327: Multidirectional cross–hole experiments

Juan de Fuca Ridge–Flank Hydrogeology, Episode III

Jennifer Rutter and Michelle Harris
Shipboard participants (Inorganic geochemist and Petrologist)
School of Ocean and Earth Science, National Oceanography Centre, Southampton, University of Southampton

July 2010 will see the return of *JOIDES Resolution* to the eastern flank of the Juan de Fuca Ridge in the northeast Pacific Ocean for the next chapter in an ongoing IODP experimental program investigating the formation–scale hydrogeologic properties within the oceanic crust. Expedition 327 will add to two decades of scientific achievements and lessons learned in this area including multiple survey, drilling, submersible and ROV expeditions; long–term observatory and laboratory testing and sampling; and modelling of coupled fluid–thermal–chemical–microbial processes.

Hydrothermal circulation of seawater through oceanic crust is a globally important process impacting the physical, chemical and biological evolution of oceanic lithosphere and the oceans. The Juan de Fuca ridge–flank study is motivated by the largely unresolved complexities of hydrothermal circulation at ridge–flanks. Heat flow studies indicate that two thirds of convective heat loss occurs in crust older than 1 Ma (Stein and Stein 1994) although at significantly lower temperatures than black smoker chimneys associated with axial hydrothermal systems. Ridge flanks represent a greater proportion of the hydrothermal circulation system with the global advective heat loss from ridge flanks three times that of the axis (Elderfield and Schultz 1996). Lower temperatures means this requires a fluid flux ten times that of axial emissions to dissipate, making fluid volumes comparable in magnitude to the annual global riverine flux to the ocean. Ridge–flank circulation generates enormous solute fluxes, profoundly alters basement rocks, supports a vast subseafloor biosphere and continues to influence the thermal, mechanical and chemical states of subducting plates at the trench. Quantification of ridge flank processes is critical for understanding ocean–ocean crust chemical, physical and biological interactions.



Juan de Fuca Ridge–Flank study area

The Juan de Fuca ridge flank study area is located on the eastern flank of the Juan de Fuca Ridge (JdFR) and ocean crust here formed along the Endeavour segment at ~3 cm/yr (Figure 1A). The study site provides an excellent experimental location because it features a variety of structures common to ridge flanks such as extrusive igneous basement overlain by sediments, abyssal hill topography, high angle faulting and basement outcrops. The sedimentation rates in this region are higher than average due to the abundant Pleistocene glacial sediments derived from the North American continental margin, and results in relatively young buried basement. This creates hydrologically and thermally isolated young (1 Ma) ocean crust with strong lateral pressure and temperature gradients, ideal for the study of ridge flank hydrothermal processes.

Through the integration of previous results and the proposed targets of Expedition 327, key first order questions about crustal hydrology and evolution will be addressed.
These include:

- What is the distribution of hydrogeologic properties in upper oceanic crust?
- To what extent are crustal compartments connected/isolated, both laterally and with depth?
- What are the linkages between ridge–flank circulation, hydrothermal alteration and geomicrobial processes?

Figure 1A.
Site Maps for Expedition 327. An index map of the field area. This also shows the ODP leg 168 transect and sites from IODP Expedition 301.
SR = Second Ridge; GRB = Grizzly Bare, FR = First Ridge, DR = Deep Ridge.

ODP Leg 168 and IODP Expedition 301

ODP Leg 168 focused on hydrothermal processes within uppermost basement rocks and sediments along an 80 km age transect from 0.9 to 3.6 Ma perpendicular to the ridge axis. The ten sites studied (Sites 1023 to 1032) covered three hydrothermal regimes: the hydrothermal transition zone between hydrologically open and sedimented crust (Sites 1023, 1024 and 1025), rough basement (Sites 1026 and 1027) where sediment thickness and basement topography are variable and influence fluid flow, and buried basement (Sites 1030/1031, 1028, 1029 and 1032) where continuous sediment coverage prevents local fluid and thermal exchange. Basement from the sediment–basement interface was recovered at nearly all sites with a maximum cored interval of 66.3 m at Site 1026. Subseafloor borehole observatories (CORKs) were installed in Holes 1024C, 1025C, 1026B and 1027C. Results from borehole packer experiments, fluid geochemistry and thermal data provided evidence for both across–strike and along–strike fluid flow. However, the limited depth penetration into basement along the Leg 168 transect left many unresolved questions.

IODP Expedition 301 sought to investigate fluid flow through the buried basement section at the Second Ridge area (near Holes 1026 and 1027) by the drilling of four new holes (U1301A, B, C and D) of which U1301A and U1301B penetrated 108 and 318 m respectively into basement (Fisher, Urabe, Klaus, et al., 2005) (Figure 1B). CORKs were installed in both basement holes and the existing CORK in Hole 1026B was replaced. Upper basement experiments in Hole 1301B revealed a layered crustal structure with permeabilities of around 10–12 to 10–11 m^2 (Becker and Fisher 2008). Differences between this result, modelled permeabilities and observations from the Leg 168 transect can be explained by azimuthal anisotropy in basement hydrogeologic properties. This hypothesis will be tested directly during and after IODP Expedition 327 when multidirectional cross–hole experiments will be undertaken.

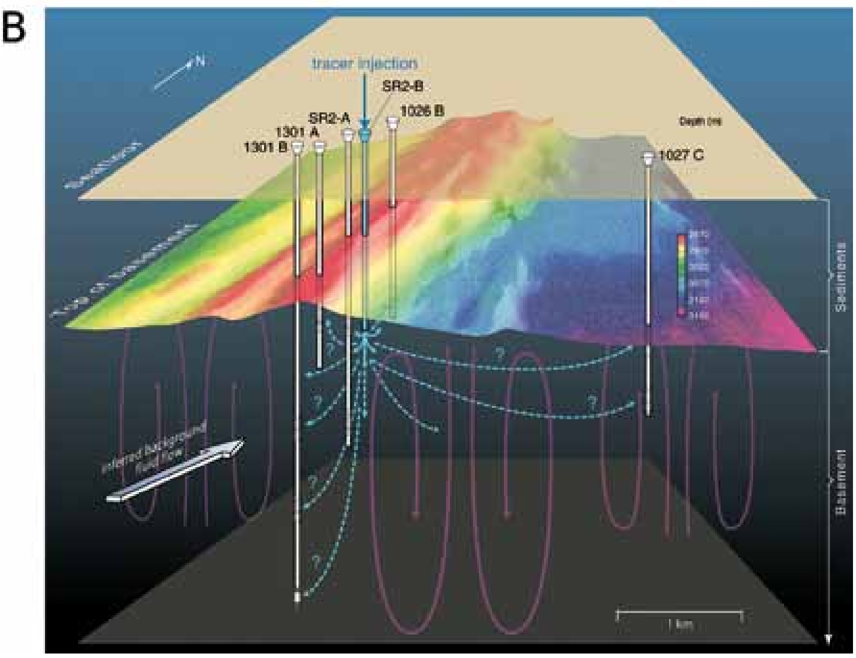


Figure 1B. Site Maps for Expedition 327.
Diagram showing the relative locations of pre–existing and planned CORK laboratories.
SR2–A and SR2–B are to be installed during IODP Expedition 327.

IODP Expedition 327

Expedition 327 is the second stage of the project in the Second Ridge area and has four primary objectives. The first priority for IODP Expedition 327 will be to drill two new basement holes at a new site (SR–2) parallel with the peak of the buried basement ridge, located ~200 m SSW of existing Hole 1026B and ~800 m NNW of Hole U1301B (Figure 1B). One of these Holes (SR–2A) will penetrate ~260 msb (metres sub–basement) and the second (SR–2B) will be a shallow basement hole (~70 msb) and both will have CORKs installed. The addition of these two new drill holes is the final stage in establishing a network of sealed borehole observatories capable of multidirectional cross–hole experiments. These Holes will host a series of experiments to evaluate the vertical distribution of permeable zones prior to CORK installation, which will evolve into a long–term 'packer' experiment in the shallower Hole SR–2B. The long test duration and scale make this fundamentally different from any experiments completed previously.
A combination of seawater and geochemical tracers (SF6, fluorescent spheres and stained cells) will be pumped into Hole SR–2B and the surrounding CORKs will be monitored for 3–4 yrs to assess the rate and geometry of fluid circulation in upper oceanic basement. The magnitude and timing of pressure responses detected at the nearby CORKs will contribute to quantifying crustal properties such as the nature of permeability anisotropy and vertical and horizontal compartmentalization.

The CORK systems to be used in IODP Expedition 327 differ from earlier models and will have a two–packer system to ensure the seal lasts for several years (Figure 2). The CORKs will measure short–term formation pressure responses to packer experiments, and will include instruments for seawater sampling and microbial studies. The CORK installed in Hole SR–2B will also have a 4 inch ball valve that will be opened a year after installation by ROV/submersible to allow a cross–hole hydrogeologic experiment to be conducted.

The other three primary objectives of Expedition 327 relate to the recovery and replacement of existing CORK observatories at Hole 1027C and U1301B. Hole U1301B will also be deepened and cored for ~40 m. The final objective is to undertake remedial cementing work at Hole U1301A.

Following Expedition 327 single and cross–hole experiments will be conducted through submersible expeditions making use of the anticipated complete multi–directional network of 6 observatory systems, utilising CORKs as perturbation and monitoring points. It is hoped that the long–term, cross–hole hydrologic experiments proposed for Expedition 327 will resolve first order questions regarding heterogeneity, flow channeling, scaling and anisotropy in transmission and storage properties in ocean crust. These plans complement IODP scientific plans to establish a cabled network of seafloor observatories across the Juan de Fuca plate.

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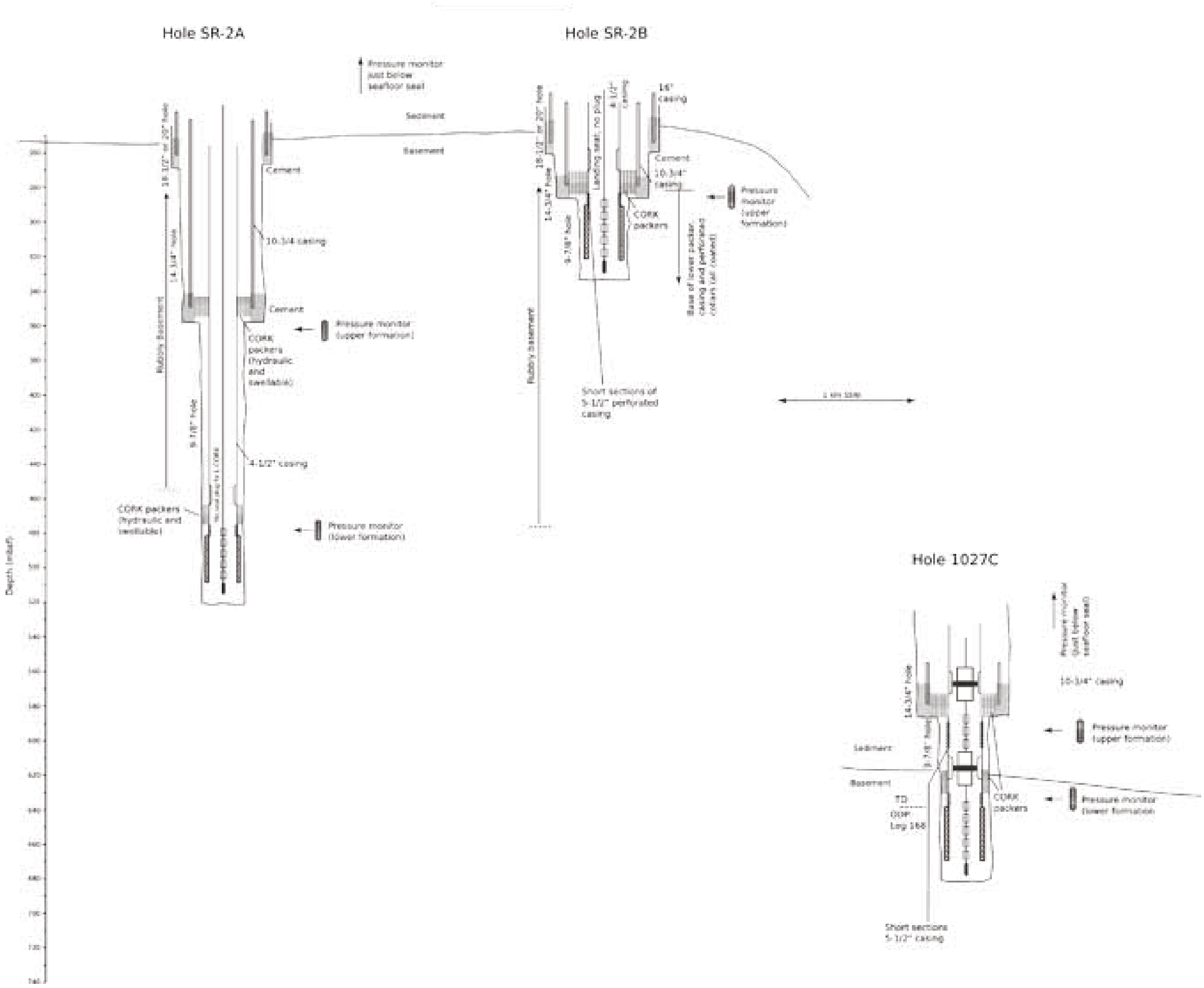


Figure 2. Schematic diagram of CORKs to be installed during IODP Expedition 327.
Seals at the sediment–water interface close open drill holes so that thermal, pressure and chemical conditions can equilibrate following the disruption of drilling. Once installed, pressure and temperature measurements are taken at different levels in the basement, as well as fluid and microbiological samples.

Very recently completed expeditions

IODP Expedition 318: Wilkes Land Glacial History, Antarctica

January 4th–March 9th 2010

Steven Bohaty (University of Southampton), Tina van de Flierdt (Imperial College London), James Bendle (University of Glasgow), Carlota Escutia Dotti (Research Council of Spain–University of Granada), Henk Brinkhuis (Utrecht University), Adam Klaus (Texas A&M University), and the IODP Expedition 318 Shipboard Science Party

Cruise Objectives

Understanding the evolution and dynamics of the Antarctic ice sheets, from their inception during the Eocene–Oligocene transition (~34 million years ago) through subsequent periods of coupled climate and atmospheric CO_2 changes, is not only of major scientific interest but also of great importance for society. In times of rapidly rising atmospheric carbon dioxide concentrations, it is vital to improve our understanding of mechanisms and rates of climate change in the past. Drillcores from high–latitude sites, in particular, hold the potential to vastly improve our understanding of forces and feedbacks in the natural climate system.

Drilling at high latitudes is however associated with more significant operational difficulties than at low latitudes. Weather and ice conditions, as well as the often unconsolidated and coarse–grained nature of glaciomarine sediments, make scientific drilling a difficult challenge in polar environments. Around Antarctica, this challenge has only been faced a few times in the ~40 year history of the Integrated Ocean Drilling Program (IODP) and its predecessor programs. Deep Sea Drilling Project (DSDP) Leg 28 was the first major drilling expedition to venture into Antarctic waters in 1973, drilling several sites both in deep waters off the East Antarctic margin and in shallow waters on the Antarctic shelf in the Ross Sea. This pioneering cruise was subsequently followed by four return expeditions to Antarctic waters: Ocean Drilling Program (ODP) Leg 113 (Weddell Sea, 1987), ODP Leg 119 (Prydz Bay, 1988), ODP Leg 178 (Antarctic Peninsula, 1998), and ODP Leg 188 (Prydz Bay, 2000). All of these cruises have added substantially to our knowledge of Antarctic glacial history, but many fundamental gaps remain.

For the science community, IODP Expedition 318 was hence the long–awaited return to the Antarctic margin. The Wilkes Land margin of East Antarctica was chosen because it is a key region for analysis of the long– and short–term behaviour of the East Antarctic Ice Sheet (EAIS). A significant proportion of the EAIS drains along the Wilkes Land coast, and the Wilkes Land and Adélie Land continental shelves represent the seaward termination of the Wilkes and Aurora subglacial basins–the two largest subglacial basins in East Antarctica. These basins are areas where the large ice sheet is grounded below sea level and are hypothesised to be the first places in East Antarctica to become unstable in a future warming world. Therefore, determining both the timing of initial glaciation and the dynamics of subsequent ice–sheet oscillations along the Wilkes Land margin can provide critical information that is representative of a large region of East Antarctica. Moreover, this information is crucial for incorporation into state–of–the–art climate models, aimed at both understanding ice–sheet behaviour over long intervals of geologic time and predicting future EAIS behaviour. Prior to Expedition 318, long cores had not been previously drilled on the Wilkes Land margin; thus, the newly recovered cores from this area have the potential to reveal many new and important aspects of Cenozoic ocean and ice–sheet history of Antarctica.

Expedition 318, led by co–chiefs Carlota Escutia Dotti (Research Council of Spain–University of Granada) and Henk Brinkhuis (Utrecht University), was designed to decipher the long–term record of Antarctic glaciation, and its intimate relationship with global climatic and oceanographic change. Drilling of sedimentary archives along an inshore to offshore transect was planned to address the three following primary objectives:

- (i) The timing and nature of the onset of glaciation during the Paleogene at the Wilkes Land margin (East Antarctica)
- (ii) A high–resolution record of Antarctic climate variability during the late Neogene and Quaternary
- (iii) An unprecedented, high–resolution record of Holocene climate variability

Figure 1. IODP Expedition 318 shipboard science party. (Photo: John Beck)

Drilling Operations

The research vessel *JOIDES Resolution* departed Wellington, New Zealand, on 9 January 2010, staffed with a science party of 33 members assembled from 11 different nations (Figure 1). In addition to the usual complement of staff and crew, two specialists were added to the shipboard team to help guide operations in the challenging environment off the coast of Antarctica. A senior weather forecaster with previous high–latitude expedition experience, Kjell Bäckvall, joined the vessel to provide analysis of the capricious weather environment of the Southern Ocean. Diego Mello, a seasoned ice observer with extensive familiarity in both the Arctic and Antarctic regions, also joined the expedition. Dedicated work by both Kjell and Diego enhanced the safety of the vessel and allowed the crew to maximize on–site operational flexibility throughout the cruise.

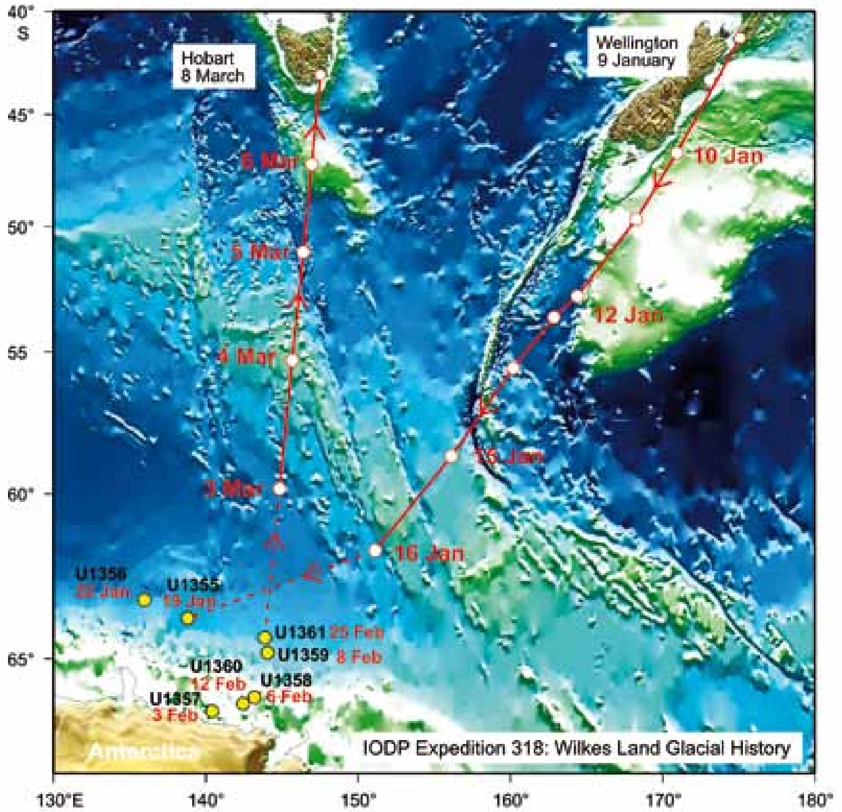
After leaving port in Wellington, the Resolution embarked on a 9 day transit to the first drill site on the Antarctic margin. Once the vessel moved past of the protection of Auckland Island to the south of New Zealand, it was exposed to the open expanse of the Southern Ocean and the powerful low–pressure systems that populate this region. The vessel negotiated through intense winds and sea conditions for several days during the transit. Frequent course changes and reductions in speed were made to avoid the most intense parts of a large and severe low–pressure system that crossed the projected ship track. Although the vessel remained on the other edge of the system, the combined sea and swell reached 40 feet and the winds were clocked as high as 60 knots.

Expedition 318 drilling commenced on 18 January 2010 at IODP Site U1355. Over the course of the next 6 weeks, seven sites (Sites U1355 to U1361) were drilled along the Wilkes Land margin of Antarctica (Figure 2) at water depths ranging between ~500 and 4000 m. Despite being subjected to several large storms and navigating heavy ice conditions on the shelf throughout drilling operations, ~1970 m of core was recovered during the cruise along a transect from the shelf to the deep sea. The average recovery rate for coring during the entire cruise was ~64%.

The sediments obtained during Expedition 318 constrain the age and nature of both the marine and terrestrial environments before and after large Antarctic ice sheets appeared (Expedition 318 Scientists, 2010). Together, they document ~53 million years of Antarctic history (Figure 3), and they tell the tale of Antarctic's climate history from the ice free, warm 'greenhouse' of the early Eocene to the fully 'icehouse' climates of the Late Neogene. As such, core material recovered on Expedition 318 provides a wealth of material for a wide range of research investigations, including the weathering and climate regime of East Antarctica under ice–free conditions, the erosional consequences of the first Antarctic glaciers, and the dynamics of the waxing and waning Antarctic ice sheet in more recent geologic epochs (Figure 4). Additionally, a thick, unprecedented 'tree ring style' Holocene record (Figure 5) with seasonal resolution of the last deglaciation that began some 10,000 years ago was also retrieved during the cruise.

Initial shipboard investigation of the Expedition 318 cores reveals that tectonic and climatic change turned the initially shallow broad subtropical Antarctic Wilkes Land shelf into a deeply subsided basin with a narrow, ice–infested margin (Expedition 318 Scientists, 2010). Thick Oligocene–Neogene sediments (from ~33 million years ago to the present), including turbidites, contourites, and larger and smaller scaled debris–mass flows witness the erosional power of the dynamic ice sheet and deep ocean currents. The recovered clays, silts and sands and the microfossils and biomarkers contained within them clearly reveal the transition of subtropical ecosystems and a vegetated Antarctica into sea–ice dominated ecosystems bordered by calving glaciers.

Figure 2. Track map and location of sites drilled on Expedition 318.



The inferred pre–glacial and glacial seismic units were successfully dated through shipboard analysis, and shore–based analysis will also reveal Antarctica's climate dynamics down to sub–orbital timescales.

The successful scientific results of the expedition were also accompanied by the chance to see the very unique and fantastic scenery of Antarctica–a place very few people are able to experience firsthand. Vast fields of large icebergs, the Antarctic coastline, and the East Antarctic Ice Sheet rising in the distance were visible at several points during the cruise when the ship was operating in shelf waters. Following the successful drilling of the Holocene section at Site U1357, the ship also briefly crossed south of the Antarctic Circle (~66.5°S latitude). These experiences, along with numerous spottings of Antarctic wildlife such as whales, seals, penguins, and birds, made for a spectacular personal adventure for all scientists, staff, and crew aboard the *Resolution*.

Outreach Activities

Expedition 318 was also unprecedented in the large effort put into educational outreach activities. Over 30 videoconferences were made by shipboard participants to schools, universities, and museums. Weekly videos were filmed and produced by a shipboard videographer, Dan Brinkhuis (Zcene Moving Media Company), contracted by Ocean Leadership (Figure 6). These weekly episodes, as well as an expedition trailer and an expedition summary in video form, are freely available on the Ocean Leadership YouTube channel: www.youtube.com/user/OceanLeadership

In addition to documenting specific activities related to Wilkes Land drilling, the videos give general information on scientific drilling and day–to–day life on the ship.

Post–cruise Research

After a smooth transit back north across the Southern Ocean, the *JOIDES Resolution* returned to port in Hobart, Australia, on 8 March 2010. Ice conditions stymied some of the planned drilling on the Antarctic shelf, but, overall, the expedition was a

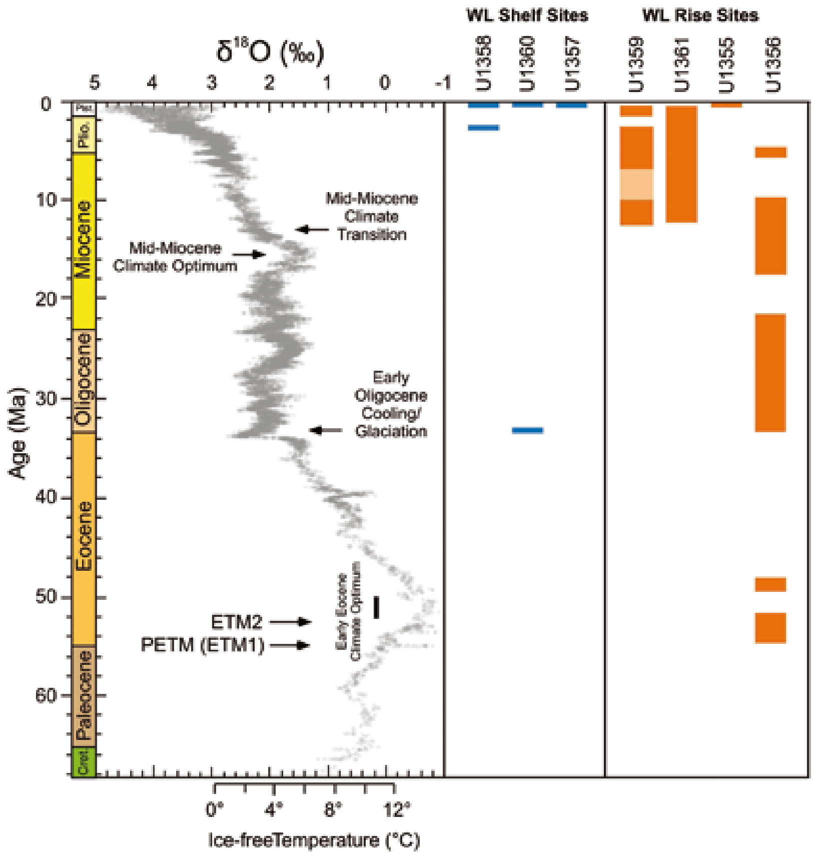


Figure 3. Chronostratigraphy summary of the sites drilled during Expedition 318. The ages of recovered cores are plotted alongside a stacked deep–sea benthic foraminifer oxygen isotope curve for 0–65 Ma, updated from Zachos et al., (2008) and converted to the timescale of Gradstein et al. (2004). [Figure modified from Expedition 318 Scientists (2010)].

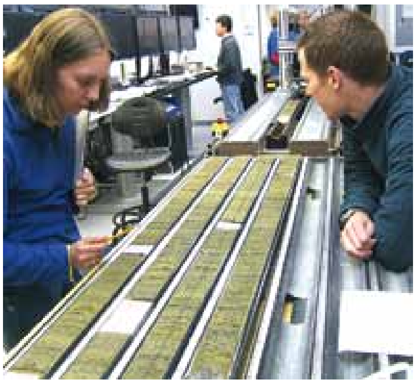


Figure 5. Expedition 318 sedimentologists Sandra Passchier and Rob McKay describing laminated Holocene sediments recovered at IODP Site U1357, with sedimentologist Gee Soo Kong working at a describing station in the background. (Photo: Steven Bohaty)

Figure 6. Production of an episode of "Penguin TV" for the weekly shipboard video on Expedition 318. Back row, left to right: Adam Klaus (staff scientist), Henk Brinkhuis (co–chief), Chieh Peng (chemistry laboratory technician), and Carlota Escutia Dotti (co–chief). Front: Dan Brinkhuis (videographer). (Photo: Christina Riesselman)

great success. Ample core material was recovered to address all of the expedition objectives. Sampling parties are now being planned for June 2010.
Two sampling parties were convened following the cruise in June 2010. The Holocene cores were split, analyzed, and sampled on board the *Resolution* while it was in port in Victoria, Canada. All other cores were sampled at the Gulf Coast Repository in College Station, Texas, USA.

Post–cruise research on Expedition 318 cores will provide significant advances in our understanding of Antarctic climate from the early Eocene to the Holocene. The initial shipboard work already completed will provide a basis for more detailed analyses on the part of a large contingent of researchers, which will include further refinements in the age dating of the cores and development of many proxy indicators of ice sheet dynamics, weathering environment, iceberg discharge, sea–ice development, ocean temperature, ocean circulation, etc. These studies will add a great deal of new information related to Antarctic ice–sheet history. In addition, the unexpected recovery of early Eocene drillcores will provide a source of much new insight into the early Paleogene 'greenhouse' world–a time when warm temperatures around the globe were associated with high atmospheric carbon dioxide concentrations. Recovery of similar strata has never been achieved before on the East Antarctic margin, and initial analysis of the cores points to the widespread presence of subtropical climate conditions in East Antarctica during this time interval. As stated by one of the expedition participants: 'We clearly went where no drill bit has gone before.' Many years of exciting science are sure to follow.
Stay tuned!

UK Participation in Expedition 318

Three scientists sailed as UK representatives on IODP Expedition 318: James Bendle (Glasgow University), Tina van de Flierdt (Imperial College London), and Steven Bohaty (University of Southampton). Collectively, they have a broad range of research specialties and are interested in the entire suite of cores recovered from the Wilkes Land margin.

Figure 4. Ice–rafted debris observed within Miocene strata recovered at Site U1356.

They are currently planning post–cruise collaboration between laboratories at their home institutions and amongst the large international group of scientists involved in the cruise.

James A.P. Bendle (University of Glasgow; organic geochemist on Exp. 318)

James Bendle is a palaeoclimatologist and organic geochemist. He is interested in molecular fossils preserved in ocean sediments and development of proxy records that reveal environmental conditions in the past, such as sea surface and land temperatures. During Expedition 318, James undertook pilot biomarker measurements on core samples ranging in age from early Eocene to Late Miocene (~53 to 5 million years ago). He found that concentrations of biomarkers from plant waxes, soil bacteria and certain marine algae increased by several orders of magnitude in the samples from the Eocene period, when the Antarctic was mostly ice–free and covered in temperate forests. James will continue to extract these biomarkers along with colleagues in the US and the Netherlands to derive terrestrial and marine temperatures from the Eocene 'greenhouse' world, in direct proximity to the Antarctic continent. Moreover, by making sophisticated isotope measurements on biomarker compounds, he also intends to reconstruct environmental parameters such as atmospheric carbon dioxide levels, changes in terrestrial aridity and wetland extent.

Tina van de Flierdt (Imperial College London; inorganic geochemist on Exp. 318)

Tina van de Flierdt is a palaeoceanographer/palaeoclimatologist and isotope geochemist. Tina is interested in learning about the climate of the past from radiogenic isotopes. Radiogenic isotopes can be used to trace or fingerprint certain processes such as ocean circulation, continental weathering and erosion, or simply the provenance of sediments. During Expedition 318, Tina was responsible for measuring the geochemical composition of the sediments and pore waters recovered at each drill site. For her post–cruise research, Tina and her US colleagues will use isotope geochemistry to reconstruct the stability of the East Antarctic ice sheet with a particular focus on the Pliocene warm interval–the last period in the past when global climate was significantly warmer than today. This work will be complemented by modelling work carried out by colleagues in Leeds and in the US. A second post–cruise focus for Tina will be the reconstruction of ocean circulation and weathering patterns across the onset of Antarctic glaciation and throughout the Cenozoic history of the drillcores.

Steven M. Bohaty
(University of Southampton; sedimentologist on Exp. 318)

Steve Bohaty is a palaeoceanographer with expertise in biostratigraphy, stable isotope stratigraphy, and cyclostratigraphy. He is primarily interested in Palaeogene climate history and has focused much attention on the initial development and history of the first large Cenozoic ice sheets on Antarctica. During the cruise, Steve was part of sedimentology group which was tasked with making initial descriptions of the cores. In collaboration with Tina van de Flierdt and colleagues at Imperial College, Steve will focus his post–cruise research on the Paleogene core intervals recovered on Expedition 318. Planned work includes clay mineral assemblage analysis and construction of neodymium–isotope records from fossil fish teeth. The goal of this work will be to deduce the weathering and circulation history along the Wilkes Land margin in the Eocene and Oligocene.

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Figure 7. Shipboard scientists Saiko Sugisaki (palaeomagnetist) and Carlota Escutia Dotti (co–chief) observing icebergs on the deck of the JOIDES Resolution during Expedition 318.
(Photo: John Beck)

Expedition 325 Great Barrier Reef Environmental Changes

February–April 2010

Carol Cotterill (ESO), Jody Webster (University of Sydney) and Yusuke Yokoyama (University of Tokyo)

On February 11th 2010, 65 scientists, technical and operations staff, engineers, drillers, ships crew and 7 mobile lab, reefer and science office containers set sail on the Greatship Maya from Townsville, Australia, bound for the Great Barrier Reef. This offshore phase was the first stage of Expedition 325, led by co–chief scientists Yusuke Yokoyama (University of Tokyo) and Jody Webster (University of Sydney), with the onshore science party soon to commence (July 1st 2010) at the Bremen Core Repository in Germany.

The scientific objectives of this expedition are to define the exact shape of the deglaciation curve for the period 20,000–10,000 cal.y BP; to define SST variations for the region over the same period; and to analyse the impact of sea level and climate changes on reef geometry and growth. A detailed description of the principal objectives can be found in the UKIODP Newsletter 34.

In order to achieve this, 40 potential sites had previously been identified through analysis of site survey and historical datasets and approved by IODP. Following thorough discussions with the Great Barrier Reef Marine Park Authority (GBRMPA) and the Australian Maritime Safety Authority (AMSA), IODP were granted permission to drill a maximum of 45 sites along the five transects identified.

As with all MSP operations, no core splitting and subsequent analysis was conducted during the offshore phase. However, scientists onboard did identify 95 samples from core catcher materials that could be sent for C–14 AMS and U/Th dating prior to the onshore science party commencing. This was to provide a preliminary stratigraphic timeframe to help guide the detailed analyses that will be conducted in Bremen.

Early results from the dating look very promising, indicating that "we have quality if not quantity", and that "the material we have will get us all of the objectives of the proposal". Alex Thomas (University of Oxford), who conducted the preliminary U/Th dating, also stated that the majority of the samples he received had an initial 234U/238U ratio close to that of modern seawater, suggesting that the corals were well preserved.

Early dating results suggest that Expedition 325 recovered fossil reef material from the LGM and beyond, substantially extending the current records of the LGM/PG sea level and climate records for the south pacific, and building on the results from Expedition 310 Tahiti Sea Level. Furthermore, samples from the LGM reef were recovered during this expedition, which is a world first, contributing significantly to the discussion on whether or not this reef existed, or was different to the modern reef structures.

In summary, well developed in–situ coral reef frameworks were recovered from 42–139 m below present sea level, with sediment cores from 42–167 m. There was good recovery from the water depths spanning the pre–LGM, LGM and subsequent postglacial reef sections, with many of the reef frameworks being dominated by shallow, high–energy coralgal assemblages, which will enable precise sea level reconstructions to be undertaken. In addition, extensive sequences of older Pleistocene reef deposits were also recovered from beneath the post glacial reef sections. In total, 34 sites were cored along 4 transects, recovering 225.22 m of core.

It certainly looks like the onshore science party will be an exciting time, as 27 scientists representing 9 countries gather to unlock the secrets held in the GBR fossil corals!

C. Cotterill © ECORD IODP

Scientific results from recent expeditions

Expedition 313: Drilling the continental shelf to provide the missing link in studies of Cenozoic eustasy

Offshore DSP: April 30th and July 17th 2009,

Onshore DSP: November 6th and December 4th 2009.

David M Hodgson, Sedimentologist, University of Liverpool; Stephen Hesselbo, Sedimentologist, University of Oxford; and Expedition 313 Scientific Party

Predicting and mitigating global rise in sea level is a major challenge. The stratigraphy of the continental shelf is an important record of the processes operating during past sea–level change. However, this archive was beyond the reach of scientific investigation until last year.

The third expedition of the Integrated Ocean Drilling Program (IODP) to use a mission–specific platform (MSP), Expedition 313, drilled three boreholes into the New Jersey Shallow Shelf off the east coast of the United States. The expedition was conducted by the European Consortium for Ocean Research Drilling (ECORD) Science Operator (ESO) between April 30th and July 17th 2009, with the onshore science party taking place at the IODP core repository, Bremen, between November 6th and December 4th 2009.

The New Jersey margin has long been known to exhibit classical sequence stratigraphic clinoform geometries in its mid to late Cenozoic successions, and it is these stratal geometries that have been related, albeit speculatively, to eustatic sea–level change. The seismically imaged clinoform surfaces are 100's m deep between the upper and lower inflection points (the 'rollover' and 'toe of slope'), with typical foreset gradients around 1–2 degrees. These clinoforms are, therefore, an intermediate scale between delta–front clinoforms (10's m deep) and basin margin clinoforms (km's deep).

Expedition 313 has three main objectives:

- (1) date late Palaeogene–Neogene depositional sequences and compare ages of the unconformity surfaces that bound these sequences with times of sea level lowerings predicted from the $\delta^{18}O$ glacio–eustatic proxy
- (2) estimate the corresponding amplitudes, rates, and mechanisms of sea level change
- (3) evaluate sequence stratigraphic facies models that predict depositional environment, sediment composition, and stratal geometry in response to sea–level change

The region between the palaeoshoreline and the ancient inner to middle shelf is the most sensitive to past sea level variations. The original Deep Sea Drilling Programme (DSDP) and Ocean Drilling Program (OPD) purposely set out to explore the deep ocean floor, which required use of a drillship that was inappropriate for shallow–water objectives. The difficulty of drilling safely and effectively in shallow water created an information gap, a missing link, within the stratigraphic record on siliciclastic continental shelf. Without data from this gap our understanding of the response of sedimentary systems to sea–level change is much the poorer. The Integrated Ocean Drilling Program (IODP) was conceived, in part, to address this kind of need for more mission–oriented technology. The New Jersey margin, because its geology is known and is easily accessible, is an especially attractive location for documenting sedimentation during times of large sea level change.

Rationale

Elucidating the causes, rates, and impact of changes in sea level is a pertinent objective of Earth system research. Globally, shorelines are encroaching the coastal plain, with the rate of transgression increasing over the last 50 yr: ~1.8 mm/yr in the last half of the twentieth century (Church and White, 2006) and ~3 mm/yr at present (Cazenave et al., 2008). In many coastal regions the rate of rise is even higher because of the additional effect of local subsidence (and extraction of hydrocarbon and water).

The geological record shows that global sea level has fluctuated by well over 100 m at rates as high as 20–40 mm/y (summaries in Donovan et al., 1979; Fairbanks, 1989; Stanford et al., 2006) at various times in Earth's history. Despite the importance, knowledge of the basic amplitudes and rates of sea level variations on timescales of tens of thousands to millions of years is surprisingly limited.

Distinguishing the effects of eustasy from those of subsidence and changing sediment supply requires a fundamental understanding of passive margin response to sedimentation. Deposits adjacent to the shoreline are replete with stratal discontinuities on all spatial scales, including those identified as sequence boundaries which partially comprise regional unconformities (Vail et al., 1977; Posamentier et al., 1988). Sequence boundaries provide a means to objectively subdivide the stratigraphic record (Christie–Blick et al., 1990; Christie–Blick, 1991; Miall, 1991; Catuneanu et al., 2009), and the intervening sedimentary sequences allow an evaluation of controls on sedimentary architecture, and for predicting sedimentary facies. Remarkably similar sequence architecture occurs on margins of widely contrasting tectonic and sedimentary histories (e.g., Bartek et al., 1991), suggesting that eustasy exerts a fundamental, worldwide control on the stratigraphic record.

The nature of facies associated with prograding clinoforms has not been thoroughly documented by scientific drilling (although participants of ODP Legs 166 and 174A made contributions to understanding facies associated with clinoforms). Furthermore, the timing and phase relationships of facies distributions with respect to sea level change have hardly been evaluated (e.g., Reynolds et al., 1991).

Various facies models have been proposed to explain shelf sedimentation in response to eustatic changes (e.g., Posamentier et al., 1988; Galloway, 1989a, 1989b; and Embry, 2008–2009; among others), but the fact remains that the response of passive margin sedimentation to large, rapid sea level changes is poorly known. One of the main reasons for this lack of information is the scarcity of direct sampling of well–imaged seismic sequences in the region most affected by sea level change. Understanding the amplitude of sea–level change and the sedimentary response requires knowledge of the depositional setting of strata that onlap sequence boundaries. Without samples it cannot be known if this onlap is coastal, marginal marine, or deep marine (~100 m or more, as suggested by Greenlee and Moore, 1988, based on seismic stratigraphy of the New Jersey margin).

Apart from depositional setting, several features of the New Jersey margin make it an ideal location to investigate the mid to late Cenozoic history of sea level change and its relationship to sequence stratigraphy: rapid depositional rates, tectonic stability, and well–preserved cosmopolitan fossils suitable for biostratigraphic and chemostratigraphic age control (see summary in Miller and Mountain, 1994). In addition, there exists a large set of seismic, well log, and borehole data with which to frame the general geologic setting from the coastal plain across the shelf to the slope and rise (Miller and Mountain, 1994)

Previous drilling into the New Jersey slope (ODP Sites 902–904 and 1073) and the onshore Coastal Plain has identified sequence boundaries from 10 to 42 Ma based on onshore facies successions and erosion surfaces. Hiatuses have been shown to correlate (within ±0.5 m.yr.) offshore to packages of seismic reflections linked to drill cores on the continental slope and to the history of glacio–eustatic lowerings inferred by the global $\delta^{18}O$ record (Miller et al., 1998, 2005a).

Unconformably bounded sequences are the fundamental building blocks of the shallow–water record (Sloss, 1963; Van Wagoner et al., 1990; Christie–Blick, 1991). Some researchers at Exxon Production & Research (EPR) claimed that similarities in the ages of stratal unconformities pointed to global sea level (eustasy) as the overriding control (Vail et al., 1977; Haq et al., 1987; Posamentier et al., 1988; Van Wagoner et al., 1988). The resulting "eustatic curve" has remained controversial and untrusted (e.g., Christie–Blick et al., 1990; Miall, 1991), largely because of basic assumptions about the stratigraphic response to eustatic change, and because the work relied in part on unpublished data and lack of specific argumentation.

Sedimentary facies between sequence boundaries vary in a coherent fashion, and various models have been proposed to explain observed spatial and temporal patterns in shelf settings (e.g., Posamentier et al., 1988; Galloway, 1989a, 1989b). Much work has been done by the exploration and academic communities to test and apply these models, and much has been learned (see Catuneanu et al., 2009). Nonetheless, the interaction of processes controlling sequence architecture is nowhere near well enough understood for a single model to successfully predict sedimentary facies successions in all depositional settings. A major reason that models are poorly constrained and difficult to apply to a variety of settings is that there has been no publicly available study of continuous cores across a prograding siliciclastic clinoform deposit, which constitutes the central element of many facies models. As a result, the water depths in which clinoforms form and the distribution of lithofacies they contain are poorly known.

It is widely debated whether clinoform tops ever became subaerially exposed or moved seaward of the clinoform rollover during sea level lowstands (Fulthorpe and Austin, 1998; Austin, Christie–Blick, Malone, et al., 1998; Fulthorpe et al., 1999; Steckler, et al., 1999). Settling these controversies will have significant implications for our understanding of how sequence boundaries develop and how much of the facies distribution within clinoforms can be attributed to eustatic variation. Some researchers assume that the palaeoshoreline is always located at the clinoform rollover (e.g., Posamentier et al., 1988; Lawrence et al., 1990; Van Wagoner, 1990). Others have presented models that suggest the shoreline and the clinoform rollover move independently of each other (e.g., Steckler et al., 1993, 1999). The sea level estimates of Greenlee and Moore (1988) are based on an argument that sea level fall exposed an entire shelf and that strata onlapping clinoform fronts are coastal plain sediments deposited during the beginning of the subsequent sea level rise. Extracting the amplitude of sea level fluctuations from sequence architecture is critically dependent on whether the lowest point of onlap onto sequence boundaries is truly coastal or deeper marine. Determination of water depths at the clinoform edge is essential to sequence stratigraphic models and to an understanding this basic element of the dynamic land/sea interface. Water depth can only be established on the basis of samples, as done during Expedition 313.

The overriding reason, then, to return to the New Jersey margin was that drill cores on the shallow shelf would recover the lowstand sediments that (1) are missing in the coastal plain, (2) have been dated at slope boreholes, and (3) can be tied to the arrangement of siliciclastic packages seen in seismic profiles. Continuous coring would provide estimates of eustatic amplitudes, a testable record of eustatic variations, relationships to climate changes, and an opportunity to evaluate models that predict the nature and distribution of facies in passive margin strata.

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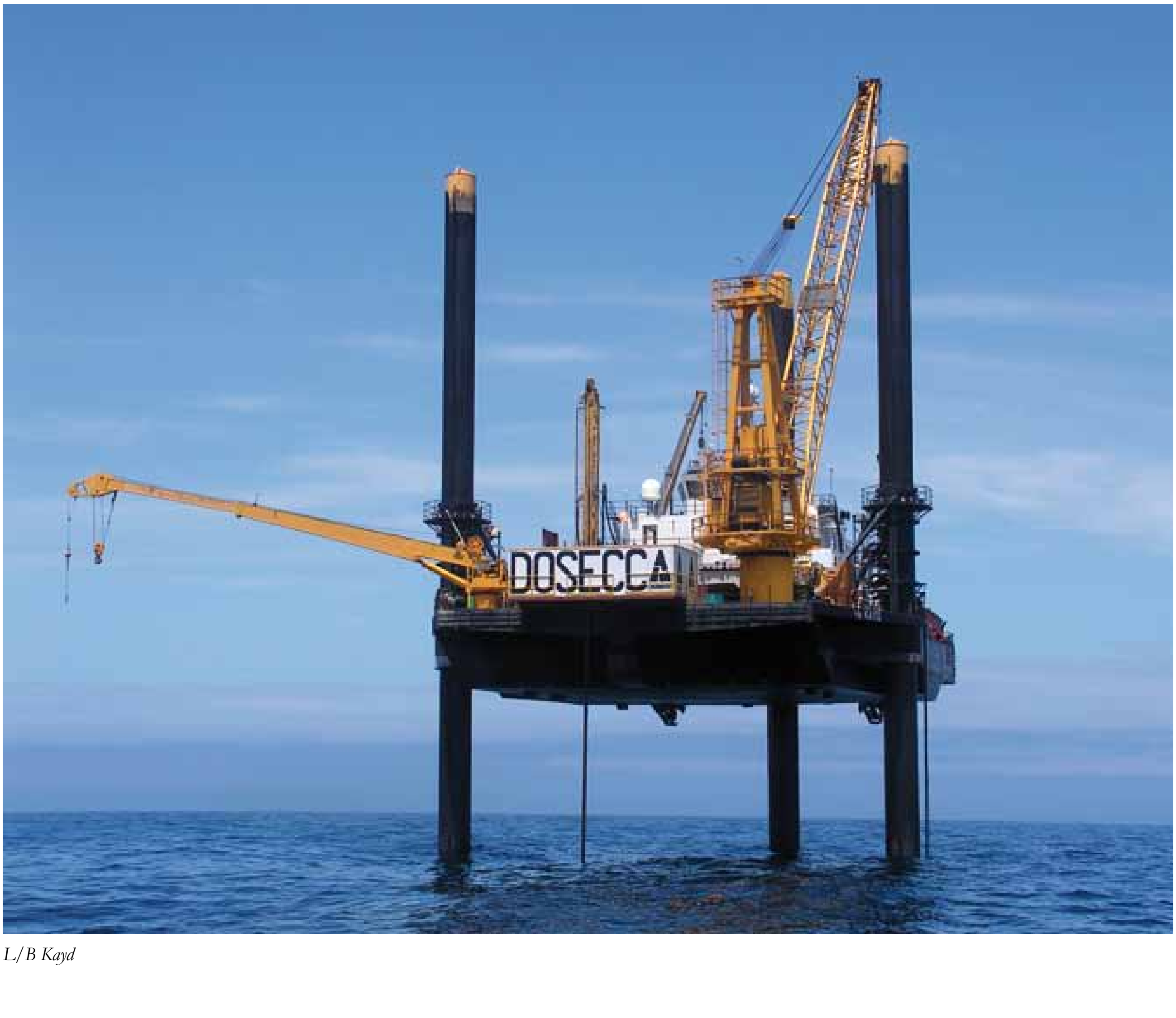

L/B Kayd

Principal initial results:

Sedimentology and stratigraphy

Drilling on the shelf was very successful in a number of ways. In contrast to ODP Leg 174A, recovery of sediment was both very good and included strata from clinoform toeset to clinoform topset. We drilled (and ate well) at three locations (M0027A, M0028A, M0029A) in 35 m of water 45–67 km offshore from a 173 ton lift boat, the L/B Kayd. The drilling strategy targeted strata at 180–750 m core depth below seafloor (CSF–A). We attempted 612 core runs with 80% recovery totalling 1311 m core length. Much of the upper 180–280 m of sand–prone Pleistocene sediment was drilled without coring, although some informative spot cores were obtained. The oldest sediment recovered was late Eocene (M0027A), and the deepest hole (M0029A) reached 757 m CSF–A.

As well as good recovery of sediment, the expedition also exceeded expectations in retrieving extremely well preserved fossils—both calcareous and organic. Thus the science party have the basis for biostratigraphy and chemostratigraphy of unrivalled detail and fidelity. In addition, paleobathymetric estimates from benthic foraminifer assemblages will provide an indication of water depths tied to sedimentary facies interpretations at the time of deposition. The lithostratigraphic description of the strata cored shows that sediments were deposited repeatedly and cyclically in two general contexts: (1) mixed wave–dominated to river–dominated shelf, with well–sorted silt and sand deposited in offshore to foreshore environments and (2) periods of clinoform slope/rollover erosion and degradation when deposition was dominated by poorly sorted silt, sand and gravel, deposited as base–of–slope debrites and turbidites. The volume of these sediment gravity flow deposits in toe–of–slope settings in this intrashelf setting is striking, and suggests a repeated sea–level modulated mechanism to remobilise sediment across the clinoform topsets and down the clinoform foresets.

Overall, the depositional systems are inferred to have been from silt–rich supply systems and there is a notable paucity of clay. The open–shelf also experienced frequent periods of dysoxia, as indicated by abrupt and repeated changes in ichnofacies and occurrences of millimetrically laminated pyritic mudstone. These dysoxic facies occur systematically within the overall sequence architecture and have been best developed at intermediate water depths.

We found no evidence of subaerial exposure at the clinoform inflection point (depositional shelf break), but the periodic occurrences of possible beach facies in the upper clinoform foreset successions, and of facies deposited below storm wave base on the topsets of the clinoforms demonstrate unambiguously large–amplitude changes in relative sea–level. The combined lithofacies and benthic foraminifer assemblages in the cores provide a rich source of information concerning depositional setting and preliminary estimates imply as much as 60 m water depth changes through single mid Miocene sea–level cycles; calculations of sediment compaction, crustal loading, and other corrections need to be made before we can estimate the corresponding magnitudes of eustatic change.

As was the case for other New Jersey margin investigations, glauconite was found to be a major component of the depositonal system; many levels comprise glauconitic sands. Glauconite occurs in all settings—from clinoform top to clinoform toe—and was formed in situ at all water depths, and was reworked into deep water at all stages in sea–level cycles.

Petrophysics and logging

Petrophysical and downhole log data collected during Expedition 313 are essential for correlation between sedimentological observations and seismic interpretations, thus aiding our correlation and understanding of the physical and seismic sequence stratigraphy of the New Jersey margin.

Offshore, the petrophysics program included wireline logging (gamma ray response was logged through the pipe for 98%, and vertical seismic profiles were acquired in 83% of drilled hole) and collection of high–resolution, nondestructive measurements on whole cores using the Geotek multi–sensor core logger (gamma density, transverse compressional wave velocity, electrical resistivity, and magnetic susceptibility). Onshore, the petrophysics program involved measuring natural gamma radiation and thermal conductivity on whole cores, split–core digital line scan imaging, and split–core colour reflectance.

The continuity and quality of the downhole through–pipe gamma log data is especially valuable in intervals where no core was obtained. There is excellent correlation between all open–hole logs with the through–pipe gamma ray logs, both in depth and in correlation of distinctive features. Also, magnetic susceptibility used in conjunction with the K/Th ratio is an excellent detector of glauconite.

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Exp 313: Representative core images

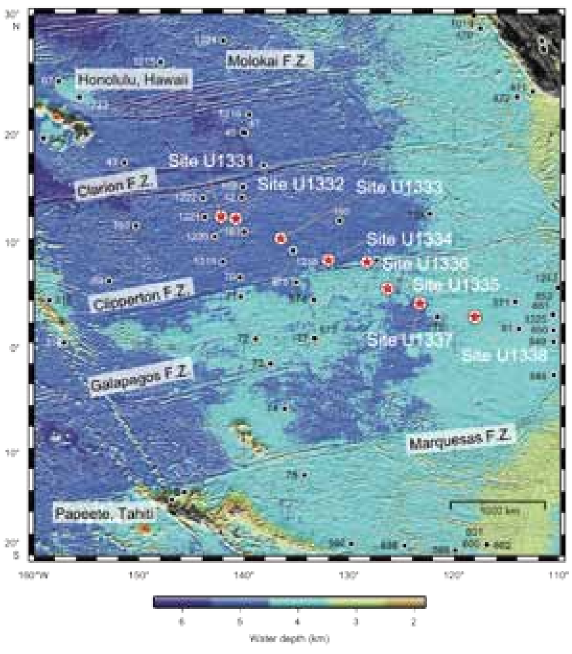
Expeditions 320/321: Pacific Equatorial Age Transect (PEAT)

Expedition 320: March 5th – May 5th 2009

Expedition 321: May 5th – July 5th 2009

Heiko Pälike (Co–chief scientist, University of Southampton), Paul Bown (UCL), Tom Dunkley Jones (Imperial College), Kirsty Edgar (University of Southampton), Peter Fitch (University of Leicester), Paul Wilson (University of Southampton) and the Expeditions 320/321 Scientific Party.

The Pacific Equatorial Age Transect (PEAT, IODP Exp. 320/321, Fig. 1) was the first science programme implemented onboard the R/V *JOIDES Resolution* after an extensive refit, and took place between March and July, 2009. PEAT was implemented as IODP Expeditions 320 and 321, and marked the successful culmination of IODP Proposal 626 first submitted in 2003. The Pacific Equatorial Age Transect (PEAT) was developed to understand how the Pacific, as the world's largest oceanic basin, developed during the Cenozoic (0–66 Ma), and interacted with global climate and the biogeochemical cycle. PEAT was designed to achieve an age transect along the palaeo–equatorial Pacific spanning early Eocene through middle Miocene crustal basement ages. Drill sites targeted specific time–slices of interest during the past 55 Ma (Fig. 2) at locations that followed the position of the palaeo–equator through time. These sites have since been moved to the northwest by plate tectonics. Here we report the background and initial highlights from these two expeditions, as reported in the shipboard Preliminary Reports for Expeditions 320/321, the Initial Results (in press), and a summary article in Scientific Drilling (in press).



The Pacific is intricately linked to major changes in the global climate system that took place during the Cenozoic. Throughout the Cenozoic the Pacific plate motion has had a northward component. Thus, the Pacific is unique in that the thick sediment bulge of biogenic rich deposits from the currently narrow equatorial upwelling zone is slowly moving away from the equator. Older sections are not deeply buried and can be recovered by drilling. Previous ODP Legs 138 and 199 were remarkably successful in outlining the workings of the climate and carbon system, productivity changes across the zone of divergence, time dependent calcium carbonate dissolution, an integrated astronomically age calibrated bio– and magnetostratigraphy, the location of the intertropical convergence zone (ITCZ), and evolutionary patterns for times of climatic change and upheaval. Together with older DSDP drilling in the eastern equatorial Pacific, both legs also helped to delineate the position of the palaeo–equator and variations in sediment thickness from approximately 150° W to 110° W longitude. However, much of the prior drilling did not have access to the latest generation of coring equipment, and thus suffered from poor recovery. Prior to the PEAT programme, it was difficult to achieve more than a reconnaissance of the environmental changes that have occurred in the equatorial Pacific. The PEAT programme was designed to augment previous drilling and to collect undisturbed sediments that could be spliced into a continuous, high–resolution environmental record of the eastern equatorial Pacific for the entire period from 56 Ma to present, promising to answer many of the important questions relating to global climatic change during the Cenozoic.

Fig. 1: Modern locations of Pacific Equatorial Age Transect (PEAT) drill sites (red stars) on a bathymetric map of the central Pacific. Also shown are locations of previous DSDP and ODP drilling (solid black circles), as well as Honolulu, Hawaii and Papeete, Tahiti (open red circles). F.Z. = fraction zone.

Drilling leg design and overarching questions

During most of the Palaeogene, the carbonate compensation depth (CCD) was between 500 and 1300 m shallower than today. Thus, a very shallow CCD makes it difficult to obtain well–preserved carbonate sediments during these stratigraphic intervals because initial thermal subsidence of the ridge crest is rapid. Nevertheless, the careful coring and site location strategy of PEAT Expeditions 320/321 allowed us to drill the most promising sites and to obtain a unique sedimentary archive of biogenic sediment for time periods just after the Palaeocene/Eocene boundary event, the Eocene cooling, the Eocene–Oligocene transition, the "one cold pole" Oligocene, the Oligocene–Miocene transition and the Miocene. These new cores and data will significantly contribute to the objectives of the IODP Extreme Climates Initiative and provide material that we were unable to recover during previous efforts.

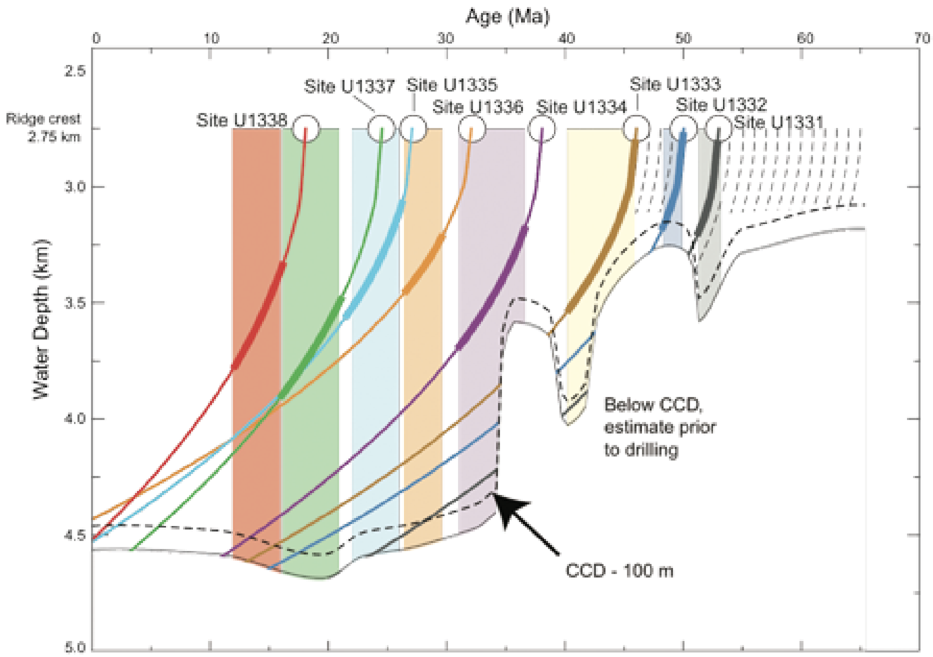


Fig. 2: Targeting drill sites prior to coring based on calcium carbonate compensation depth (CCD) history (van Andel, 1975), with additional data from ODP Leg 199. Coloured boxes = critical time interval targeted for each site. Coloured subsidence lines are critical time intervals where we also expected carbonate to be deposited (i.e., when site is above CCD). Subsidence curves use a subsidence parameter calculated from estimated basement age of PEAT sites and their present–day depth.

The shallow CCD of the Eocene and Palaeocene prevented deposition of carbonate except on crust at relatively shallow depths. Drilling near the palaeoposition of the ridge crest at the critical time interval allows the recovery of the shallowest sections available in the pelagic oceans and thereby assures the best possible preservation of the carbonate sediments recovered. As the crust cools and sinks, the seafloor on which the sediments are deposited approaches the lysocline and CCD. Thus, the best preserved part of the sections recovered in such "time line" transects is restricted by the depth at which carbonate dissolution significantly increases, as well as by the northward movement of sediment sections out of the region of high equatorial productivity. This limitation was exemplified by the results from ODP Leg 199, which recovered only limited amounts of carbonate prior to the Eocene/Oligocene boundary (e.g., at ODP Site 1218 on 42 Ma crust).

For the PEAT program, we planned to overcome this limitation of the time line strategy by pursuing an equatorial age transect, or flow line strategy (Fig. 3), to collect well–preserved equatorial sections through the Cenozoic while also making use of the Pacific plate motion to add an oblique latitudinal transect across all time slices. We drilled a series of sites on the palaeo–equator at key stratigraphic intervals in the evolution of the Cenozoic climate (Fig. 2). These intervals span the extremely warm times of the early Eocene, through the cooling of the late Eocene through Oligocene and the early Miocene time of relatively warm climates (or low ice volume), and into sections deposited during the development of the major Southern and Northern Hemisphere ice sheets. There were very few previous drill sites that match our site selection criteria. Each site was selected to be close to the geographic palaeo–equator and on crust aged slightly older than the age intervals of particular interest.

In this way we were able to track palaeoceanographic conditions at the palaeo–equator in the best preserved sediments obtainable within the Pacific basin. We can also make use of the high level of correlation between tropical sediment sections and seismic stratigraphy to develop a more complete model of equatorial productivity and sedimentation. The primary design of PEAT was to recover sediments deposited in the equatorial zone during different time slices of the Cenozoic and to then assemble them into an equatorial Pacific 'megasplice' covering the interval from 56 Ma to present. The main scientific objectives of the PEAT program are outlined in the text box page 20.

PEAT Science objectives:

1. To detail the nature and changes of the carbonate compensation depth (CCD) over the Cenozoic in the palaeoequatorial Pacific.
2. To determine the evolution of palaeoproductivity of the equatorial Pacific over the Cenozoic.
3. To validate and extend the astronomical calibration of the geological time scale for the Cenozoic, using orbitally forced variations in sediment composition known to occur in the equatorial Pacific, and to provide a fully integrated and astronomically calibrated bio– chemo– and magnetostratigraphy at the equator.
4. To determine temperature (sea–surface and bottom water), nutrient profiles, and upper water column gradients.
5. To better constrain Pacific plate tectonic motion and better locate the Cenozoic equatorial region in plate reconstructions, primarily via palaeomagnetic methods.
6. To make use of the high level of correlation between tropical sedimentary sections and existing seismic stratigraphy to develop a more complete model of equatorial circulation and sedimentation.
7. To provide information about rapid biological evolution and turnover rates during times of climatic stress.
8. To improve our knowledge of the reorganization of water masses as a function of depth and time, as the PEAT drilling strategy also implies a palaeo–depth transect.
9. To develop a limited N–S transect across the palaeoequator, caused by the northward offset of the proposed sites by Pacific plate motion, providing additional information about N–S hydrographic and biogeochemical gradients.
10. To obtain a transect of mid–ocean–ridge basalt (MORB) samples from a fixed location in the absolute mantle reference frame, and to use a transect of basalt samples along the flow–line that have been erupted in similar formation–water environments to study low–temperature alteration processes by seawater circulation.

Initial Results and Highlights

During Expedition 320, 16 holes at 6 sites (Holes U1331A–U1331C, U1332A–U1332C, U1333A–U1333C, U1334A–U1334C, U1335A, U1335B, U1336A, and U1336B) were cored as part of the PEAT program. During Expedition 321, two major Neogene equatorial Pacific sediment sections were recovered by drilling seven holes at two sites (Holes U1337A–U1337D and Holes U1338A–U1338C). The combined PEAT programme retrieved a total of 712 cores, coring 6322.1 m and recovering 6140.9 m (97.1% recovery). By drilling a series of sites that follow the position of the palaeo–equator and a limited latitudinal and depth transect, we recovered cores that allow us to address the combined PEAT objectives.

One of the prime objectives for the PEAT program was a detailed intercalibration of bio–, magneto–, and chemostratigraphic records for the Cenozoic from the early Eocene to the present within an astronomically age–calibrated framework. Shipboard results indicate that we can achieve this objective, based on the observation that even decimeter–scale features in the sedimentary record from the drilled sites can be correlated over large distances across the Pacific seafloor, and to the seismic survey data that were collected in support for PEAT by a cruise jointly funded by the NERC and NSF.

IODP Expedition 320/321 Summary

Duration: 110 days

Scientists: 58

Number of sites: 8

Number of holes: 23

Number of cores: 712

Core length: 6140.9 m

Core recovery: 97.1%

Deepest water depth: 5128 m

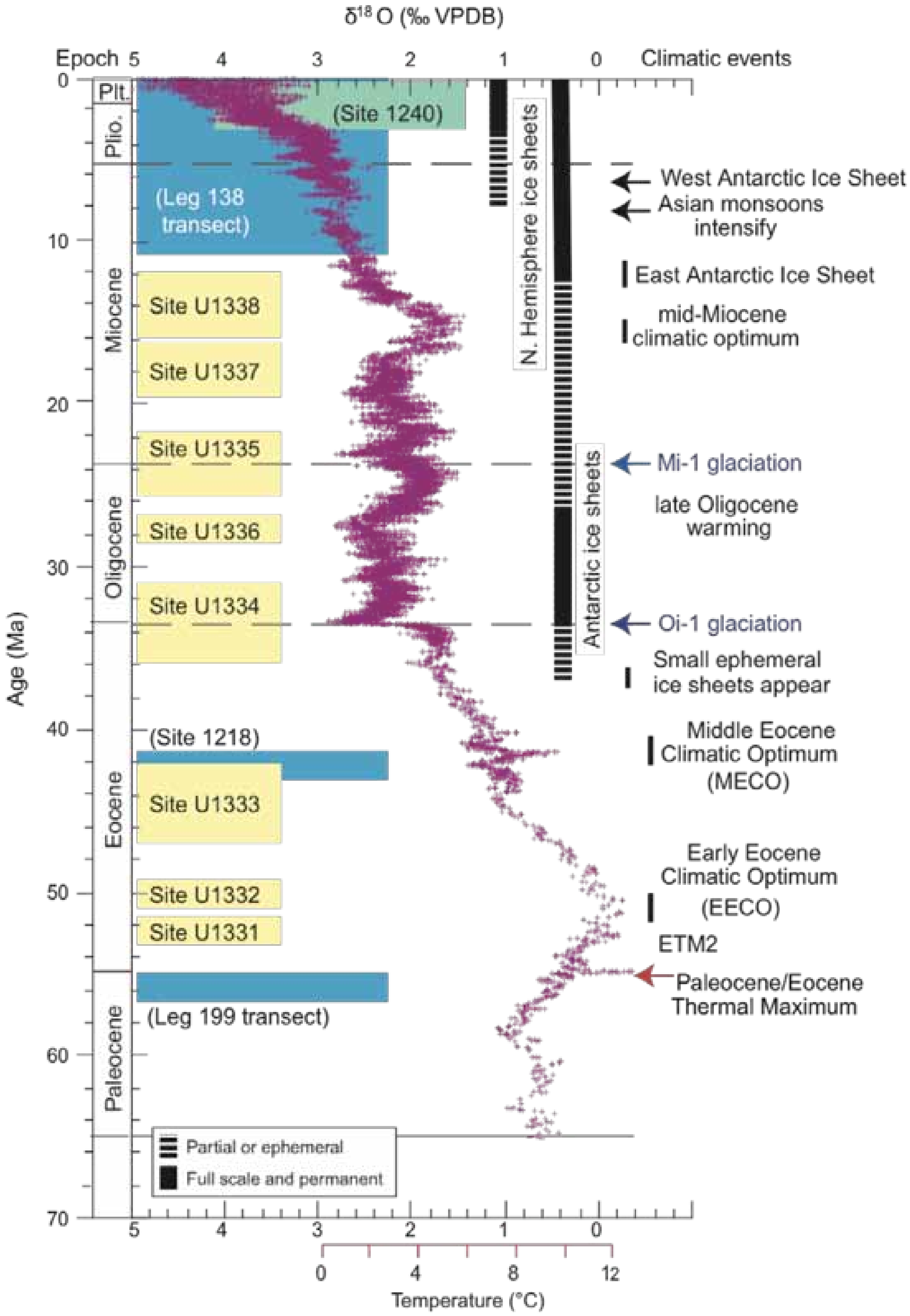


Fig. 3: Evolution of oxygen stable isotopes (d[18]O) through the Cenozoic and related major phases of climate change (modified from Zachos et al., 2008). Yellow boxes = time slices of interest for the PEAT program, green and blue boxes = ODP legs and sites previously drilled in the equatorial Pacific region. These additional sites will be used with the PEAT sites to obtain a nearly continuous Cenozoic record of the equatorial Pacific region. VPDB = Vienna Peedee belemnite. Oi–1 = Oligocene isotopic Event 1, Mi–1 = Miocene isotopic Event 1 (Miller et al., 1991). ETM2 = Eocene thermal maximum 2.

The PEAT program will leave a long–lasting legacy for the detailed intercalibration of all major microfossil groups, a detailed magnetostratigraphy with >800 dated reversals, and sedimentary cycles that can be calibrated across large distances in the Pacific Ocean (Fig. 4). A study of palaeoceanographic processes and variations of mass accumulation rates across the PEAT latitudinal transect and its evolution over time depends on a detailed knowledge of sedimentation rates. The integrated bio—and magnetostratigraphies obtained for all Expedition 320/321 sites will allow us to fully exploit and understand the complex interplay of productivity, dissolution, and spatial biogenic sedimentation patterns, which leave their imprint in the sedimentation rates recorded at different drill sites. Depending on the crustal subsidence and age for each site, sedimentation rates vary from site to site over time (Fig. 4). Our results reveal the change in linear sedimentation rates in both the latitudinal and age transect components of the PEAT program. By combining the available data from Leg 199 and Expeditions 320 and 321, we will obtain a continuous history of sedimentation rates in the equatorial Pacific region for the past 55 million years.

Detailed descriptions of PEAT drilling can be found in the Exp 320 and Exp 321 Preliminary Reports, and in the Exp 320/321 Initial Reports (in press). Eight sites (U1331 to U1338) were drilled; their basement ages span from 52 Ma to 18 Ma. PEAT shipboard science has determined that the sediments recovered fill gaps from previous drilling and can be used to create a high–resolution megasplice of equatorial Pacific sedimentation. Cross–calibration of magneto–, bio–, and ultimately orbital stratigraphy will significantly improve chronological estimates of sedimentation and ages of significant events. The study of fluxes of different sediment components will then add a new dimension of information about biogeochemical cycling.

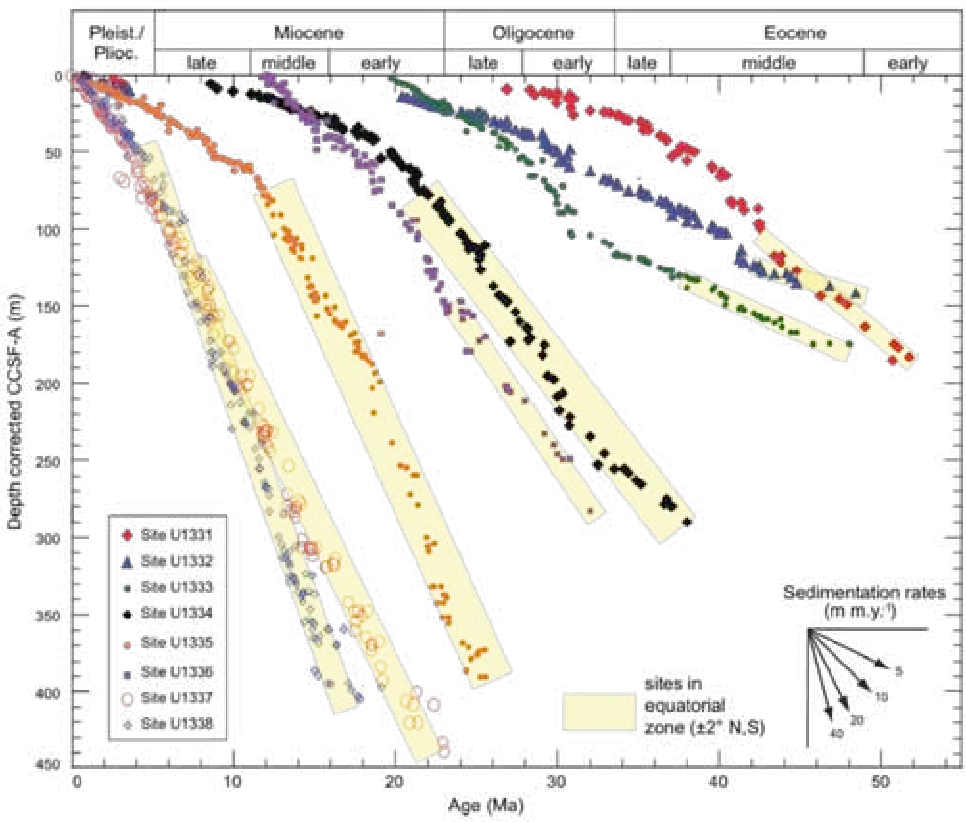


Fig. 4: Summary of chronostratigraphic datum levels identified at PEAT sites plotted versus corrected composite depth (spliced depth compacted back to depth measured by the drill string). A steeper slope corresponds to a higher sedimentation rate. Yellow boxes mark approximate times when each drill site was within the equatorial zone (±2° N or S of the Equator) based on estimated absolute motion of the Pacific tectonic plate.

The PEAT program recovered sediments similar in lithology to previous DSDP and ODP expeditions to the central equatorial Pacific region (Lyle et al., 2002). Fig. 5 summarises the lithostratigraphy of the northwest–southeast transect of sites drilled during Expedition 320/321 together with the sedimentary sequence from ODP Site 1218, which is also included in the PEAT flow line strategy. As expected due to the decreasing age of crust toward the southeast, the Eocene sequence (Fig. 5, green shading) thins from northwest to southeast, pinching out east of Site U1334, the last site drilled on Eocene crust. In contrast, the Miocene sequence (Fig. 5, yellow shading) thickens substantially from northwest to southeast. The Miocene section is thickest at Site U1337, which targeted crust of latest Oligocene age, and thus is the drill site that spent the most time within the Miocene equatorial zone. The Oligocene sequence (Fig. 5, blue shading) is thickest in the middle of the PEAT transect (U1334 and U1336) and thins in both directions, marking the Oligocene equatorial zone.

Because of the drilling design, the PEAT program was successful in collecting carbonate sediments from the late Eocene and across the Eocene–Oligocene boundary. Carbonate sediments were also recovered for significant parts of the Eocene where it had been impossible from previous equatorial Pacific drilling to study the proxy climate information stored in carbonates. In addition, the Neogene PEAT sites are the first essentially complete Miocene sediment sections from the equatorial Pacific. These Miocene sediment sections will provide the first high–resolution studies of this poorly understood Cenozoic interval. Stable isotope studies on all the new sedimentary sequences will provide the backbone of information to understand the interrelationships between development of polar ice and equatorial circulation.

The **Eocene–Oligocene transition** (~34 Ma) was recovered at four sites drilled during Expedition 320. Sites U1331–U1334 capture the lithostratigraphy of the Eocene–Oligocene transition in the equatorial Pacific Ocean in a depth transect from ~3600 to 4300 m palaeowater depth. At each site, a downhole transition takes place from white to pale brown nannofossil ooze of earliest Oligocene age to much darker brown sediments of Eocene age. The lithostratigraphy of the Eocene–Oligocene transition from Expedition 320 sites is remarkably consistent with both the expedition rationale for drilling these sites and Leg 199 results and will allow the study of the early history of Cenozoic glaciation and CCD behaviour across a depth transect.

At the end of the Oligocene a significant multimillion year–long rise in the oxygen isotope record is closely followed by a relatively short, sharp increase in oxygen isotope values that has been interpreted as a major glacial episode (Fig. 2) and correlated to a pronounced drop in sea level. This event is very close to the **Oligocene/Miocene boundary**. Although there

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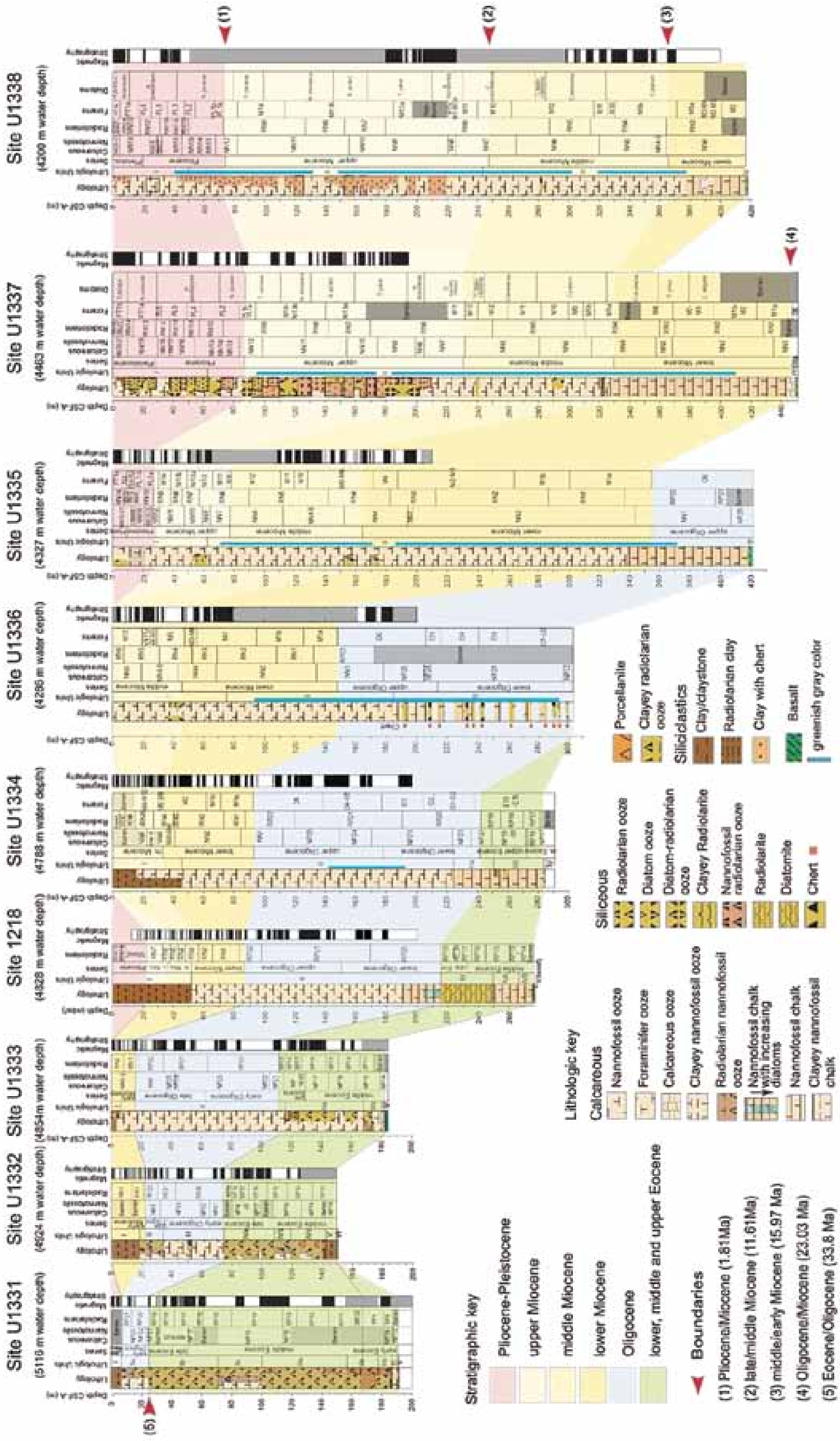

Fig. 5: Stratigraphic summary plot for PEAT drill sites and ODP Site 1218. For each site the stratigraphic column and lithology are plotted against drilled depth, together with the magnetostratigraphy and biostratigraphic zonation schemes. The Eocene intervals are shaded in green, Oligocene in light blue, Miocene in dark and light shades of yellow, and Pliocene–Pleistocene in pink.

are clear periodic isotopic signals indicating major changes in ice volume, ocean temperatures, and/or ocean structure, this biostratigraphic boundary has always been somewhat of an enigma. Complete sequences to the biozone and magnetochron level of the Oligocene–Miocene transition were recovered at Sites U1332–U1336, providing an excellent integrated stratigraphy. Sites U1332–U1334 display unambiguous magnetostratigraphy coherent with biostratigraphy and a distinct record of alternations in sediment constituents and physical properties. The Oligocene–Miocene transition in Expedition 320 sediments is characterized by alternations of nannofossil– and radiolarian/clay–dominated intervals upsection of the Oligocene/Miocene boundary at Sites U1332 and U1333 and by subtle light–dark color alternations of nannofossil ooze at Sites U1334 and U1336.

The cores recovered from Expedition 320/321 provide the raw material to address **Neogene** PEAT objectives for the equatorial Pacific megasplice. Shipboard research has provided the framework of studies to define the lithology, show continuity of the sediment section, and define the basic time framework. Shorebased work will refine the chronostratigraphy through orbital tuning and will measure proxies of surface and deep water change and palaeoproductivity/carbon cycles to show how the modern equatorial Pacific evolved as the icehouse world developed. For the PEAT program, only Sites U1337 and U1338 recovered sedimentary sections of the late Miocene–Holocene with relatively high sedimentation rates and preserved carbonate (~15 m/million years) (Fig. 4). Sites further west and north on older crust (Sites U1331–U1336) suffer from low sedimentation rates or hiatuses in the younger section because they are farther from the modern equatorial productivity zone and on deeper (older) ocean crust where depth–dependent carbonate dissolution is prevalent. Of the older sites, the best higher sedimentation–rate sediment sections for the middle Miocene through late Oligocene are found at Sites U1334–U1336. One of the important accomplishments of Expedition 321 was to recover two continuous essentially complete Neogene sedimentary sections, Site U1338 from 0 to >17 Ma and Site U1337 from 0 to >23 Ma, just beyond the Oligocene/Miocene boundary. These represent the only complete Neogene sections in the equatorial Pacific, possibly for all the tropics, which have high enough sedimentation rates to resolve orbitally forced sediment cycles.

Acknowledgements

We thank the ship's captain, crew and drilling crew on the *JOIDES Resolution*, and the technical staff of the U.S. Implementing Organization who made it possible to translate our plans into recovered core. We also thank the support of UKIODP and NERC, as well as NSF, who supported the initial site survey cruise in 2006 onboard the Roger Revelle in 2006, without which we would not have been able to drill.

Conclusions

One of the key achievements of the shipboard scientific programme was to better constrain Cenozoic stratigraphy, showing the potential to achieve detailed bio–, magneto–, and chemostratigraphies for the Cenozoic from the early Eocene to the present, within a cyclostratigraphic framework. Shipboard results indicate that we can achieve this objective based on the observation that even decimeter–scale features in the sedimentary record from the drilled sites can be correlated over large distances across the Pacific seafloor. The PEAT program will leave a lasting legacy through detailed correlation of all major fossil groups, a detailed magnetostratigraphy with over 800 dated reversals, and sedimentary cycles that can be correlated across large distances in the Pacific Ocean. These fundamental new datasets will allow a detailed deciphering of how climate and the oceans interacted, as represented by the microfossil record, and a multitude of geochemical signals recorded in the sediment cores.

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Expedition 322, Stage 2 NanTroSEIZE; Subduction Inputs

1st September–10th October 2009

Joanne Tudge, petrophysics and sedimentology PhD student, University of Leicester
Kevin T. Pickering, sedimentologist, University College London, (UK Expedition 322 participant), and Expedition 322 Shipboard Scientific Party

Expedition 322 was part of Stage 2 of the on–going multi–stage Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE). The completion of Expedition 322 in October 2009 marked the end of Stage 2 drilling operations, bringing the total number of drilled sites for NanTroSEIZE, to–date, to twelve (Figure 1). The main aims of the NanTroSEIZE project are to investigate fault mechanics, fault development and the seismogenic process at the Nankai subduction zone, Japan (Figure 1), using the Japanese research vessel Chikyu to drill a transect from the seaward pre–subduction sediments, shallow plate fault systems to the deep seismogenic zone, ultimately installing long–term observatories (Tobin and Kinoshita, 2006a, 2006b).

The primary goal of Expedition 322 was to characterise the subduction input material entering the Nankai subduction zone, through drilling and sampling the sediments and igneous basement of the Shikoku Basin (Saito et al., 2009).
By studying the initial sediment properties (e.g. clay composition, fluid composition, pore pressure, thermal state) prior to entering the subduction zone, the changes that occur as the sediments are transported to higher pressures and temperatures in the subduction zone can be investigated.

The Philippine Sea plate is currently subducting to the northeast at a rate of ~4 cm/yr (Seno et al., 1993), approximately orthogonal to the Nankai Trough. Sediments from the Shikoku Basin, together with overlying Quaternary trench wedge sediments, are actively accreting at the deformation front of the Nankai subduction zone, as demonstrated by NanTroSEIZE Stage 1, IODP Expeditions 314, 315, 316 (Tobin et al., 2009).

The Shikoku Basin formed as part of the Philippine Sea plate during the early and middle Miocene by rifting and seafloor spreading along the backarc side of the Izu–Bonin volcanic chain (Okino et al., 1994; Kobayashi et al., 1995). The underlying igneous basement of the Shikoku Basin created strong seafloor relief which strongly influenced the basin's early depositional history (Moore et al., 2001; Underwood, 2007). To learn more about the influence of basement topography on the stratigraphic architecture of the Shikoku Basin, two sites located around a bathymetric high (Kashinosaki Knoll) were cored during Expedition 322 (Figure 1). Site C0011 is located on the northwest flank of the knoll, and Site C0012 is located near the crest of the knoll (Figure 2).

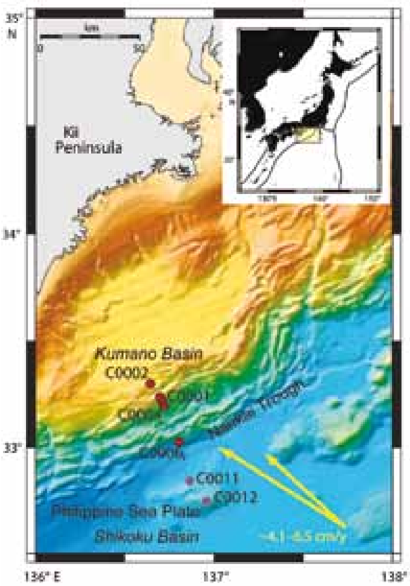

Figure 1: Map of the Nankai Trough showing the NanTroSEIZE transect including all previous expedition drill site locations (red) and those from Expedition 322 (purple). Inset shows tectonic setting. Convergence vectors between Philippine Sea plate and Japan show range from Seno et al. (1993), Miyasaki and Heki (2001), and Heki (2007).

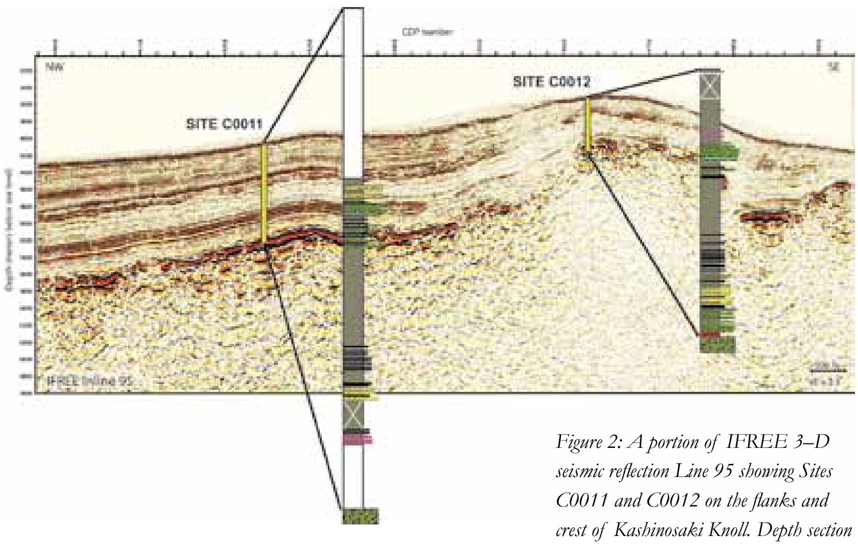

Figure 2: A portion of IFREE 3–D seismic reflection Line 95 showing Sites C0011 and C0012 on the flanks and crest of Kashinosaki Knoll. Depth section corrected during Expedition 322 after adjustments to velocity model following acquisition of LWD data at Site C0011. VE = vertical exaggeration.

Individual Site Summaries

IODP Site C0011

Both core and log data were obtained at Site C0011. Measurement–while–drilling (MWD) and logging–while–drilling (LWD) data were collected at Hole C0011A near the end of Expedition 319 (Saffer et al., 2009) to a depth of 950 m LSF (logging–while–drilling metres below seafloor). During Expedition 322 core was obtained between 340 m and 876 m CSF (cored metres below seafloor) at Hole C0011B. Coring commenced at 340 m CSF depth rather than the mudline due to time constraints, and ceased at 876 m CSF due to destruction of the drill bit.

The LWD data (acquired using Schlumberger geoVISION tool) included natural gamma radiation, five different resistivity readings and resistivity images from button resistivity measurements. Overall the data quality was good and we were able to characterise five logging units based on variations in the gamma ray and ring resistivity responses. These logging units correlated reasonably well with the seismic stratigraphy. It was determined that a good correlation existed between the LWD data and subsequent core data, with a consistent vertical offset of ~4 m between the coring hole (C0011B) and the logging hole (C0011A). Analysis of the resistivity images for structural data identified bedding dips <20 ° toward the north, consistent with the gentle dip down the seaward slope of the trench observed in the seismic profiles (Figure 2). The location of the borehole breakouts indicated a maximum horizontal stress field (SHmax) orientated NNE–SSW, roughly perpendicular to the convergence direction of the Philippine Sea plate.

The structural features observed in the core at Site C0011 included gently dipping bedding planes and small faults, with mineral–filled veins precipitated along faults indicating deformation–fluid interactions. The poles to the bedding structures are distributed along a NNW–SSE trend, perpendicular to the present trench axis, and these orientations show a nice correlation to the LWD–based measurements.

Five lithological units were also determined primarily from core data. The exception was lithologic Unit I (seafloor to 340 m CSF) which was not cored, so LWD data was used to infer its characteristics. The dominant lithology was determined to be hemipelagic mud (silty clay to clayey silt) with thin interbeds of volcanic ash. Lithologic Unit II was named the middle Shikoku Basin facies, as it differs in both age and composition from the previously established characteristics of upper and lower Shikoku Basin facies. Interbedded with the moderately lithified bioturbated silty claystone are tuffaceous sandstone, volcaniclastic sandstone, dark grey clayey siltstone and mass transport deposits (Figure 3). The volcanic–rich sandstones contain mixtures of primary eruptive material and reworked pyroclastic and sedimentary deposits, with the Izu–Bonin arc located along the northeast margin of the Shikoku Basin probably the closest volcanic source at the time of deposition.

Lithologic Unit III is typical of the hemipelagic deposits found throughout the Shikoku Basin (Underwood et al., 2003), and is dominated by bioturbated silty claystone, with very thin beds of calcareous claystone. In Unit IV and Unit V core recovery became increasingly poor, and the decision to wash down without coring from 782.6 to 844.0 m CSF was made (Underwood et al., 2009). Core recovery in Unit V was limited, and prior to reaching basement, coring ceased and the hole was abandoned. Despite this setback the dominant lithologies of Unit V were recognised as tuffaceous silty claystone and light grey tuff with minor occurrences of tuffaceous sandy siltstones. These tuff deposits are probably correlative with the thick rhyolitic tuffs that were recovered at ODP Site 808 from the Muroto transect of the Nankai Trough, which yielded an age of ~13.6 Ma (Taira, Hill, Firth, et al., 1991).

The integrated age–depth model allowed for rates of sedimentation (uncorrected for either compaction or rapid event deposition by gravity flows) to be determined (Figure 4). A change in sediment accumulation rate at ~11 Ma was observed around the middle of Unit III; changing from ~4.0 cm/k.y. to 9.5 cm/k.y. A shift in the MSCL (multi–sensor core logger) magnetic susceptibility correlated with this change in sediment accumulation rate.

Figure 3: A selection of core photographs, from left to right: Volcaniclastic sandstone turbidite from Site C0011; Wet–sediment deformation in thin–bedded volcaniclastic turbidite sandstones from Site C0012; Red claystone overlying the basalt basement of Kashinosaki Knoll.

IODP Site C0012

Core data at Site C0012 was obtained from 60–560 m CSF, with the successful penetration of igneous basement despite overall modest to poor core recovery and extensive core damage. In total seven lithologic units were identified; with Units I–VI sedimentary in nature and Unit VII igneous basement (figure 2). Due to time constraints and a typhoon near the end of the expedition, wireline logging data was not obtained at Site C0012.

Lithologic Unit I is characterised by green–grey intensely bioturbated silty clay, typical of hemipelagic mud deposits in the upper Shikoku Basin. Modest amounts of calcite within this unit suggest deposition on top of Kashinosaki Knoll at a water depth close to (but above) the calcite compensation depth. Lithologic Unit II is representative of the new middle Shikoku Basin facies due to the volcaniclastic rather than siliciclastic sandstone compositions (Figure 3). There is a strong correlation between Lithologic Units II–V at Sites C0011 and C0012 (Figure 2), with the units sharing similar characteristics and ages despite different thicknesses.

Two new lithologic units (VI and VII) were identified at Site C0012 relating to the sediment–basement contact. Unit VI, only 9.3 m thick, is characterised by variegated red, reddish brown and green calcareous claystone, interpreted as the pelagic clay deposited in direct contact with igneous basement (Figure 3). Lithologic Unit VII, the igneous basement, is composed entirely of basalt, with evidence of mixing between sediment and lava near the upper contact.

Another exciting outcome from Site C0012 was from the geochemical analysis of the interstitial waters. The results are as close as we can get to a true geochemical reference site for the Nankai Trough, with no obvious effects of abnormally high heat flow and/or deep burial beneath trench wedge and accretionary prism toe (Underwood et al., 2009). The dissolved sulphate profile shows some structure consistent with biogeochemical processes. The profile clearly documents an abnormal sulphate reduction zone, occurring significantly deeper than at other sites along the Nankai margin. The chlorinity values at Site C0012 increase by 12 % relative to seawater, and show no indication of freshening patterns observed elsewhere (e.g. Taira et al., 1991). This steady increase in chlorinity is thought to be related to hydration reactions during alteration of dispersed volcanic ash and volcanic rock fragments within Units IV and V (Underwood et al., 2009).

Overall, the geochemical analysis suggests the likely presence of two distinct fluid regimes within the sedimentary strata seaward of the trench. One regime is characterized by dehydration reactions, freshening trends in chlorinity, and possible flow toward the Shikoku Basin from subducting sediments through high–permeability horizons of the lower Shikoku Basin facies. This hypothesized flow, however, does not reach the crest of Kashinosaki Knoll. Instead, a separate pore water regime is driven by in–situ hydration reactions, increasing chlorinity, and diffusive exchange with a more seawater–like fluid that flows through the underlying igneous basement.

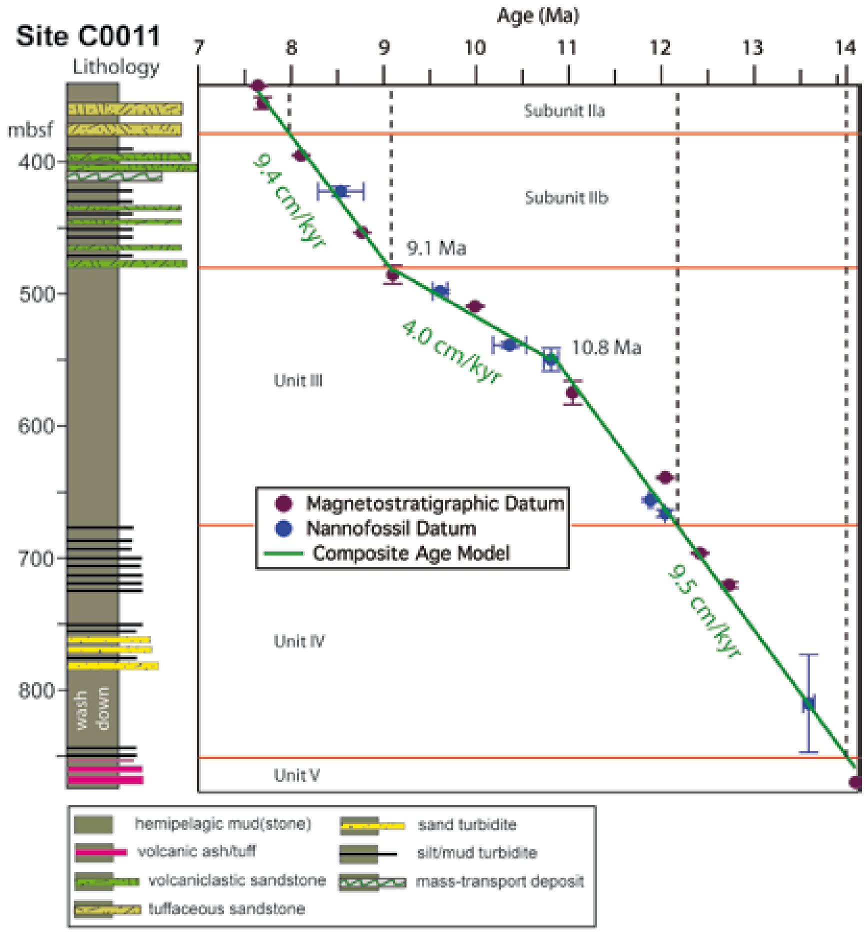

Figure 4: Age–depth model of sedimentation rates at Site C0011.

Conclusions

Overall Expedition 322 can be considered a success. One of the main aims was to penetrate the igneous basement. This was successfully achieved at Site C0012, where the sharp contact between sediment and basement basalt was recovered in the core. In addition a new middle Shikoku Basin facies was recognised at both sites; characterised by volcanic–rich sandstones. This indicates that two sand–rich turbidite systems developed during the middle and late Miocene in the Shikoku Basin (Underwood et al., 2009). In addition the pore–water geochemistry profiles, for Site C0012, represent the closest seen to a true geochemical reference site for the Nankai Trough. Much of the science party's post–expedition research will focus on analyses of samples from the lower stratigraphic units of the Shikoku Basin. Those studies will provide much–needed information about the pristine physical, chemical, compositional, and hydrological properties of the subduction inputs prior to the effects of subduction.

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Expedition 323: Bering Sea Palaeoceanography, 5th July–4th September 2009

Sev Kender (British Geological Survey) and Expedition 323 Shipboard Scientific Party

IODP Expedition 323 set sail for the Bering Sea from Victoria, BC, on the *JOIDES Resolution* in July 2009, and the following eight weeks were spent drilling various sites in the Aleutian Basin (Figure 1). This was a unique undertaking, as the last time the Bering Sea was targeted for deep coring was in the 1970 s (DSDP Leg 19; Scholl and Creager, 1973), which was drilled with old rotary coring technology, obtaining incomplete recovery. Therefore almost nothing was known about the sedimentological and climate history of the Bering Sea beyond a few shallow piston cores reaching the Last Glacial Maximum (LGM; see Takahashi, 2005).

The primary goal of this expedition was to obtain sediment records suitable for palaeoceanographic reconstruction via proxies for ocean chemistry, biological productivity, sea ice cover, sediment input, and terrestrial vegetation. Therefore sites were chosen where relatively undisturbed continuous sedimentation was preserved, exhibiting high sedimentation rates (up to 30 cm/kyr), and covering the spatial and bathymetric range of the Aleutian Basin. Preliminary results have proven to be very exciting, and show the considerable potential of the sediments collected during this expedition.

Seven sites were targeted totalling over 5,700 m of sediment at water depths ranging from 848 to 3,220 m, stretching back 5 Ma. Operations continued around the clock for almost the entire time at sea to enable the crew to deal with the vast amount of material. Unfortunately, clearance to enter Russian waters was not granted and potential sites at the Shirshov Ridge and Kamchatka Strait were abandoned. This however freed up time to core at additional sites, where excellent preliminary results have been obtained.

The Bering Sea Region

The Bering Sea is the third largest marginal sea in the world after the Mediterranean and South China Seas, but in contrast to these very little is known of its palaeoceanographic past. The Bering Sea today exhibits high surface–water productivity and low subsurface oxygen concentrations. 'Old' deep water, characterised by low dissolved–oxygen (Figure 2), high nutrients (e.g. phosphate and nitrate) and high dissolved–CO_2, flows into the Bering Sea at depth from the North Pacific through the western Aleutian passes (Figure 1). It cycles counter–clockwise around the Aleutian Basin, exiting largely through the Kamchatka Pass in the far west. Along the way much of the nutrient–rich water upwells over Bowers Ridge and the continental shelf margin via the Bering Slope Current (the so–called 'Green Belt', Springer et al., 1996), feeding one of the world's most productive regions. As large fluxes of organic carbon make their way to the sea floor, intense scavenging at depth helps create a massively expanded oxygen minimum zone.

Surface water enters the Bering Sea via the Aleutian passes from the warm Alaskan Stream to the south. Much of this water circulates counter–clockwise over the Bering Sea shelf and Aleutian Basin, and eventually back to the Pacific. But about 0.8 Sv of water enters the Arctic Ocean through the Bering Strait (Coachman, 1993), which acts as a link between the Pacific and Arctic Oceans and contributes a significant component of the Arctic halocline (Cooper et al., 1997). Changes to the throughflow of the Bering Strait have been implicated in ice sheet growth during glacials (Hu et al., 2010). The vast Bering Sea shelf, <200 m deep, was largely exposed during the LGM, drastically

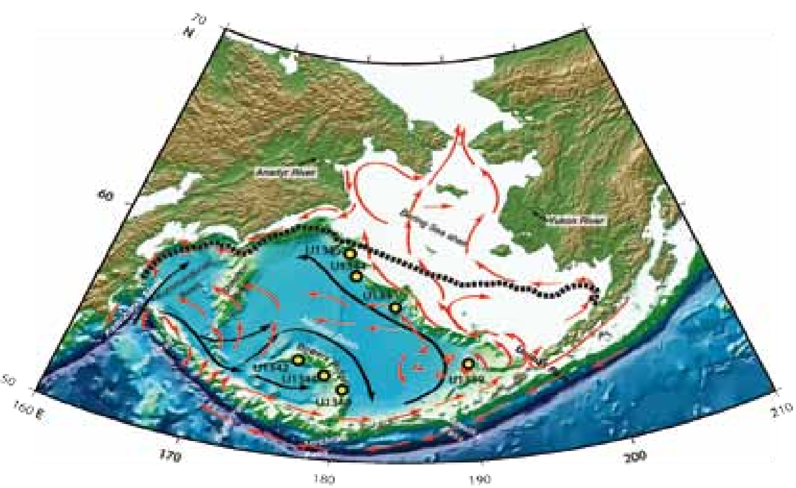

Figure 1. Map of the Bering Sea with Expedition 323 Sites U1339–45. Red arrows indicate surface water currents, black arrows indicate deep water currents, and dashed line indicates extent of >15% winter sea ice (Expedition 323 Scientists, 2009).

changing the location of the coastline and sedimentary input. Sea ice covers much of the northern part of the Bering Sea in the winter (Figure 1), and completely retreats in the summer. During the LGM sea ice was much more extensive, and its impact on primary productivity greatly affected intermediate water properties. It has been suggested that, although only a minor contributor today, a significant proportion of expanded North Pacific Intermediate Water may have been formed in the Bering Sea during the LGM (e.g. Matsumoto et al., 2002. Horikawa et al., 2010).

The high rate of clastic input to the Bering Sea from the surrounding landmasses, including the vast Yukon and Anadyr Rivers, and the high seasonal biological primary productivity, has provided elevated sedimentation rates when compared to the North Pacific region. The new sedimentary records therefore offer for the first time the possibility to reconstruct high resolution climate records not available elsewhere in the subarctic North Pacific. As changes to the stratification and productivity of high latitude Southern Ocean and subarctic North Pacific regions have been implicated in the onset of Northern Hemisphere Glaciation (NHG) and glacial–interglacial cycles (e.g. Haug and Sigman, 2009), Bering Sea sediments can be used to test these hypotheses as other high latitude regions do not contain well preserved calcareous sedimentary records with the fossils primarily used in palaeoceanography. In addition, located in the high northern latitudes, this region is particularly sensitive to Milankovitch and millennial–scale climate oscillations and can act as a test–bed for studying processes that amplify high latitude climate change to radiative forcing.

The high primary productivity and deep water nutrient concentrations of the Bering Sea allow extensive microbial–driven biological activity to occur in the sediments, and an additional aim of the expedition was to monitor this biogeochemical cycling for the first time in a region of such high primary productivity.

Scientific Objectives

- 1. To elucidate a detailed evolutionary history of climate and surface ocean conditions since the earliest Pliocene in the Bering Sea, where amplified high–resolution changes of climatic signals are recorded.
- 2. To shed light on temporal changes in the origin and intensity of NPIW and possibly deeper water mass formation in the Bering Sea.
- 3. To characterize the history of continental glaciation, river discharges, and sea ice formation in order to investigate the link between continental and oceanic conditions of the Bering Sea and adjacent land areas.
- 4. To investigate linkages through comparison to pelagic records between ocean/climate processes that occur in the more sensitive marginal sea environment and processes that occur in the North Pacific and/or globally. This objective includes evaluating how the ocean/climate history of the Bering Strait gateway region may have affected North Pacific and global conditions.
- 5. To constrain global models of subseafloor biomass and microbial respiration by quantifying sub–seafloor cell abundance and pore water chemistry in an extremely high productivity region of the ocean. We also aim to determine how subseafloor community composition is influenced by high productivity in the overlying water column.

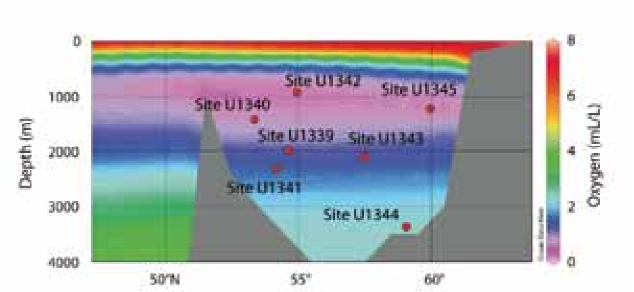

Figure 2. Vertical profile for dissolved oxygen in the Bering Sea along 180° longitude (data from World Ocean Atlas, 2005), with bathymetric position of core sites.

Drilling Operations

Advanced piston coring (APC) was the primary method of core collection, and technical advances in this methodology meant the drilling team were able to go deeper with better recovery than ever before, beating the world record APC by reaching 458.4 mbsf (Figure 3). The majority of sites were triple APC cored to ~200 m providing a continuous spliced record at each, with rotary extended core barrel (XCB) below. The longest Sites U1340, U1341, U1343 and U1344 (Figure 4) were collected at Bowers Ridge and the shelf slope, where sedimentation rates were slightly higher than anticipated. The unusually high gas contents of the cores, probably the result of high productivity conditions and organic material, presented some challenges, and several technical and science crew members were the victims of 'exploding cores' from time to time. The majority of coring was completed without hitch, although the occasional large ice–rafted clast or sandy interval halted coring sporadically. The high rate of 'cores on deck' put incredible strain on all staff dealing with the core material, but we managed to cope with it all in the end. The most technically difficult site to core was U1342, as coarse sandstones and eventually basaltic basement were drilled. Although this took valuable time, and gave the soft–rock sedimentologists something to scratch their heads over, it allowed the rest of us the opportunity to catch up with work.

Figure 3. Expedition 323 scientists on the JOIDES Resolution drill–floor, holding the world record breaking longest APC piston core ever collected. The record now stands at 458.4 m below seafloor. (photo courtesy of William Crawford, Expedition 323 imaging specialist).

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Preliminary Results

Sea Ice, Productivity and Deep Water

All seven sites were successfully cored with high recovery (97.4%), and shipboard preliminary analysis was carried out on lithology, micropalaeontology, physical properties, magnetostratigraphy, downhole logging and biochemistry (Expedition 323 Scientists, 2009). The two stratigraphically oldest sites (U1340 and U1341) were at Bowers Ridge, which reached ~5 Ma, and the deepest sites (U1343 and U1344) were at the northern slope, which reached ~2 Ma (Figure 4). Good age control was provided by several magnetostratigraphic and biostratigraphic markers (Figure 5). The cores recovered at Bowers Ridge were predominantly diatom ooze, with a characteristic green colour (Figure 6). It was surprising that laminations and low oxygen benthic foraminifera were found sporadically throughout the entire Plio–Pleistocene sequence at Bowers Ridge, suggesting periods of low oxygen conditions had persisted in the Bering Sea for at least this length of time. The diatom–rich sediments and diatom and dinoflagellate species recovered on Bowers Ridge indicate higher productivity and a lack of sea ice over Bowers Ridge before NHG, with low percentages of sea ice diatoms and dinoflagellates appearing after this transition.

Calcareous benthic and planktonic foraminifera were common at Bowers Ridge back to ~1.5 Ma, and at the northern slope sites to ~2 Ma. This will allow isotope stratigraphies to be constructed over this period, which includes the Mid–Pleistocene Transition (MPT, 0.6–1.2 Ma). Productivity and low oxygen bottom waters appear to have decreased after the MPT, although significantly higher variability in post–MPT samples indicates large swings in Quaternary glacial–interglacial palaeoceanographic conditions. In contrast to Bowers Ridge, the northern slope sites contained a higher proportion of clastic material partly accounting for the higher sedimentation rates. This is most likely from their relative proximity to the shelf break and glacial coastline. However, these sites also contained high proportions of diatoms and high productivity microfossil indicators, as well as low oxygen benthic foraminifera indicating high surface water productivity. As expected, sea ice diatom and dinoflagellate cyst species were more abundant at the northern slope sites than at Bowers Ridge. But surprisingly, sea ice appears to have expanded at all sites and by inference the entire Bering Sea at ~1 Ma, and not gradually as many global climate changes were over the MPT. Detailed follow–up work is needed to fully resolve these findings.

Late Pleistocene (0–0.6 Ma) sediments at all sites record reduced productivity in the majority of samples corresponding to glacial intervals, probably the result of increased sea ice and stratification. The low resolution shipboard sampling was unable to fully resolve glacial–interglacial variability, but preliminary results point to significantly higher productivity and low oxygen bottom water during interglacial intervals, as was found during the last deglacial from previous piston core analysis in the Bering Sea (e.g. Okazaki et al., 2005; Cook et al., 2005). Sporadic laminated intervals indicative of dead zones appear to correlate with some deglacials in several cores both on Bowers Ridge and the northern slope. Intermediate water ventilation may have had a part to play in the better oxygenation during glacial intervals, but further analysis is needed to clarify if this was the case.

Figure 6. Kelsie Dadd (left) and Mea Cook examining some of the characteristic green 'diatom ooze' sediments from Bowers Ridge (photo courtesy of Carlos Alvarez Zarikian).

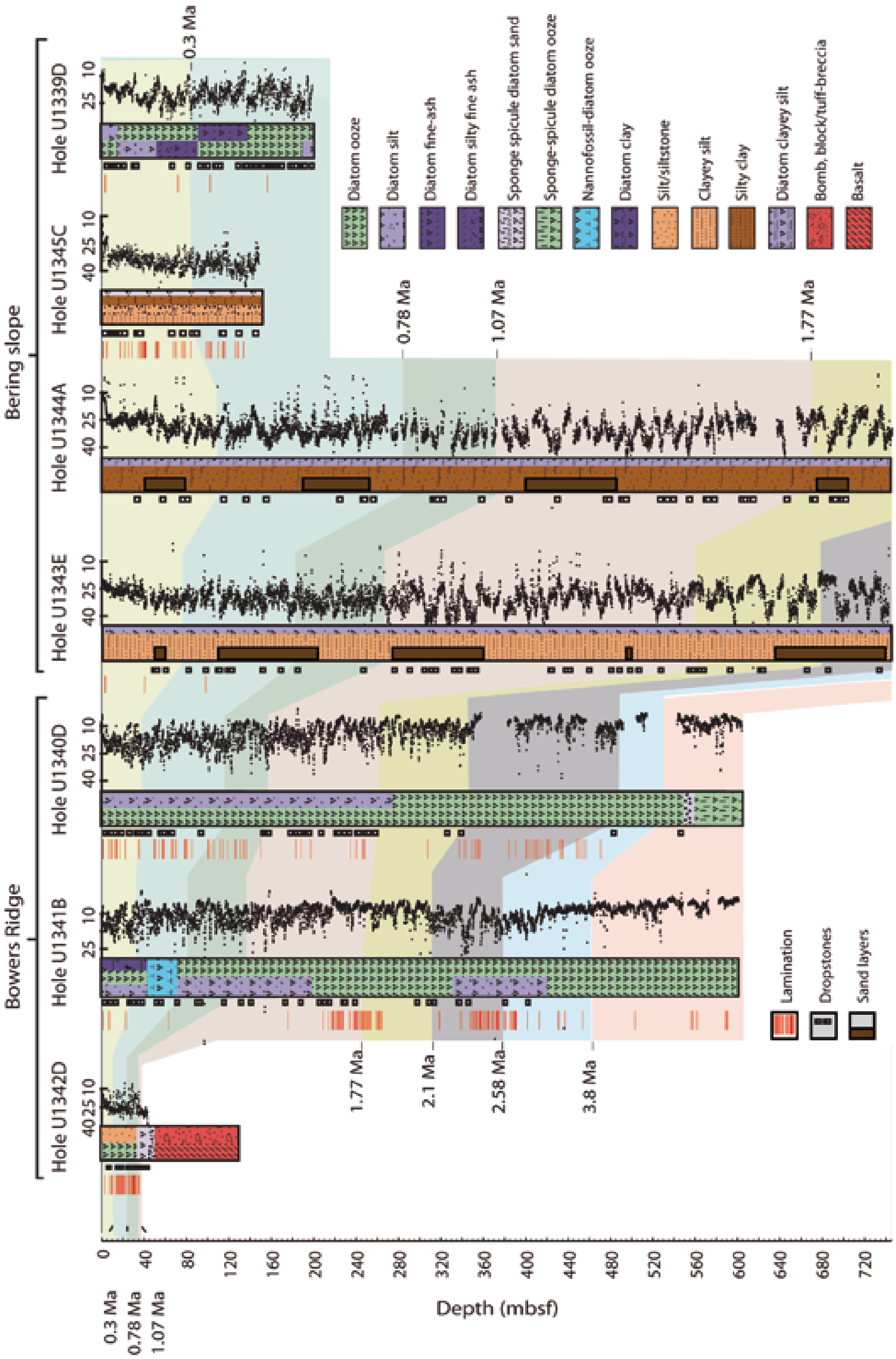

Figure 4. Lithostratigraphic summary of Expedition 323 sites, with natural gamma ray data and biostratigraphic and magnetostratigraphic marker horizons shown (Expedition 323 Scientists, 2009).

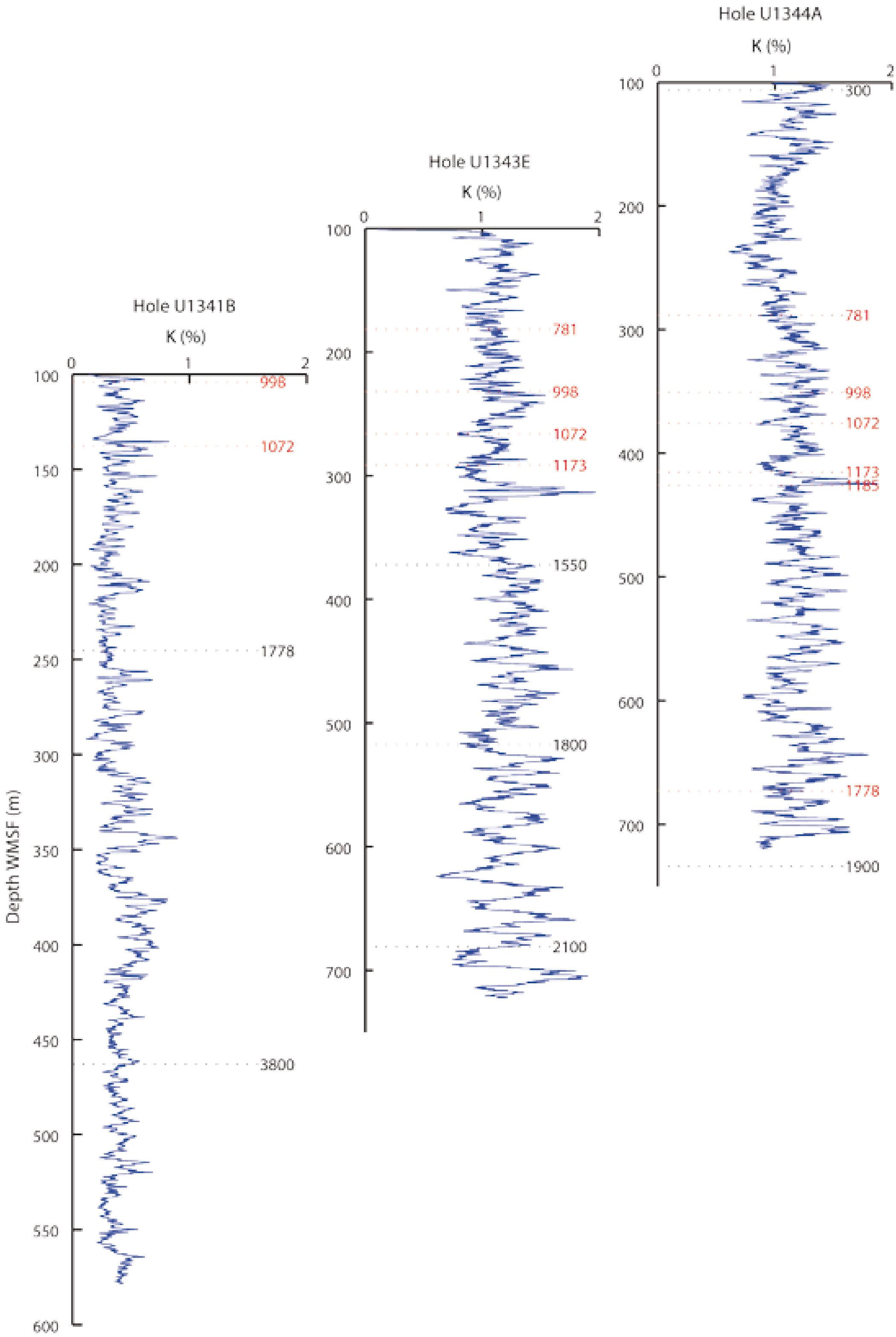

Figure 7. Variations in potassium content measured by downhole logging in Holes U1341B, U1343E, and U1344A, illustrating changes in frequency and amplitude. Biostratigraphic (black) and paleomagnetic (red) age estimates are also shown (Expedition 323 Scientists, 2009).

Cyclicity

One of the very exciting aspects of these new cores is the Milankovitch and millennial–scale cyclicity clearly evident from both logging and palaeomagnetic data at most Bering Sea sites. Both natural gamma (Figure 4) and elemental concentrations like potassium (Figure 7) show large cyclical variability at all sites with depth. As Bering Sea sediments are dominantly composed of siliciclastic material and biogenic microfossils (largely siliceous diatoms), these changes probably indicate shifts in a two–component system forced by biological productivity and terrestrial input, both of which are controlled by glacial–interglacial environmental change. Preliminary spectral analysis of K%, believed to largely represent siliciclastic input during glacials, indicates a predominantly 40 ka periodicity before ~1 Ma at U1341, U1343 and U1344 (Expedition 323 Scientists, 2009). After ~1 Ma, major interglacial stages are present, indicating a change from the 40 ka world to 100 ka world over the MPT. Significantly, sub–Milankovitch variability resembling D–O cycles identified in ice cores can be resolved at some sites, confirming the Bering Sea acted to amplify climate change in this high latitude region. These high frequency changes were possibly a response to sea ice and melt–water input affecting productivity, rather than from longer term sea level fluctuations.

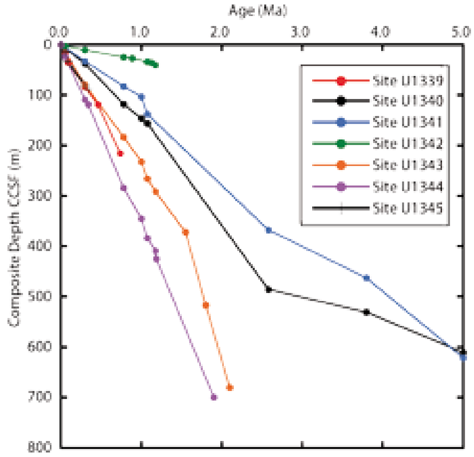

Figure 5. Sedimentation rates for all Expedition 323 sites (Expedition 323 Scientists, 2009).

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Microbiology

High–resolution sampling for microbiological analyses and pore water chemistry was carried out at Sites U1339, U1342, U1343, U1344, and U1345 on microbiology–dedicated cores to ~40 mbsf. The geochemical data show that microbial activity along the higher primary productivity slope sites is substantially higher with more diverse respiration pathways than at Bowers Ridge. A shallow sulfate–methane transition zone (~6–11 mbsf) was present, indicating that both methanogenesis and sulfate reduction based on methane oxidation occur in these sediments. Interstitial water data further suggested the presence of microbial–mediated Fe and Mn reduction. Interestingly, the geochemical profiles even suggested significant microbial activity as deep as 700 mbsf. In contrast, at Bowers Ridge sulfate penetrated to the basement and was almost unaltered with depth, suggesting only very low rates of microbial–mediated sulfate reduction, and methane was below the detection limit. A larger and more diverse microbial community at the slope sites is a likely explanation. Specifically, elevated cell abundance and a consortium of bacteria and archaea at the sulfate–methane transition zone is expected. At the slope sites, geochemical profiles suggest that methanogens, iron reducers, manganese reducers, and sulfate reducers exist throughout the sediment column. At Bowers Ridge, geochemical profiles indicate that only sulfate reducers and nitrate reducers are present.

Concluding Remarks

Intense follow–up work by shipboard and shorebased scientists is now underway to analyse these and many other aspects of the new cores, and research is set to continue for some years to come. In December 2009 a large group of these scientists met up at the Kochi Core Center in Japan to take samples for future analysis. This lasted two weeks, but despite long hours only about half of the 45,000 or so samples were able to be collected!
The remainder have now been taken by the dedicated Kochi staff and Japanese volunteers during a second recently completed sampling party, for which all Bering Sea researchers are most grateful. We all look forward to seeing results at the post–cruise science meeting next year.

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Expedition 324: The shatsky rise–testing the plume head hypothesis

4th September–4th November 2009

Julie Prytulak (University of Oxford), Mike Widdowson (Open University), Kate Littler (University College London) and the Expedition 324 Shipboard Scientists

From September to November 2009, thirty scientists from eight countries, including three UK participants, took part in IODP Expedition 324 to drill and recover hard rock from the Shatsky Rise oceanic plateau (Figure 1).

Knowledge about large igneous provinces (LIPs) has played a fundamental role in shaping the prevailing view of mantle geodynamics, that of largely plate–driven flow in the upper mantle punctuated by rising, thermally driven plumes from the lower mantle (e.g., Davies, 1992). The largest LIPs, including oceanic plateaus, reach volumes ranging from 10^6 km^3 to greater than 10^7 km^3, and are apparently the product of relatively short lived massive magmatic episodes that represent the largest non–ridge volcanic process on Earth (e.g., Coffin and Eldhom, 1994). In terms of magma flux, volume, and extent, such LIPs dwarf even the most prodigious present day hotspots, such as Iceland and Hawaii. Magma production rates for the largest LIPs rivaled or even surpassed that of the global mid–ocean ridge system for short periods of time (e.g., Tarduno et al., 1991; Duncan and Richards, 1991; Mahoney et al., 1993; Coffin and Eldhom, 1994). Moreover, because many of the largest continental LIPs formed during the Mesozoic, they may represent a mantle convection regime different from that of the ridge volcanism–dominated Cenozoic (e.g., Stein and Hoffman, 1994; Machetel and Humler, 2003).

A widely accepted explanation for oceanic plateaus and continental flood basalts is the plume head hypothesis, which posits that large, bulbous, primarily thermal diapirs are created at depth in the mantle, and then rise toward the surface, causing cataclysmic volcanism when they impact the lithosphere (e.g., Richards et al., 1989; Griffiths and Campbell, 1990). Similar to the related plume hypothesis for hotspot volcanism (Morgan, 1972, 1981; Sleep, 2007), the plume head hypothesis has been accepted by many scientists because it provides a simple framework tying together many observations. Moreover, the plume head phenomenon occurs naturally in many numerical and laboratory experiments (e.g., Whitehead and Luther, 1975; Griffiths and Campbell, 1990, 1991). The trouble is that there is currently no unequivocal geological evidence proving the plume head mechanism has operated within the Earth. Many existing data are indirect indicators of eruption rate and magmatic volume and could be explained by alternative hypotheses. Ongoing debate about the number, characteristics, and even existence of mantle plumes (e.g., Smith and Lewis, 1999; Anderson, 2001, 2005; Fougler, 2002; Courtillot et al., 2003; Sleep, 2003; Fougler and Natland, 2003; DePaolo and Manga, 2003; Fougler, 2007) makes it desirable to consider alternative explanations for oceanic plateaus. Because these plateaus are arguably the most direct expression of mantle plume heads (in contrast to continental LIPs, whose magma must have first passed through continental lithosphere), understanding oceanic plateau formation is considered critical to understanding mantle geodynamics.

In order to address the plume head versus alternative hypothesis, it is necessary to study a plateau for which the relation to contemporaneous mid–ocean ridges is known. Unfortunately, this condition is no met for plateaus formed during the Cretaceous Normal Superchon (a.k.a., the Cretaceous Quiet Period)–like Ontong Java, Manihiki, and Kerguelen plateaus–because of the lack of magnetic reversals and thus linear seafloor magnetic anomalies to mark the locations of spreading ridges. Shatsky Rise is the only large intraoceanic plateau formed at a time of magnetic reversals. Contemporaneous magnetic lineations exist around and within the Shatsky Rise plateau, providing a framework that allows the development of a tectonic model (Nakanishi et al., 1999; Sager et al., 1999). However, this model is currently based on geophysical inferences with little geological evidence from sampling.

Shatsky Rise is also unique because it has characteristics that suggest both plume head and ridge–controlled origins (Sager, 2005). The plateaus size, morphology, apparent eruption rate, and age progression are consistent with a plume head origin (Sager and Han, 1993; Nakanishi et al., 1999; Sager et al., 1999; Sager, 2005). However, sea floor magnetic anomalies reveal that, the plateau formed at a triple junction during a time of ridge reorganization, thus suggesting a link to ridge tectonics (Sager et al., 1999; Sager, 2005). Furthermore, Nd–Pb–Sr isotopic data for the sparse basalts cored and dredged from Shatsky Rise prior to Expedition 324 show a similarity to Pacific mid–ocean–ridge basalt (MORB), but not the expected ocean island–type signature of a plume head eruption (Mahoney et al., 2005). Whether or not this MORB affinity is representative of all of Shatsky Rise, or whether it characterizes only a few minor, late stage magmas, remains a major unanswered question. However, the fact that existing data can be interpreted both ways suggests that this plateau is uniquely suited for testing plume head versus ridge tectonic models. Moreover, because several, perhaps many, oceanic plateaus are formed at triple junctions (e.g., Winterer et al., 1976; Larson et al., 2002; Sager, 2005; Ishikawa et al., 2005; Smith, 2007), Shatsky Rise likely represents a significant class of oceanic plateau, and may indeed be representative of all.

To address the formation of oceanic plateaus, Expedition 324 had three primary objectives:

- 1.Determine the basement age to constrain temporal evolution of the Shatsky Rise.

- 2.Determine the chemical and isotopic compositions of igneous rocks cored from the plateau.

- 3.Determine the source temperature and degree of partial melting that produced the plateau lavas.

These research goals are currently being pursued by Expedition scientists, and in this newsletter, we provide some highlights of findings from the preliminary report.

http://publications.iodp.org/preliminary_report/324/index.html

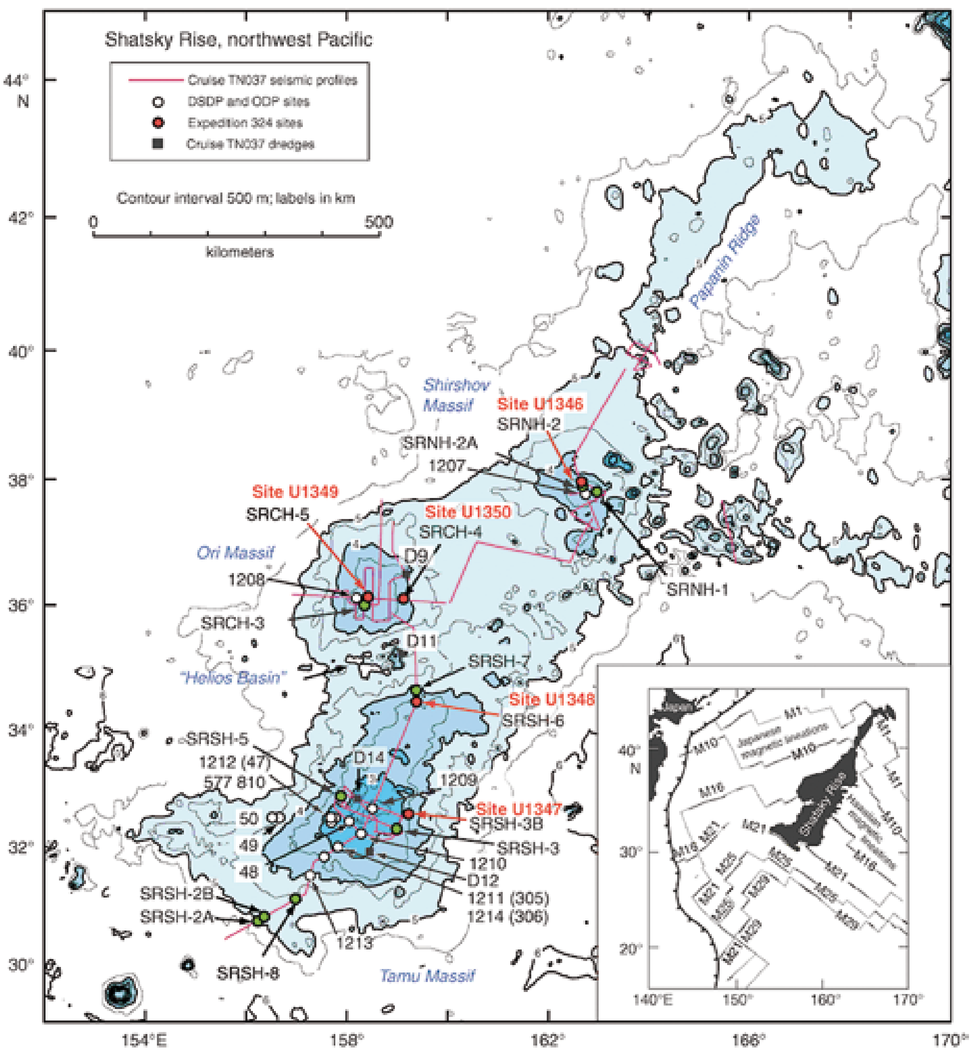


Figure 1–Location chart of major feature names (blue), DSDP and ODP drill sites, and site drilled during Expedition 324. Light blue shading = elevations shallower than 5 km on Shatsky Rise. Site 1213 is the location where igneous rocks were drilled during ODP Leg 198. Inset illustrates the location of Shatsky Rise in relation to western Pacific magnetic lineations (thin lines), trenches (toothed line) and Japan. This figure is F2 in the Expedition 324 preliminary report.

Drilling Operations

The three UK participants on Expedition 324 spanned the full gambit of career stages, including a PhD student, a postdoc, and a lecturer. That said, we were all on a level playing field in terms of our previous sea–going experience. None. The scientific party gathered in Yokohama, Japan and spent 4 days familiarizing ourselves with ship operations whilst getting to know one another over sushi and Asahi.

On the 9th of September, we set sail from Yokohama, and headed out into the Pacific Ocean towards to Shatsky Rise. It quickly became apparent that some of us (Kate in particular) had perhaps left our sea legs at home. However, the 4–day transit to our first site gave us all time to adjust to life onboard and provided a tangible illustration of the isolation of the region we were to spend the next 2 months in. The *JOIDES Resolution* had recently been renovated, and our Expedition was only the fourth since the refitting. One of the main improvements that we all appreciated was the introduction of 2 person, instead of 4 person, cabins. With a cabinmate on the opposing shift, essentially, you had a cabin completely to yourself off–shift. This was entirely more privacy than had been expected. During the transit, we spent our time learning our respective jobs, and became somewhat obsessed with weather updates. Expedition 324 sailed in the height of the typhoon season, and we had to modify our drilling plan on a few occasions to accommodate our windy friends. The most significant of these was Typhoon Choi–Wan (Figure 2) whose untimely arrival made it necessary to alter the planned order of our drill sites.

Figure 2–Typhoon Choi–Wan image from September 15th, 2009. Image downloaded from: www.wunderground.com/tropical/

One memorable drilling highlight was the emplacement of a free–fall funnel at Hole U1347A ; this was deployed to permit re–entry of a new drill bit in order to further extend coring at this site. Seeing this massive funnel lowered from the ship (Figure 3) and then seeing the same funnel (via sub–sea camera) on the ocean bottom over 3 km beneath your feet as the crew expertly re–entered the Hole still boggles the mind. A crew member was heard to describe the mechanics of the process as 'dangling a length of spaghetti from a 30 story building and getting it to land end first in a pint glass on the ground'. A truly apt sentiment.

The Expedition had a long final transit of 14 days during which we sailed down to Townsville, in north–western Australia. The transit enabled not only the completion of shipboard reports, but also allowed personal sampling to take place on board. Indeed, when we arrived home, most of us discovered that our samples had beaten us there! Oh yes, the final transit also featured the small matter a visit from King Neptune and his colourful entourage as we crossed the equator.

Figure 3–Preparing for hole re–entry at Site U1347 after the bit–change. The crew is about to drop the free–fall funnel through the moon pool and down to the seafloor over 3 km below the boat. The pipe is then pulled up and a new drill bit attached to the end. The drill string is then lowered back into the water and the hole is re–entered with the aid of the funnel and a grainy black–and–white camera image of the seafloor (inset image). Photo credit Will Sager.

Highlights of scientific results

Despite sporadic typhoon interruptions, Expedition 324 successfully drilled 5 holes, recovering the desired igneous basement in 4 of them. Holes were cored on the TAMU (U1347, U1348), ORI (U1349, U1350) and Shirshov (U1346) massifs (Figure 1). The sediment cover of the Shatsky Rise has been extensively explored over the past 32 years.

In succession, DSDP Legs 6 (Sites 47–50), 32 (Sites 305 and 306), and 86 (Site 577) as well as ODP Legs 132 (Site 810) and 198 (Site 1209–1214) all recovered sedimentary material. Given the extensive previous sedimentary sampling, and the essentially hard rock goals of Expedition 324, all sites started core recovery at only 50–70 m above the inferred sediment/basement interface.

Below we detail a few highlights from the drill sites. We achieved our goal of sampling igneous lithologies, with significantly above average recovery for hard rock drilling (Figure 4).

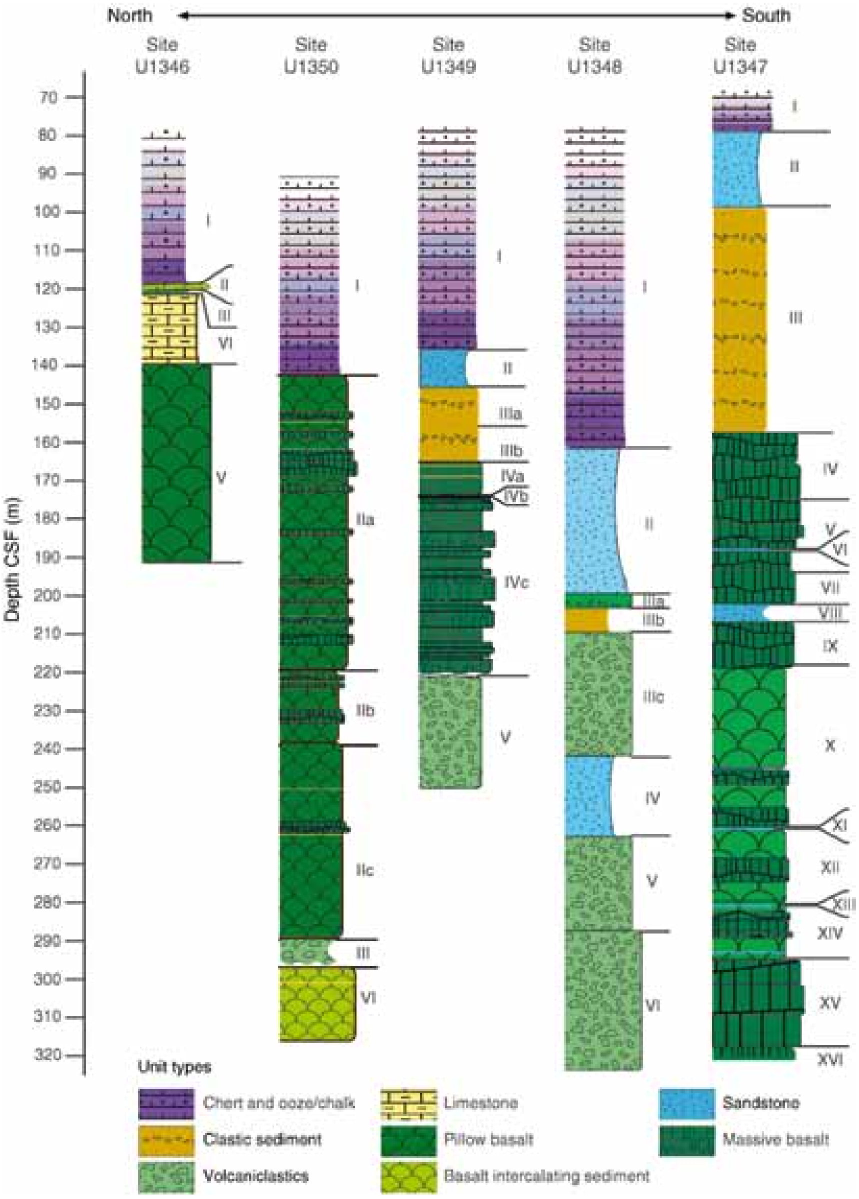


Figure 4–The lithological summary. This figure is F9 in the Expedition 324 preliminary report.

U1346: a tubiditic blanket for altered pillow basalts

Site U1346 is situated at the north edge of the Shirshov Massif. A single hole was drilled, penetrating 191.8 mbsf, with 139.2 m of sedimentary cover and 52.6 m of igneous rock (Figure 4).

Our very first drill site generated some excitement for the sedimentologists, who might have otherwise been expecting a rather limited sample set given our drilling goals. In particular, we recovered a series of laminated volcaniclastic sequences, which are interpreted as turbiditic in origin. These sediments display grading from very coarse sand to clay and evidence for lateral transport in the form of erosion features and rip–up clasts. The remaining sediments are composed of carbonaceous mudstones with abundant biogenic fragments, glauconite and altered volcaniclastics. Taken together, these components are indicative of a relatively shallow marine depositional environment in close proximity to a volcanic material source.

Basement coring encountered a 53 m thick stack of highly vesicular basaltic pillow lava inflation units. Within the lava stack, individual pillow units were readily identified by the presence of chilled glassy margins, and upper and lower chill zones, characteristic pillow vesicle patterns, and associated crystal grain size variations. In total, 40 individual lava–cooling units were recognized in the cores, but the sequence taken as a whole is interpreted to represent a single eruptive event. Extensive low temperature water rock alteration left a marked impression on all igneous rocks recovered at this site, resulting in near complete replacements of primary minerals and glasses.

Despite moderate to complete alteration, shipboard geochemical analyses show that several elements including Ti, Zr, Y, Cr, V, and Sc remain relatively unaffected by alteration processes and show coherent behaviour within the tholeiitic basalts. These elements indicate a strong similarity with previously recovered, older basalts from Site 1213 of ODP Leg 198, which lies 870 km to the southwest on the edge of the TAMU Massif (Figure 1).

U1347: Massive flows on the TAMU Massif

Site U1347 is situated on the upper flank, east of the summit of the TAMU Massif (Figure 1). The hole penetrated 317.5 m below the seafloor, including a 157.6 m sedimentary section and a 159.9 m igneous section (Figure 4).

The recovered sedimentary material at this site is dominated by a thick sequence of radiolarian–rich silt and mudstones, with evidence for lateral transport processes in the form of grading and erosion contacts. However, one of the more interesting sedimentary features at Site U1347 are the abundant and varied radiolarians in the overlying siliceous limestones which, in many instances have been spectacularly replaced and preserved by secondary glauconite.

The 159.9 m thick volcanic basement succession consisted of packages of massive basalt flows and pillow inflation units intercalated by sedimentary successions up to 5 m thick. In many instances, the high recovery (average 64.2 %) yielded well–preserved lower and upper contact zones with chilled margins, baked sediment contacts, and folded pahoehoe–type upper crusts. The frequent recovery of thick (often fresh) glassy rinds within the pillow unit stack indicates that alteration was essentially buffered in these rocks, presumably from the sediment interbeds acting to cap and preserve the igneous material.

The majority of the volcanic units are plagioclase–pyroxene phyric basalts. The mineralogy throughout the drill site indicates that the rocks have experienced low–pressure plagioclase–clinopyroxene cotectic crystallization during all stages of their cooling and differentiation. Olivine phenocrysts occur rarely as early co–precipitating liquidus minerals, but are now completely replaced by clays and calcite. Remarkably, we actually discovered fresh olivine containing melt inclusions in a few thin sections.

The basalts appear more differentiated compared with several other sites (1213, U1346, and U1349). This is evident from the predominance of plagioclase and clinopyroxene intergrowths at all stages of crystallization, the scarcity of olivine, and the almost complete absence of Cr spinel. The phenocryst assemblage and character of intergrowths compare well to those of evolved low–temperature gabbros and formed in shallow crustal magma chambers beneath fast and super fast spreading ridges. In general, the primary mineralogy is well preserved, especially close to the pillow margins. There is little significant variation in the style of alteration, and is interpreted to have been caused by shallow–water interaction with seawater–derived fluids at less than 100° C.

Figure 5–A scene from sampling parties during the transit from the Shatsky Rise to Townsville, Australia. This photo is remarkable for its capture of all three elusive UK participants: Kate Littler (foreground), Mike Widdowson (Left) and Julie Prytulak (purple t–shirt, background).
Photo credit Will Sager.

U1348–A thick, altered hyaloclastite succession

Site U1348 is situated on the north flank of TAMU Massif (Figure 1). It represented our most challenging drill site in terms of scientific interpretation and was the only hole in the Expedition that failed to penetrate 'true' igneous basement. The disappointment of this, however, was counterbalanced by the sheer variety of sedimentary material recovered above and within the main volcanic detritus succession, which included nannofossil oozes, multicoloured cherts, bioclastic sandstones, green zeolitic clays and thick, highly altered volcaniclastic units. It was this ~120 m thick volcaniclastic succession (Figure 4) which presented the greatest classification challenge and, after considerable head scratching and debate, the tentative interpretation is a sequence of highly altered marine hyaloclastites. Based on the marine fossil content, grading and bedding structures, they are thought to represent a mixture of in–situ and re–deposited material that was erupted in a submarine environment. Petrology reveals that the volcanic glass shards and larger vitric clasts are all pervasively altered.

The near complete alteration of the volcanogenic constituents, which masks both the original composition and structure, was a major obstacle to the interpretation and even recognition of the hyaloclastite material. This is because almost without exception, the hyaloclastite composition has been entirely transformed to secondary palagonite, zeolite, and calcite.

U1349–The altered basaltic summit of the ORI Massif

Site U1349 is located at the summit of the ORI Massif (Figure 1). The Hole penetrated 250.4 m below the sea floor, through 165.1 m of sediment and 85.3 m of igneous basement (Figure 4).

Only 10.1 m of sedimentary material was recovered, which was mostly composed of chert and porcellanite fragments, but one thin, yellowish red clay–rich horizon has been tentatively interpreted as a paleosol. The cored basaltic succession is ~55 m thick and consists of 25 lava units characterised by high (40–75%) vesicularity, the presence of magma mixing features and, in all but the interiors of the thickest inflation units, a pervasive reddish brown Fe oxyhydroxide hematite alteration. This succession also contains 10 weathered flow tops readily identified by a reddening over 5–10 cm intervals, tentatively interpreted as subaerial alteration occurring between emplacement of successive eruptive units.

Petrographic examination reveals that the basalts are all Cr spinel bearing and olivine–phyric. The basalts have 8–15 wt% MgO and thus may be termed picritic. Olivine phenocrysts are sparsely to moderately abundant but are usually entirely altered to iddingsite, clays, and Fe oxyhydroxides. The combination of crystal accumulation and severe alteration makes the liquid evolution of the magma difficult to determine. However, shipboard measurements suggest that U1349 basalts are the least differentiated rocks recovered at the Shatsky Rise.

U1350–The fresh basaltic flank of the ORI Massif

The final site was located on the lower east flank of ORI Massif, and we used our previous experience drilling the TAMU Massif eventually choosing this site due to its similarity to Site U1347 (i.e. on the flank, not the summit), which had yielded relatively fresh basalt. The hole penetrated 143.1 m of sediment and 172.7 m of igneous basement to a total depth of 315.8 m below the sea floor (Figure 4).

Only small fragments of chert and porcellanite were recovered lying atop the igneous basement. The entire basement section of pillow lavas has been affected by slight to high degrees of low temperature water rock interactions. However, plagioclase phenocrysts and glassy margins of the pillows are often completely preserved, which made the geochemists and geochrolonogists extremely happy, and justified our plan to drill on the flank of this volcanic edifice. The pillow lava sequence is particularly spectacular because it is intercalated with carbonate muds containing several small, 'cooked' brachiopod fossils. The final site proved, once more, that despite the primary objectives of the cruise, there was considerable fun to be had by the sedimentologists.

The shipboard chemical data reveal that the basement section is composed of variably evolved thoeliitic basalts. Broad similarities with Sites U1347 and ODP Leg 198 Site 1213 (Figure 1) are present, but U1350 lavas differ in important respects: for example, they show systematic downhole variation in several key chemical parameters, exhibit a wide range of TiO_2, Zr, and Mg numbers, extend to higher Mg values and have high Sr concentrations. They also show variable Zr/Ti ratios, implying that variations in the amount of partial melting and/or source composition are important.

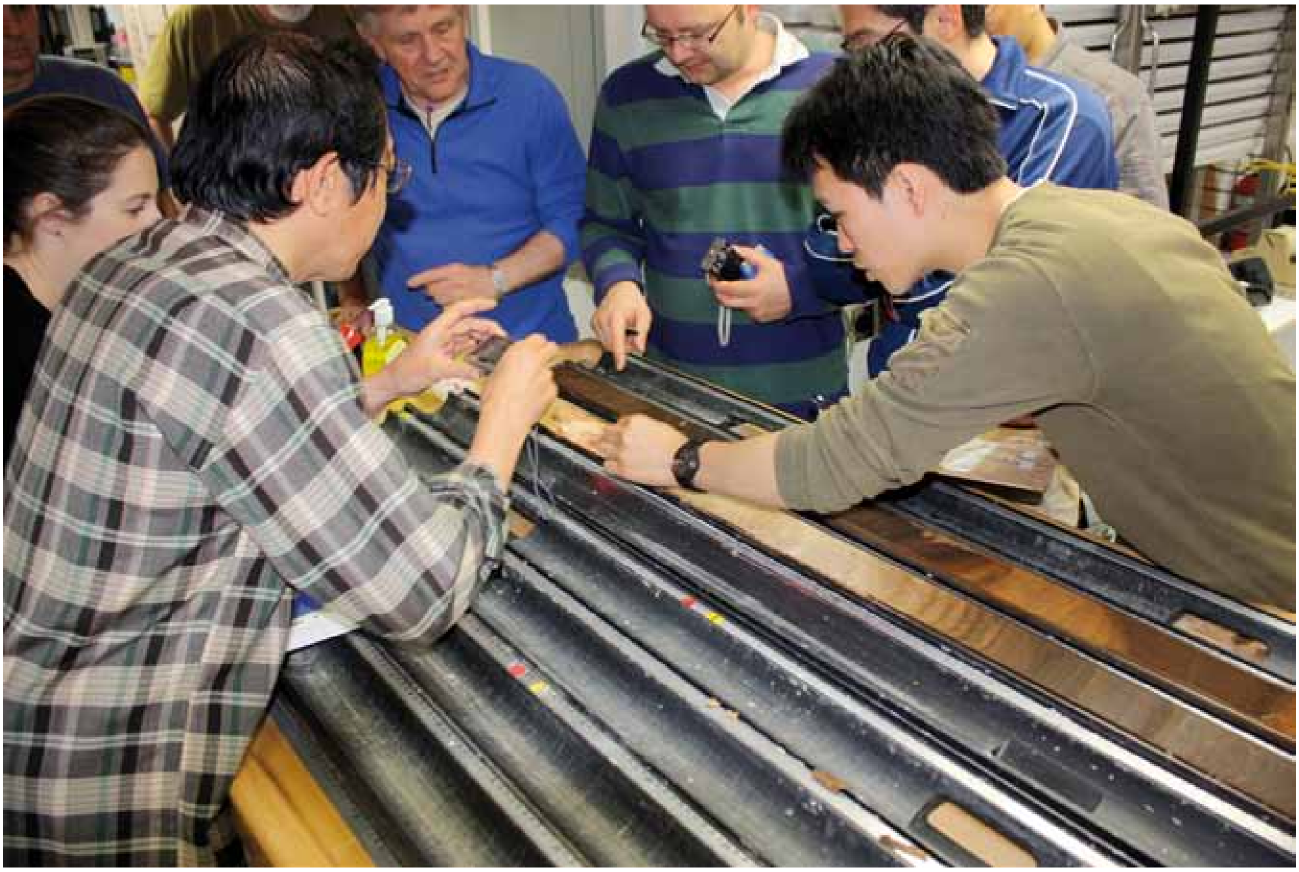
Continuing study

The goals of the cruise–to test the plume head hypothesis–look to be readily achievable considering the quality and abundance of igneous material recovered. Additionally, preliminary information gleaned regarding whether Shatsky Rise edifices were emergent (or not) places strong constraint on the evolution of large oceanic plateaus and the expected styles of volcanism. The recovery of datable material on spatially dispersed Massifs also provides a promising means by which to address the first main objective of the cruise. Onshore studies of the relatively fresh, mafic igneous material will be able to address the second major objective, and hopefully decisively determine whether the Shatsky Rise shares geochemical affinity with typical MORB; if so, this will support a ridge tectonics model, whilst if it displays the enrichments associated with deeper thermally driven sources, a mantle plume orgin will be favoured. The abundance of igneous material, in particular the key finds of fresh olivine and melt inclusions, should enable us to address the final objective of determining the source temperature and to constrain the degree of melting experienced during generation of the Shatsky basalts.

The coming years of research on Expedition 324 samples promises to be an exciting time for constraining the origin and evolution of large, but little understood, oceanic plateaus such as the Shatsky Rise.

UK participants

Julie Prytulak (Oxford University) sailed as a physical properties specialist. Mike Widdowson (Open University) sailed as lead volcanologist. Kate Littler (University College London) sailed as a sedimentologist.



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UK IODP News

Grant Rounds

- **Ice Sheets and sea level reconstructions and sensitivity**
  Awarded in March, 2010, 5 grants were awarded by UK–IODP of total RC contribution of ~£310,000.

- **Standard and Small grants round**
  This grant round closed April, 2010 with RC allocations of £1.5 m (Standard), and £0.6 m (Small). This was a directed round with topics ranging from the geodynamics of plate boundaries to the marine record of global biogeochemical cycles. There was excellent proposal pressure with 27 applications. Awards will be announced Jul/Aug, 2010.

Arctic Document

In conjunction with the ECORD ILP, the UK–IODP office has been leading the effort to encourage industry support for scientific drilling in the Arctic. Forthcoming in 2010 are a brochure and workshop with this aim in mind.

M. Mowat © ECORD IODP

Post–Cruise funding for PhD students and post–doctorates

The UK–IODP management is increasing emphasis on post–cruise funding so that early career scientists may optimise their IODP experience.

Historically we have found that sailing on an IODP expedition has been for PhDs and Post–docs very exciting and educational. However, returning from the expedition and immediately resuming their ongoing research, which may be completely unrelated, results in a somewhat disjointed and unfulfilled experience. For this reason we hope to award more post–cruise funding to enable PhDs/Post–Docs to conduct follow–up expedition related research.

From 1 April 2010, any PhD students or Post–Doctorates sailing on IODP expeditions and receiving FEC for their participation will be **required** to submit a post–cruise grant application not longer than 2 months following their return from the expedition, though this does not guarantee funding.

See the NERC UK–IODP Grants page for further details:
www.nerc.ac.uk/research/programmes/ukiodp/grants/

Science Meetings

UK IODP has been active in organising science meetings for the

programme grant rounds awarded to date.

- **Forcings and Feedbacks round–Awarded 2009.**
  This Science meeting will be held in Autumn 2010.

- **Ice Sheets and sea level reconstructions and sensitivity–Awarded 2010**
  This meeting will be held in conjunction with the 3rd international PALSEA workshop, to be held this 20–24 September in Bristol. This is an excellent opportunity to integrate UK–IODP funded science with an existing well respected, and well organised meeting which is otherwise invitation only.

Ocean Drilling Review

Sasha Leigh

Background

An independent Review group will be convened later this year to provide the Natural Environment Research Council (NERC) with an assessment of the benefits of ocean drilling to UK science. This review will examine all of the available evidence to assess the benefits of the Integrated Ocean Drilling Programme (IODP) and to advise NERC of ocean drilling's potential to deliver strategic science in the future.

The outputs of this review will form part of the evidence that will be used to inform NERC Council's future funding decision on the membership subscription to the ocean drilling programme that will follow IODP in 2013, and also any UK support Research Programme funding.

Review Group

The Ocean Drilling Review Group will be convened by NERC towards the end of 2010 and will report to NERC on its findings in early 2011.

A 'Call for Evidence' for this review was published by NERC in June 2010. Written responses from the UK community, along with evidence provided directly by the UK IODP Research Programme, will be primary sources of evidence for this review and it is anticipated that the Review Group will invite a number of representatives of the community to present their evidence in person. This review will be informed by the US National Research Council review–that will report in October 2010 on ocean drilling and its potential for future transformative discoveries–and the emerging international Science Plan: (www.marum.de/iodp–invest.html)—that is currently being developed with strong inputs from the UK science community and will define the future science strategy for ocean drilling. Relevant NERC Theme Leaders will also be consulted for fit to NERC strategy and their upcoming Theme Action Plans.

The final review meeting will consist of open sessions where the Review Group will be able to call on members of the community or of the UKIODP Executive Board/Management team to interview. The Review Group will then meet in closed session to discuss the full evidence material and documentation provided. The meeting will be based on the format of the main Review documentation and evidence base.

The Review Group's Final Report will be submitted to NERC in early 2011 and this fits in with the timetable for the international IODP 'renewal' process–which will require ocean drilling partners to sign a new Memorandum of Understanding in 2012.

Terms of Reference

The two main objectives of the NERC Ocean Drilling Review are to:

- Advise on the past performance and value for money of the UK's involvement in the Integrated Ocean Drilling Programme–in terms of scientific excellence and impact, science community and national economic benefits, and the delivery of NERC's current (and previous) science strategy;
- Advise on the potential future benefits and value for money from the UK's continued involvement in ocean drilling and its potential to deliver NERC strategic and science priorities.

In addition, the Review will:

- Advise on the relative priority for UK science of the three IODP platforms in the future ocean drilling programme.

For further information and queries, please contact:
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INVEST

(IODP New Venture in Exploring Scientific Targets)

The INVEST meeting was held in September 2009 to define the scientific goals and required technology for a new ocean drilling programme. The meeting was a substantial success with over 550 participants from 21 countries. UK–IODP supported the participation of more than 20 UK scientists at INVEST, including 4 session chairs. See below for a report from one of these breakout sessions.

One important product of the meeting was the construction of the Science Plan Writing Committee (SPWC), which is charged with drafting the science priorities of a new program. Again the UK is well represented, as Prof. Mike Bickle of Cambridge University was appointed chair of this committee.

Meeting Website:
www.marum.de/iodp–invest.html

Access to the >100 submitted white papers

General Meeting Report:
IODP Ventures in Exploring Scientific Targets (INVEST): Defining the new goals of an International Drilling Program". April, 2010, Scientific Drilling, no. 9.

C. Cotterill © *ECORD IODP*

INVEST: Report on discussions of 'Co–evolution of ocean chemistry and the surface/sub–surface biosphere'

Scientific ocean drilling has been instrumental in establishing that the chemical composition of seawater has evolved over time. Today, the main question is what causes these changes? Addressing this is both hugely challenging, but also hugely important, because ocean chemistry is linked to and therefore provides information about the operation of all aspects of the earth system, from the lithosphere to the biosphere to the atmosphere.

As the co–evolution of the surface biosphere and ocean chemistry, was being addressed by a number of other working groups, e.g. ocean acidification, our working group focused on defining the major hypotheses and outstanding questions concerning the co–evolution of the sub–surface biosphere and ocean chemistry, that could be addressed by a new ocean drilling programme. Unsurprisingly, given that we really didn't appreciate the extent of the sub–seafloor biosphere until a decade or so ago, a large number of research targets could be identified. In this report, I summarise some of the key aspects of our discussions.

What we do now know is that the carbon, nitrogen and sulphur cycles could not function in the way that they do without a deep biosphere. Crucially, however, the deep biosphere does not currently feature in ocean budgets because we simply don't know the fluxes involved. The fluxes will be dependent on microbial activity, which in turn is dependent on the 'habitability' of the sediments, e.g. lithology, hydrology, chemistry, as well as the diversity of the microbial community. The step change is that by investigating gene expression, microbiologists can now identify exactly what the microbes are doing. Bringing this work into a new ocean drilling programme will increase its scientific impact in countless ways.

New ocean drilling is key to constraining the linkages between ocean chemistry and the sub–seafloor biosphere. Only ocean drilling can provide information on the variability of fluxes in both space and time. The multi–disciplinary nature of ocean drilling provides the necessary information on microbiology, chemistry and hydrology. Transects are a key strategy: we need to know how fluid chemistry and microbiology evolve along a flow path. Establishing fluxes from diffuse sources is challenging and requires synoptic coverage. Finally, long–term observations, provided by scientific drilling boreholes, are essential for dealing with transient signals and for making in situ measurements of metabolic activity and chemical fluxes.

ECORD Summer Schools

While this work will address key scientific challenges, such as the impact of microbial activity on the carbon cycle, it is also relevant to society. It will provide information about the role of microbes in petroleum generation, it will identify enzymes, that operate under conditions of high temperature and pressure, as well as other marine natural products, that could be used in industrial processes, antibiotics, etc.

A summary of these discussions was presented to all Theme 1 participants, and then to the entire INVEST community. We look forward to seeing at least some of our ideas being incorporated into the science plan for a new ocean drilling programme and, in the longer term, their translation into samples and research publications!

These summer schools are held to further the education of young scientists in marine–related sciences and to train a new generation to participate in the ocean drilling expeditions of the future. These provide an excellent immersive opportunity for students to interact with peers and host of top international scientists. In 2009 there were 2 summer schools: 1) The Geodynamics of Mid–Ocean Ridges (Bremen, Germany), and 2) Summer School in Palaeoclimatology. UK–IODP funded the participation of 6 UK students to attend the summer schools, with further students supported by ECORD.

2009 Urbino Summer School in Palaeoclimatology.

IRFAN U. JAN, PhD Student.University of Leicester, UK

The Urbino Summer School is an annual event, organized by the University of Urbino and ECORD. The city of Urbino is on the eastern coast of Italy, set in a beautiful landscape. Scientifically the course proved highly beneficial to me. The lectures concerning stratigraphy, biogeochemical cycling, and paleoceanography, along with the interactive nature of the classroom and field sessions provided me an invaluable experience. During the summer school we developed an in depth familiarity with palaeobiological and geochemical proxy data and their use in the reconstruction and modelling of past climates.

Included in the program was a one day CIOPINNO workshop on Transient Changes in past warm climates, a half–day poster session organized for the student participants' own research, and field trips to classic regional exposures of the Cretaceous–Tertiary Boundary.

Apart from the excellent science, we experienced the unique culture, vibrant history, and excellent food of the region. The school organised several dinners at local restaurants, providing an excellent opportunity to socialize with the other meeting participants.

The summer school was a great success that provides the participants a cutting edge understanding of the knowledge in the palaeoclimatology; I consider myself very lucky to have been given the opportunity and would highly recommend the experience to other aspiring palaeoclimatologists.

Participants of the School visited the K–T boundary.

Getting Involved in IODP

Application forms and instructions are available at the websites of each Implementing Organization. Also, the UK–IODP mailing list frequently includes calls for IODP participation. To join the mailing list, email the Science Coordinator (ukiodp@bgs.ac.uk).

For UK scientists and scientists from other ECORD countries applications must be submitted to the ECORD Science Support Advisory Committee (ESSAC). ESSAC has been appointed by ECORD as the "National Office" for ECORD participation in IODP. ESSAC is responsible for the scientific planning and coordination of European contribution to, and participation in IODP, including nominating scientists for IODP cruises and representatives on IODP science panels and committees.

Staffing decisions are made in consultation with, co–chief scientists, the implementing organizations (JOI Alliance for the *JOIDES Resolution*, ECORD Science Operator for mission–specific platforms, and CDEX for the riser vessel Chikyu), and reviewed by the IODP Central Management Office. Final staffing authority lies with the respective implementing organization.

The IODP is a unique scientific endeavour. One of the most unusual aspects is the opportunities it presents for people at all stages of their academic careers to be involved, from distinguished professor to undergraduates.

Applying

Anyone interested in participating in an expedition is encouraged to complete an application as instructed on the ESSAC website www.essac.ecord.org/index.php?mod=participation. Calls for applications to sail are made regularly and interested parties are asked to consult the ESSAC and IODP websites for information on upcoming expeditions.

All UK applicants must complete the online application to sail on the ESSAC website. Please inform the UK IODP Science Coordinator (ukiodp@bgs.ac.uk), and the UK delegate to ESSAC (R.H.James@soton.ac.uk) when you make your application. Applicants will be notified in due course.

If you have any comments or questions then please do not hesitate to contact the UK Science Coordinator: (ukiodp@bgs.ac.uk).

UK–IODP Grants

Available Awards

Strategic grants

To support UK membership in the international Integrated Ocean Drilling Program (IODP), NERC runs a UK research programme to enable UK scientists to:

- 1. Participate in and obtain material from drilling expeditions,
- 2. Ensure that IODP carries out the best and highest priority science, and
- 3. Capitalise on the results of IODP drilling and UK technologies, allowing them to benefit from technological advances in deep sea drilling.

The current phase of NERC's UK–IODP science support started in September 2008 and runs until 2013. Part of the funding for the programme is directed toward supporting research grants with the objective of taking forward IODP–related research in the UK.

C. Cotterill © ECORD IODP

Rapid response grants

IODP rapid response awards support a limited number of small–scale, short research activities specifically related to IODP Leg objectives. They are typically awarded to help with sample processing costs or small equipment purchases. Please note that applications for Rapid Response Grants will now need to be costed under FEC requirements. The maximum amount, to include all FEC costings is now £2,750 for Rapid Response Grants.

Proposals (no more than two pages long) should clearly state the aims, deliverables and the case for support. Where relevant, the proposal should be supported by a statement from an IODP Leg co–chief or chief scientist. For students, this may be replaced by, or combined with, a statement from an appropriate member of the departmental academic staff.

Rapid Response proposals will be reviewed by members of the UK IODP Committee and awards will be limited by the funds available for this scheme. Although there is no closing date, applications should be submitted by e–mail to the science coordinator (ukiodp@bgs.ac.uk) as early as possible.

Expedition and post–cruise funding

From 1 April 2010, any PhD students or Post–Doctorates sailing on IODP expeditions and receiving FEC for their participation will be required to submit a post–cruise grant application not longer than 2 months following their return from the expedition.

An outline of this potential work must be included in the FEC application (see below) although UKIODP appreciate this is just an indication and not a commitment to the work plan.

Participation in an IODP expedition does not guarantee post–cruise funding.

Application submission requirements

Expedition participants claiming FEC must submit their proposal in a Small Grant format through the Je–S system. Previous Track Record must not exceed 2 sides of A4 and the Description of the Proposed Research must not exceed 2 sides of A4 (including all necessary tables, references and figures). The Justification of Resources should be completed as a separate item. Up to an additional 2 sides of A4 may be used for this purpose. A CV of the expedition participant is required, (up to 2 sides A4 for each CV).

FULL ECONOMIC COSTING GUIDANCE FOR EXPEDITION PARTICIPANTS

Under full economic costing, all IODP expedition participants from the UK are eligible to apply to NERC for funding to cover their time on board ship. As with research grants, awards will be made at 80% FEC.

The different categories of expedition participant and eligible costs are listed below:

Co–chief

- Directly Incurred costs:
  - Staff Time (for offshore and onshore co–chief activities)
  - Travel and Subsistence (for expedition, sampling parties and post–cruise meetings)
- Directly Allocated costs:
  - Estates Costs (only for time spent onshore)
- Indirect costs:
  - Only for time spent onshore

Expedition participant (sailing)

- Directly Incurred costs:
  - Staff Time (for offshore only)
  - Travel and Subsistence (for expedition, sampling parties and post–cruise meetings)
- Directly Allocated costs:
  - Estates Costs–not eligible
- Indirect costs–not eligible

Expedition participant student (sailing)

- No costs eligible
- Expedition, sampling party and post–cruise meeting Travel and Subsistence costs should be claimed via the UKIODP Science Coordinator (ukiodp@bgs.ac.uk)

Applications for FEC must be submitted via the Research Councils' Joint electronic–Submission system (Je–S) at least 1 month ahead of the expedition start date. The 'scheme' should be completed as 'Directed FEC' and the 'call' as 'IODP'.

See the Je–S website for information on the Je–S process (Further information, including details on Full Economic Costing, is also available in the NERC Research Grants Handbook for Full Economic Cost Grants. Potential applicants are reminded that they and their institution must be registered with Je–S, in order to submit applications.

Standard NERC rules for institutional and investigator eligibility apply to all components of the call. For example, submissions must be made via UK universities or NERC–recognised bodies.

Applications we would expect to see submitted to NERC via the Je–S system would contain the following documents:

- Application Form.

Attachments including:

- Case for Support incorporating the Previous Track Record (up to 2 sides A4) and Description of Proposed Research (up to 2 sides A4).* NB: This is one attachment in the Je–S system.
- Justification of Resources (up to 2 sides A4).
- CVs for Principal Investigator named in the proposal (up to 2 sides A4).
- Impact Plan (up to 2 sides A4).

* If participating as Co–chief the case for support should include

more detail and we therefore require up to 4 sides A4.

Applicants can use their original application to sail as a basis for this submission although specific information is required on their own contribution to the cruise. Impact plans are required and should include the wider significance of the work completed on the expedition.

Guidance for submission of final reports for FEC applications

Je–S will prompt a final report to be submitted following the end date of the FEC award. This final report should be submitted in the requested format, using 'Not Applicable' in sections where necessary. The Summary section should be completed in up to 4,000 characters, including information on cruise reports, core recovery data, any preliminary microbiology/core chronology and any information that was taken onboard (eg logging, geophysical, etc data). Some information on the PI's plans for follow–up work should also be included. Links to relevant cruise reports, cruise diary updates, etc should also be included.

Advice on application and administrative arrangements is available from the Programme Administrator, (kawa@nerc.ac.uk) or the Deputy Programme Manager (snbl@nerc.ac.uk).

Any queries regarding the Je–S system and submission of applications should be directed to the dedicated Je–S Helpdesk.

Post–cruise support for post–doctoral and post–graduate research assistants

This scheme provides additional support for Post–Doctoral Research Assistants (PDRAs) and Post–Graduate Research Assistants (PGRAs) who sail with the Integrated Ocean Drilling Program (IODP) on behalf of the UK. The scheme aims to ensure that more PDRAs and PGRAs can complete up to 6 months post–cruise research. The application procedure is separate from the main UKIODP strategic grant rounds and has specific conditions.

Specific conditions for post–cruise support applications

- As with applications to any other NERC grant scheme, applications must be led by a Principal Investigator from an eligible UK institution. The PDRA or PGRA should be named as the Recognised Researcher for the application. All eligibility criteria are the same as for all other NERC directed programme grant applications.
- Applications must be on behalf of a PDRA or PGRA who has been accepted as (not simply applied to become) a UK shipboard participant on a forthcoming IODP expedition. No shore–based contributors will be considered under any circumstances.
- Applications for both PDRAs and PGRAs will be peer reviewed.
- The application must cover a discrete body of work based only on material collected during an IODP cruise. It must not be a continuation of any other unrelated project funded by NERC or other organisations.
- On return to port, the candidate will have to write to NERC confirming that the necessary samples have been obtained, otherwise funding will not be made available.
- Candidates should apply to the UK IODP Science Co–ordinator, (ukiodp@bgs.ac.uk), before sailing. Applicants will need to give a brief description of the post–cruise work that they intend to perform, using the NERC small grants application form.
- You must apply not longer than 1 month following the return from the expedition (if you think you have exceptional circumstances, please contact UK IODP Science Co–ordinator, (ukiodp@bgs.ac.uk)).
- At least one first–authored peer–reviewed publication should result from the work.
- All other conditions and eligibility requirements are the same as for other NERC funding and can be found on the forms and handbooks section of this website.

Special criteria for PDRA applications

- Applications for Post Cruise Grants will now need to be costed under FEC requirements. The maximum amounts, to include all FEC costings is now £19,500 to cover up to 6 months of post–cruise research or £12,000 to cover up to 3 months of post–cruise research. Extra time will be allowed only if another funding source is procured.
- To be eligible for this funding, a PDRA must hold a recognised PhD. Doctoral students can apply if they are close to submitting their thesis, or have submitted at the time of sailing, but funds will not be released the until the student has successfully defended their thesis.

Special criteria for PGRA applications

- Applications for Post Cruise Grants will now need to be costed under FEC requirements. The maximum amounts, to include all FEC costings is now £9,500 to cover up to 6 months of post–cruise research or £6,000 to cover up to 3 months of post–cruise research. Extra time will be allowed only if another funding source is procured. This applies to applicants taking a PhD break.
- To be eligible for this funding, a PGRA must be at least 18 months into their PhD before taking up the award.

UK–IODP Contacts

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IODP Panel Members from the UK

Science Advisory Structure Executive Committee (SASEC)
Damon Teagle, National Oceanography Centre, Southampton

Science Planning Committee (SPC)
Hugh Jenkyns, Department of Earth Sciences, University of Oxford
To be replaced in 2010 by Heiko Pälike, National Oceanography Centre, Southampton

Science Steering and Evaluation Panel liaison (SSEP)
David Hoddell, University of Cambridge
John Maclennan, University of Cambridge

Scientific Technology Panel liaison (STP)
Marc Reichow, Department of Geology, University of Leicester

Engineering Development Panel liaison (EDP)
John Thorogood, Drilling Global Consultant
To be replaced in 2010 by Neal Whatson, OMV

Site Survey Panel liaison (SSP)
Neil Mitchell, School of Earth, Atmospheric and Environmental Sciences, University of Manchester
To be replaced in 2010 by Peter Clift, University of Aberdeen

Environmental Protection and Safety Panel liaison (EPSP)
Bramley Murton, National Oceanography Centre, Southampton

ECORD Science Operator Science Manager
Dave McInroy,
British Geological Survey

UK Industrial Liaison Panel Chairman
Richard Hardman, Consultant

IIS–PPG liaison
Richard Davies, Director CeREES Department of Earth Sciences,
University of Durham

IODP Review–Contributors from the UK

Science Plan Writing Committee (SPWC)
(Chair) Mike Bickle,
University of Cambridge

Triennium Review Committee
Joanna Morgan,
Imperial College

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Useful Websites

Integrated Ocean Drilling Programme (UK)
www.ukiodp.bgs.ac.uk and www.nerc.ac.uk/research/programmes/ukiodp/

ECORD Sites
European Consortium for Ocean Research Drilling (ECORD)
www.ecord.org

ECORD Science Support Advisory Committee
www.essac.ecord.org

IODP Central Sites
IODP Management International Inc
www.iodp.org

Initial Science Plan for IODP
www.iodp.org/isp

JAMSTEC
www.jamstec.go.jp/chikyu/eng/index.html

IODP Science Advisory Structure
www.iodp.org/sas

IODP Implementing Organisations
Centre for Deep Earth Exploration (CDEX)
www.jamstec.go.jp/chikyu/eng/index.html

ECORD Science Operator
www.eso.ecord.org

JOI–Alliance US Implementing Organisation
www.iodp–usio.org

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IODP National Offices
Finland
http://iodpfinland.oulu.fi/

France
www.iodp–france.org/

Germany
www.iodp.de/

Italy
www2.ogs.trieste.it/iodp/

Netherlands
www.iodp.nl/

Portugal
http://e–geo.ineti.pt/ecord/

Spain
http://carpe.usal.es/~iodp/

Switzerland
www.swissiodp.ethz.ch

IODP China
www.iodp–china.org/chs/

IODP Korea
www.kodp.re.kr

ODP Australia
www.odp.usyd.edu.au

IODP Related Sites

European Science Foundation (ESF)
www.esf.org

Japan Drilling Earth Consortium (J–DESC)
www.j–desc.org/

International Continental Scientific Drilling Program (ICDP)
www.icdp–online.org/contenido/icdp/front_content.php

Lamont Doherty Earth Observatory
www.ldeo.columbia.edu

MEXT Ministry of Education, Culture, Sports, Science and Technology
www.mext.go.jp/english/

National Science Foundation
www.nsf.gov

Natural Environment Research Council
www.nerc.ac.uk

USSSP U.S. Science Support Program
www.usssp–iodp.org

ODP Legacy Sites

Joint Oceanographic Institutions for Deep Earth Sampling
www.ifm–geomar.de

Consortium for Ocean Leadershio
www.oceanleadership.org/

ODP Wireline Logging Services
www.ldeo.columbia.edu/BRG/ODP/

Science Operator Texas A&M University (TAMU)
www–odp.tamu.edu/index.html

Mid–Ocean Ridge Links

InterRidge Office
www.interridge.org

NOAA Vents Programme
www.pmel.noaa.gov/vents

DeRIDGE
www.deridge.de

Margins Links

HERMES (hotspot ecosystem research on the margins of European seas)
www.eu–hermes.net/

US Margins Programme
www.nsf–margins.org/

NERC Marine Programmes

Joint Climate Research Programme
www.nerc.ac.uk/research/programmes/jointclimate/

Oceans 2025
www.nerc.ac.uk/research/programmes/oceans2025/

RAPID
www.nerc.ac.uk/research/programmes/rapid/

Technology Proof of Concept
www.nerc.ac.uk/research/programmes/technologypoc/

Completed NERC Marine Programmes

Autosub Under Ice (AUI) Programme
www.nerc.ac.uk/research/programmes/autosubunderice/

COAPEC (Coupled Ocean–Atmosphere Processes and European Climate)
www.nerc.ac.uk/research/programmes/coapec/

Ocean Margins LINK Programme
www.nerc.ac.uk/research/programmes/oceanmargins/

Surface–Ocean/Lower–Atmosphere Study (SOLAS)
www.nerc.ac.uk/research/programmes/solas/

Acronym List

www.iodp.org/acronyms/

ACEX
Arctic Coring Expedition

BCRBremen
Core Repository

BoG
Board of Governors

CDEX
Center for Deep Earth Exploration

CDP
Complex Drilling Projects

DSDP
Deep Sea Drilling Project

ECORD
European Consortium for Ocean Drilling Research

EDP
Engineering Development Panel

EMA
ECORD Management Agency

EPC
European Petrophysical Consortium

EPSP
Environmental Protection and Safety Panel

ESO
ECORD Science Operator

ESSAC
ECORD Science Support and Advisory Committee

ETF
Engineering Task Force

GCR
Gulf Coast Repository

ICDP
International Continental Scientific Drilling Program

IIS–PPG
Industry–IODP Science Program Planning Group

ILP
Industry Liaison Panel

IO(s)
Implementing Organization(s)

IODP
Integrated Ocean Drilling Program

IODP–MI
Integrated Ocean Drilling Program–Management International

ISP
Initial Science Plan

J–DESC
Japan Drilling Earth Science Consortium

JOI
Joint Oceanographic Institutions, Inc.

KCC
Kochi Core Center Repository

LUBR
Leicester University Borehole Group

MEXT
Ministry of Education, Culture, Sports, Science, and Technology (Japan)

MOST
Ministry of Science and Technology (People's Rep. of China)

MSP
Mission Specific Platform

NanTroSEIZE
Nankai Trough Seismogenic Zone Experiment

NERC
Natural Environment Research Council (UK)

NSF
National Science Foundation (USA)

ODP
Ocean Drilling Program

OTF
Operations Task Force

PI
Primary Investigator

POC
Platform Operations Costs

SAS
Science Advisory Structure

SASEC
Science Advisory Executive Committee

SOC
Science Operating Costs

SPC
Science Planning Committee

SSEP
Science Steering and Evaluation Panel

SSP
Site Survey Panel

STP
Scientific Technology Panel

TAP
Technology Advice Panel

USAC
United States Advisory Committee for Scientific Ocean Drilling

USIO
United States Implementing Organization

USSAC
United States Science Advisory Committee

USSSP
United States Science Support Program

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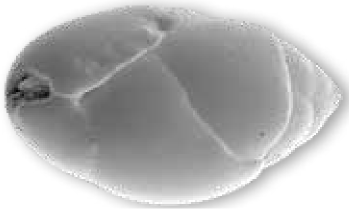
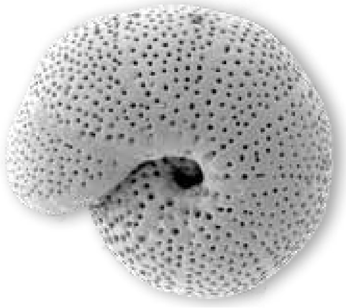
IODP

INTEGRATED OCEAN DRILLING PROGRAM





NATURAL ENVIRONMENT RESEARCH COUNCIL