

# Transect Drilling During Transits

Report of the Workshop convened in College Station, TX  
November 11-13, 2013

Funded by the IODP U.S. Science Support  
Program at the Consortium for Ocean  
Leadership

**Steering Committee:**

Debbie Thomas, Texas A&M University  
Gail Christeson, University of Texas at Austin  
Damon Teagle, University of Southampton  
Brandi Kiel Reese, University of Southern California



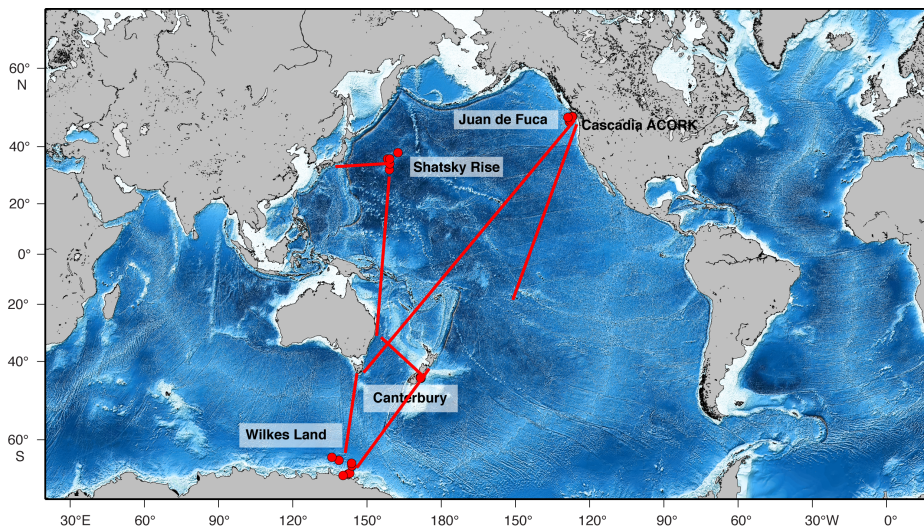
**IODP**  
INTERNATIONAL OCEAN  
DISCOVERY PROGRAM



### Executive Summary

The *JOIDES Resolution* recently has traversed significant spans of the ocean basins at great fuel cost but without accomplishing any science. With planning, coordination, and a community desire to more efficiently use transits, these necessary ship transits could be exploited to yield important cores and observations. The hypotheses driving the drilling program's 2013-2023 Science Plan Challenges require numerous drill sites worldwide. Many important drilling targets - targets that could simultaneously address high priority questions within each of the major drilling themes – will require drill times that fall between the traditional 3-day APL or 56-day expedition. However, individual and carefully planned holes taken during a transit, or when the ship is in a particular region, can have a transformative impact on our understanding of multiple Challenges.

The Transect Workshop discussions identified a conceptual framework for the development of potential transit opportunities – a Multiphase Drilling Proposal (MDP) that will form the mechanism to unite individual “transect drilling” efforts. Using this framework we identified sites and transects of holes consisting of multi-disciplinary targets along the likely path the ship would take from the South Pacific into the South Atlantic (as well as other potential ship tracks). Preferably, each hole would consist of piston coring the sediments (triple coring ideally), drilling basement until bit destruction (or setting of a re-entry cone and casing at selected sites), and a curation protocol in place for dedicated microbiological sampling. These holes would contribute substantially to the achievement of the 2013-2023 Science Plan Challenges. Modern seismic reflection data may be sparse in some regions, and will require flexibility in evaluating the site characterization data.



**Fig. 1.** FY 2010 *JOIDES Resolution* transit distances totaled 25,019 nmi at a fuel cost of \$4,727,666. Workshop discussions focused on how to strategically exploit long transits to recover cores capable of addressing Science Plan challenges.

The scientific ocean drilling community has long sought a more flexible mechanism for using the *JOIDES Resolution*, but the 2-month expedition model based on staffing rotations has been the sole model for several decades. With

this MDP we hope to renew the discussion of devising more flexible and efficient ways of

using the *JOIDES Resolution*, and to provide the conceptual platform for evaluating and scheduling these “mini-legs”.

## **1. Introduction**

### **Participants:**

Gary Acton, Sam Houston State University  
Brandon Briggs, Miami University  
Rick Carlson, Texas A&M University  
Laurel Childress, Northwestern University  
Gail Christeson, University of Texas  
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Ali Dehghani, Universität Hamburg  
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John Kirkpatrick, University of Rhode Island  
Mark Leckie, University of Massachusetts  
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Marta Torres, Oregon State University  
Geoff Wheat, MBARI  
Trevor Williams, Lamont  
Xixi Zhao, University of California – Santa Cruz

### **Agenda:**

#### **Monday, November 11**

8:15am Coffee at IODP

8:30am Welcome and Meeting  
Logistics (workshop conveners)



**Fig. 2.** Workshop discussions focused on integrating regional and scientific priorities during Day 2.

8:40am Overview: Increasing *JOIDES Resolution* Efficiency and the Projected Ship Track (Mitch Malone)  
9:00am Disciplinary Overview: Using transects for Paleoclimate Objectives (Debbie Thomas)  
9:30am Disciplinary Overview: Using transects to study aging process of oceanic crust (Damon Teagle)  
10:00am Coffee Break  
10:30am Disciplinary Overview: Using transects for microbiology studies (Brandi Reese)  
11:00am Logistics Overview: Engineering issues for multidisciplinary programs (Jay Miller)  
11:30am Logistics Overview: Site survey considerations (Gail Christeson)  
12:00pm Lunch  
1:00pm Introduction to Thematic Breakout groups  
    a. Paleoclimate  
    b. Ocean crust aging  
    c. Microbiology  
2:45pm Coffee Break  
3:15pm Resume Thematic breakout discussions  
4:30pm Thematic Breakout group presentations  
5:30pm Adjourn for the day

## **Tuesday, November 12**

8:15am Coffee  
8:30am Plenary Discussion: linkages and drilling strategies, and organization of regional breakouts  
9:15am Breakout groups: Regional, based on Day 1 breakout group reports.  
    a. Pacific Ocean  
    b. Atlantic Ocean  
    c. Indian Ocean  
    d. Southern Ocean  
10:30am Coffee Break  
11:00am Regional Breakout group reports  
12:00pm Lunch  
1:00pm Open Discussion: Integrating Themes and Regions  
2:45pm Coffee Break  
3:15pm Integrated Breakout groups  
4:45pm Breakout presentations  
5:30pm Adjourn for the day

## **Wednesday, November 13**

8:15am Coffee at IODP  
8:30am Open Discussion: existing and needed site survey information based on Day 2 breakout reports  
9:30am Organization of proposal/preproposal/APL working groups  
10:00am Coffee Break  
10:00am Proposal working groups frame drilling proposal plans

11:15am Meeting wrap-up

11:30am Meeting concludes (travel to airport or remain at IODP as needed for discussions, sampling, etc).

## **2. Scientific Motivation**

It is essential for in the next phase of scientific ocean drilling, the International Ocean Discovery Program (IODP; 2013-2023), to develop more efficient ship tracks that minimize transits and maximize scientific output in relation to time and cost. However, long transits between basins (e.g., Indian Ocean to Atlantic Ocean), or within basins (e.g., South Atlantic to North Atlantic), are likely unavoidable as the ship ultimately circumnavigates the world oceans to accommodate high priority expeditions. We therefore convened a workshop in November 2013 to produce the foundations for *multi and interdisciplinary transect drilling proposals to exploit the likely transits of the drillship between or within large basins*.

One of the significant strategies that emerged from the 2012 U.S. Building Strategies Workshop (<http://iodp-ussp.org/workshop/strategies/>) was the concept of Flow Line Transects that could address multiple Science Plan challenges. A number of high priority science objectives require transects of boreholes across ocean basins. Drillship transits provide the opportunity to conduct transects, or portions of transects, within or between major ocean basins. The transect idea is not new; in fact, such ideas have been discussed for years, and the more efficient use of long ship transits were of concern to the community throughout the first phase of IODP. One obstacle to multi-disciplinary transect drilling in the past has been the conflict between the time required to recover thick sediment sequences for paleoceanographic targets versus the time required to drill multiple holes in basement for crustal alteration studies. However, the drilling strategy employed on Leg 199 (PET), Exp 320/321 (PEAT), and in the proposed South Pacific Latitude Transect (SPLAT), is to target sediments that would have been deposited on fairly young crust that had not yet subsided below the CCD. Thick accumulations of sediment are not required throughout the entire depositional history but only for the targeted time interval. The revelation we had at the 2012 U.S. Building Strategies Workshop was that the age of crust paleoceanographers seek is also of great interest for crustal alteration investigations (e.g., 20-110 Ma). The fundamental point is that *with foresight and careful planning, a transit transect would advance science across numerous 2013-2023 Science Plan themes*. For example, to address Challenges 1 and 2 in the Climate and Ocean Change theme, the community requires key Late Cretaceous and Paleocene-Eocene stratigraphic sections. The same drilling targets also would provide crucial sections to examine crustal exchange with seawater (Challenge 10) in 30 to 70 million-year-old ocean crust. This portion of the ocean floor also fills gaps in the global understanding of the subseafloor biosphere (Challenges 5 and 7). The additional time required to drill a useful depth into basalts (>100 m) has most often precluded basement operations while the JOIDES *Resolution* is on site for paleoceanographic goals. However, the thorough characterization of sedimentary sections required for paleoceanographic studies means these sites could be re-occupied for basement drilling during future transits.

### **2.1. Transects to Address Evolution of Ocean Crust**

Challenge 10 of the IODP Science Plan for 2013-2023 asks 'What are the mechanisms, magnitude, and history of chemical exchanges between the oceanic crust and seawater?' Since the discovery in the 1970s of high temperature hydrothermal vents and the mid-ocean ridges it has been clear that hydrothermal circulation at the ridge crest produces a large exchange of heat and materials between the crust and ocean. Conductive heat flow deficits and pore water studies indicate that seawater-basalt exchange continues at lower temperatures on the ridge flanks as the crust ages (Fig. 3).

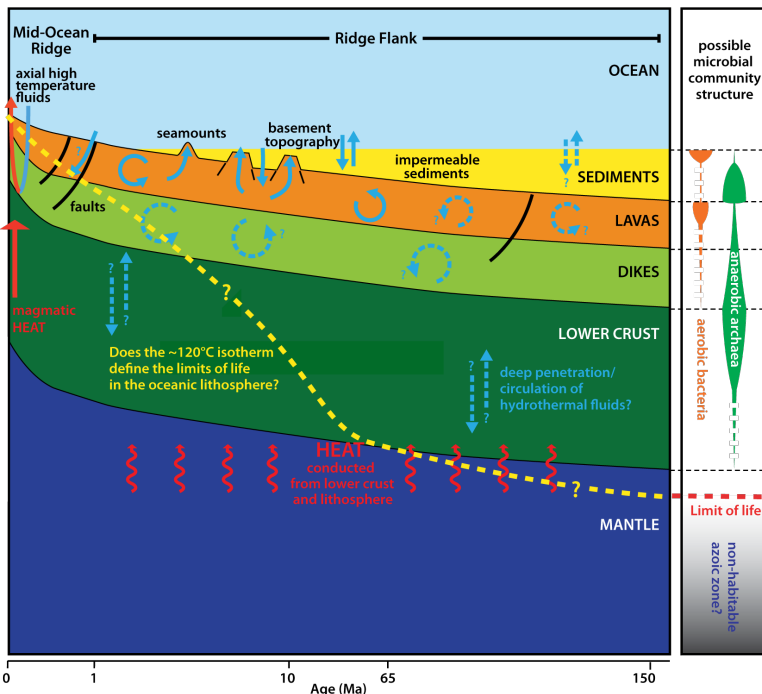
Challenge 10 notes that drilling and sampling oceanic crust of a variety of ages will quantify the timing, duration, and extent of fluid-rock exchange, as well as the oceanic crustal contributions to the geochemical cycles of important elements such as strontium, magnesium, potassium and carbon. Low-temperature exchange continues on ridge flanks to at least 65 Ma on average, and even longer depending on the environment (Fig. 3). Quantifying the extent and timing of low-temperature exchange requires drill holes that penetrate ~300-500 m into the igneous basement at a variety of ages. Fig. 4 illustrates the current dearth of basement holes, especially between 20-110 Ma. Hidden in Fig. 4 is that most of the basement holes drilled more than a few hundred meters into lavas, have all been undertaken in regions with anomalously thick sedimentary cover (e.g., Holes 504B/896, Hole 1256D, Juan de Fuca experiments ODP Leg 168 and IODP Exp. 301 and 327). This is partly due to the engineering requirements to install a re-entry cone and casing to enable basement drilling. However, this bias has led to a very poor characterization of normally or poorly sedimented ocean crust.

Accomplishing Challenge 10 requires the drilling of a series of ocean-basin-wide transects that extend from 0 to 100 Ma crust, with the goal of measuring the rates, magnitudes, and distribution of chemical alteration in the ocean crust, and the influence of lithospheric alteration processes on ocean chemistry through time. The intensity of seawater-basalt exchange will depend on numerous factors including the volcanic stratigraphy, the sedimentation and tectonic history, sediment type, and the age of the crust. The 2012 Denver Workshop on Building U.S. Strategies for 2013-2023 Scientific Ocean Drilling recognized that Challenge 10 is strongly linked to Challenge 7 'How sensitive are ecosystems and biodiversity to environmental change?' and Challenge 14 'How do fluids link seafloor tectonic, thermal, and biogeochemical processes?'

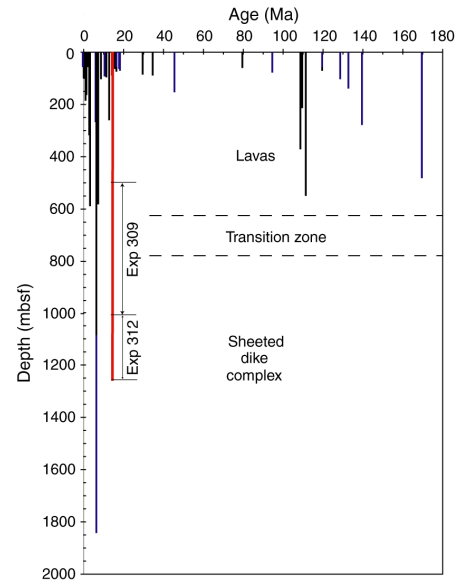
To date, our limited observations of seafloor aging has been restricted to relatively intact ocean crust. The recent documentation of the tectonic exposure of lower crustal rocks and the upper mantle along some slow-spreading ridges has brought to light a whole variety of previously unknown seawater alteration targets, such as buried gabbro or serpentinite massifs, that may have unquantified roles in global chemical cycles (e.g., B, Li) and provide hitherto unrecognized microbial niches.

Ocean crust drilling at a variety of ages could make important contributions to understanding the origin of seafloor magnetic anomalies and the relative contribution of different lithological layers or rocktypes (e.g., serpentinitized upper mantle). Paleomagnetic directions may place constraints on timing and duration of magmatism or tectonic rotations. Key regions could be

targeted to improve apparent polar wander paths or test the fixed vs. moving hotspot models (e.g., Late Cretaceous to Paleocene regions of the southern Pacific Plate). Similarly estimates of secular variation from extrusive sections at high-latitude sites (>45° latitude) can be used to constrain geomagnetic field models that currently lack high-latitude observations from volcanic rocks.



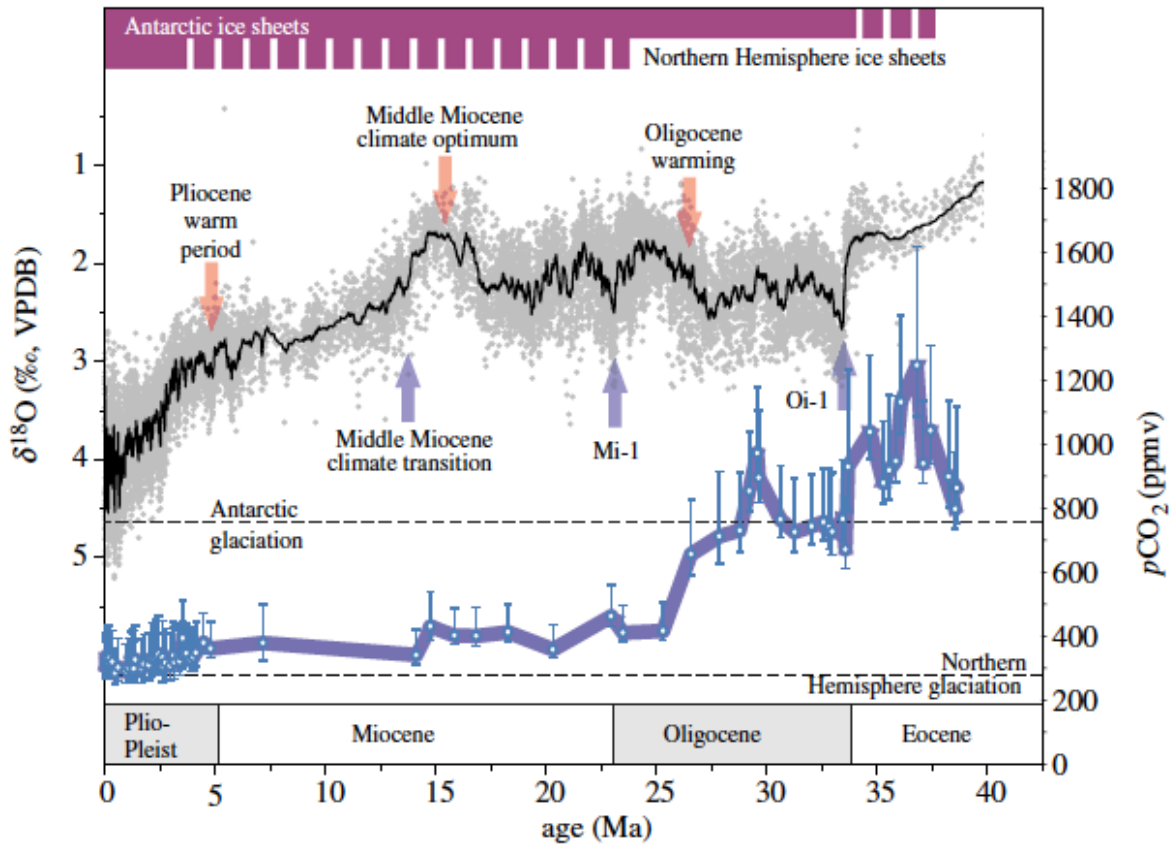
**Fig. 3.** Schematic architecture of a mid-ocean ridge flank (not to scale) illustrating the parameters that may influence the intensity and style of hydrothermal circulation, such as faults, seamounts, basement topography, and impermeable sediments that isolate the crust from the ocean. Arrows indicate heat (red) and fluid (blue) flow. The yellow dashed line is a hypothetical trajectory of the 120°C isotherm as oceanic crust moves away from the ridge crest. From IODP Science Plan 2013-2023, Fig. 4.7 (Original figure R. Coggon).



**Fig. 4.** Basement age versus depth of basement penetration for scientific drill holes deeper than 50 m drilled into *in situ* ocean crust formed at the mid-ocean ridges. From Fig. F1 of Expedition 309/312 Preliminary Report.

## 2.2. Transects to Address Climate and Ocean Change

One of the most pressing needs of the paleoceanographic/paleoclimatic community is data to quantify the past sensitivity of the climate system to atmospheric CO<sub>2</sub> levels that were 400ppm and higher. Representatives of the paleoceanographic/paleoclimatic community at the 2012 Denver Workshop on Building U.S. Strategies for 2013-2023 Scientific Ocean Drilling identified Challenge 1 of the IODP Science Plan for 2013-2023, 'How does Earth's climate system respond to elevated levels of atmospheric CO<sub>2</sub>?' as the top priority of the Climate and Ocean Change theme, and this priority is directly related to Challenge 4, 'How resilient is the ocean to chemical perturbations?', and Challenge 7 'How sensitive are ecosystems and biodiversity to environmental change?'. Thus high-priority transect drilling targets must contribute crucial data to testing hypotheses related to these three challenges.



**Fig. 5.** A summary of CO<sub>2</sub> and climate indicators spanning the last 40 million years (Zhang et al., 2013). The benthic marine δ<sup>18</sup>O record (red line; Zachos et al., 2008), an indicator of deep-ocean and high-latitude surface ocean temperatures, illustrates the long-term climate record over the past 40 million years. Over this same time period, alkenone-based proxy indicators suggest that atmospheric CO<sub>2</sub> (blue symbols) likely exceeded 400 ppm since the early Pliocene.

The likely interval of time characterized by paleo-CO<sub>2</sub> levels in excess of 400ppm spans ~4 to 100 Ma, the Early Pliocene through Late Cretaceous (with the record to ~40Ma depicted in Figure 5). High-fidelity proxy data for paleoceanographic reconstructions typically derives from sediments that accumulated relatively quickly (~cm's/kyr) and were buried at relatively shallow sub-seafloor depths (~<200 mbsf) to ensure high preservation of the microfossils and compounds best suited for floral/faunal/geochemical analyses. One challenge in reconstructing climate during intervals characterized by high atmospheric CO<sub>2</sub> is that these intervals likely were characterized by relatively shallow calcite compensation depths (CCDs). A strategy to overcome this challenge involves identifying basement slightly older than the targeted sediment age (e.g., ~<1 million years older), such that the basement was still relatively young and buoyant (hence situated at relatively shallow water depth along the ridge or rise). Thus the targeted sediment would have accumulated on the basement prior to seafloor subsidence below the CCD. This drilling strategy is well-suited for multidisciplinary holes because the overall sediment thickness does not have to be great – although the targeted sedimentary interval would have been characterized by high accumulation rates, once the seafloor subsided

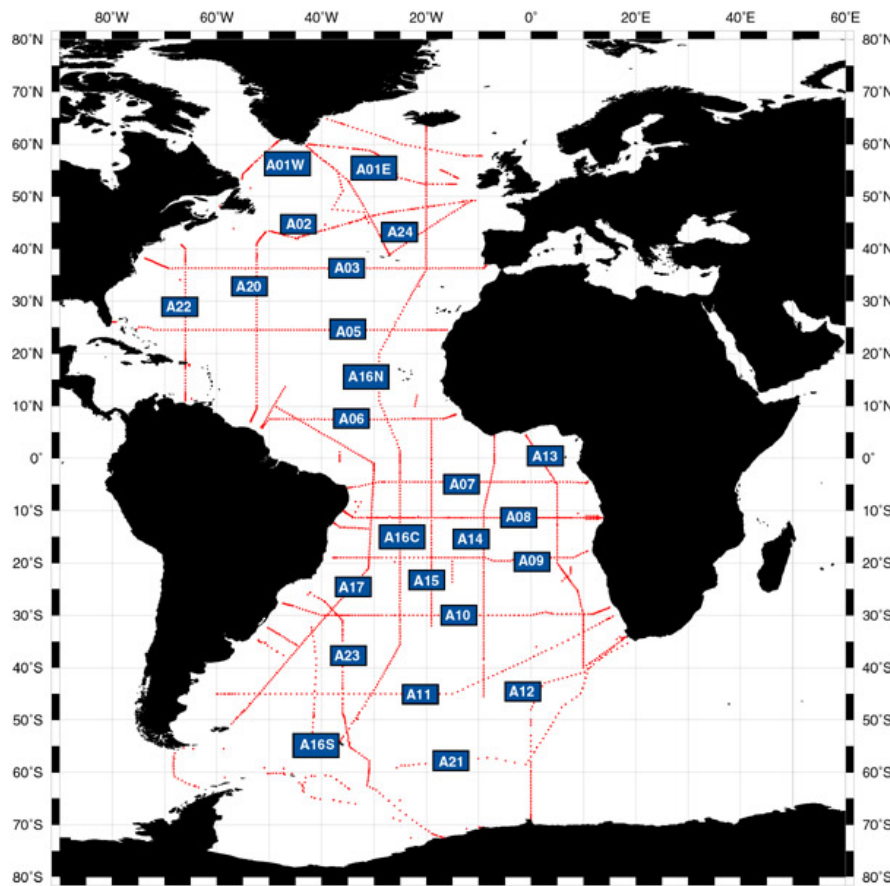


below the CCD, accumulation rates would have decreased resulting in a relatively thin overall sediment thickness. Triple coring a relatively thin sediment sequence would leave ample time to recover basement for high-priority crustal aging targets (drilling to bit destruction in most cases).

The idea that onshore-offshore and meridional transects of drill sites are required to reconstruct ice sheet history and thermal gradients for different climate states has long been entrenched in the paleoceanographic/paleoclimatic community. However, one of the most transformative ideas that emerged from the paleoceanographic/paleoclimatic discussions during the Transect Drilling workshop was that key oceanographic and thermal properties of the ocean basins could be fully characterized with minimal but strategic geographic coverage. For example, because of western intensification of ocean currents, we could reconstruct deep-water mass properties such as temperature or water mass composition, and thus the history of thermohaline circulation, merely by characterizing the western portion of the major ocean basins, rather than a transect spanning an entire basin. Thus, an array of transect drill sites sited in the western regions of the ocean basins would provide key data to test hypotheses regarding the role of evolving thermohaline circulation patterns in climate and how high latitude sea surface (and hence deep-ocean) temperatures varied in response to atmospheric CO<sub>2</sub> changes, which in turn is necessary for understanding the climate sensitivity to greenhouse

gas forcing during intervals characterized by high atmospheric CO<sub>2</sub>.

The most efficient way to compare paleoceanographic proxy reconstructions of ancient intervals of high atmospheric CO<sub>2</sub> to modern/historical conditions would be to recover sediments from drill sites situated along transects of modern water column data such as the World Ocean Circulation Experiment (WOCE) sites and the current GEOTRACES cruise tracks. The concept of drilling transects that coincided with “paleo-WOCE”



**Fig. 6.** Map of the WOCE lines conducted between 1988 and 1998. ([http://www.ewoce.org/gallery/Map\\_Atlantic.html](http://www.ewoce.org/gallery/Map_Atlantic.html))

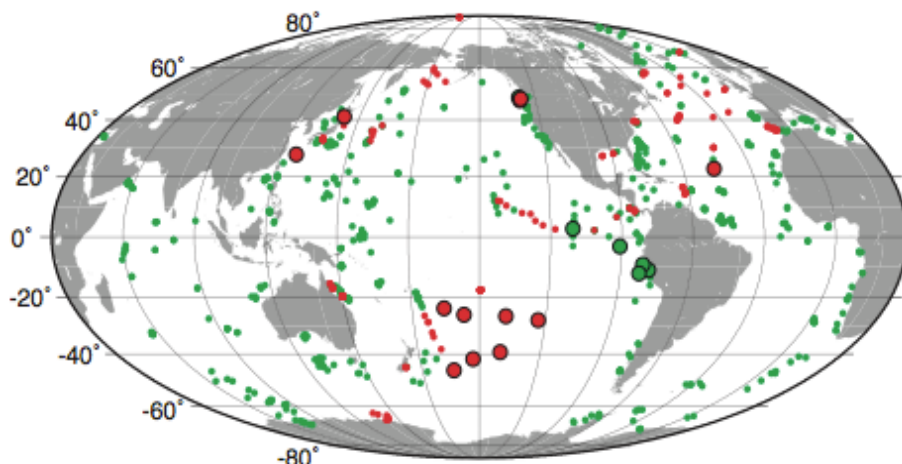
lines to reconstruct key heat, mass, nutrient distributions and transport in the past would be a truly novel way in which to plan transect drilling expeditions of any duration. For example, the proposed transect across the western South Atlantic (see below) could “occupy” the western portion of WOCE line A10 (Figure 6). Alternatively, a transit to move the drillship from the South to North Atlantic could drill a few sites on WOCE A17.

### 2.3. Transects to Address Biosphere Frontiers

Scientific ocean drilling has made a critical contribution to the rapid growth of deep biosphere research; despite Although only a handful of locations that have been investigated thus far (Figure 7). Several IODP expeditions have focused on testing specific hypotheses regarding factors that control microbial community structure, function, and distribution within the deep biosphere in a diverse array of subsurface environments. Thus far, these environments have included a near-shore upwelling regime (Expedition 201: Peru Margin), extremely low energy sediments (Expedition 329: South Pacific Gyre and Expedition 336: North Pond), oceanic crust (Expeditions 301 and 327: Juan de Fuca Ridge and Expedition 336: North Pond), near hydrothermal vents (Expedition 331: Deep Hot Biosphere), and a carbon-rich environment (Expedition 337: Deep Coalbed Biosphere off Shimokita). However, deep biosphere research remains in its infancy and from the over 800 sites drilled during the course of the ODP-IODP programs, less than 4% of the sites have been properly sampled, documented and archived for microbiological purposes (Figure 7). Despite this small percentage of sites, a large number of transformative discoveries have been made in deep biosphere research resulting from these samples. The greatest discovery has been that microorganisms (archaea and bacteria) are present, intact, and metabolically active in uncontaminated deep subsurface sediments (Biddle et al. 2006; Mills et al. 2012; Parkes et al. 2005). Not only are they present, but they are taxonomically diverse, and expanding the branches on the tree of life (Inagaki et al. 2006; Orsi et al. 2013). The growing census of deep subsurface sedimentary cell count measurements has shown this vast ecosystem to rival the microbial biomass of the ocean water column (Kallmeyer et al. 2012). Furthermore, Expedition 329 has provided the first glimpse into life in sediments with very low

deposition rates and energy-starved sediments. Small populations of slowly metabolizing microorganisms continue to drive diagenetic processes therefore stretching the limits of life in extreme environments (D'hondt et al. 2009).

These findings represent a major breakthrough in our



**Fig. 7.** Combined ODP (green) and IODP (red) drill sites map. Large circles show sites where a complete and well-documented microbiological sampling campaign was adopted (Orcutt et al., 2014, Scientific Drilling).

understanding of how life can be sustained by alternative energy sources, possibly fueled by the radiolysis of water (Blair et al. 2007). Other expeditions have shown that life can also exist within seafloor crust, suggesting that even deeper samples will yield new discoveries (Lever et al. 2013). Additional microbiological sampling on future drilling transits is likely to result in even more transformative research on life in deeply buried sediments and crust.

The 2012 Workshop on Building U.S. Strategies for 2013-2023 Scientific Ocean Drilling report recommends comprehensive microbial sampling in ocean basins of ranging maturity and age, and transects across hydrothermal ridge systems; ideally routine microbial sampling would be obtained on all drilling legs. The top challenge of the Biosphere Frontiers theme is Challenge 5 'What are the origin, composition, and global significance of seafloor communities?' Significant progress on this question can only be obtained by dramatically increasing the seafloor locations where microbial communities are sampled including oceanic crust, moderate temperature (e.g.,  $>50^{\circ}\text{C}$ ) or low temperature regimes (e.g.,  $<4^{\circ}\text{C}$ ), highly alkaline or acidic environments, siliceous ooze, low-energy gyre cross-sections (e.g., South Atlantic Gyre), as well as areas that are above, within, and below geochemical transition zones. Imperative to this, a full standard suite of geochemical analyses (e.g., anions, cations, pH, alkalinity, TOC/TC) should be collected from the same hole as the microbiological sampling in order to put biological findings into context. This type of sampling plan will also address the other challenges of the Biosphere Frontiers theme, which are Challenge 6 'What are the limits of life in the seafloor' and Challenge 7 'How sensitive are ecosystems and biodiversity to environmental change'. Furthermore, collecting samples on transects would add to the global biogeographic database that is being assembled in a joint effort with Census of Deep Life and the Center for Dark Energy Biosphere Investigations (C-DEBI).

Attendees of the Transect Drilling Workshop reiterated the need for routine microbiological sampling during each expedition, including sterile sample collection, sample collection toward the center of each section, storage at  $-80^{\circ}\text{C}$ , collection of drill fluid at every hole, contamination testing with PFC or microspheres, and performing cell counting during each expedition. To facilitate microbiological sampling and processing, advanced training of current technicians or ideally a microbiology-specific technician sailing on each expedition was also recommended. It was noted that similar recommendations for standard and routine sampling, and advanced training of technicians have been presented to IODP and ship operators in the past without successful implementation (for example, SPC Consensus 808-10, 808-11, 808-12, and 808-15). For future success of IODP biosphere research, a revised recommendation from the subsurface community, including new techniques and technologies, should be crafted and presented to the broader drilling community.

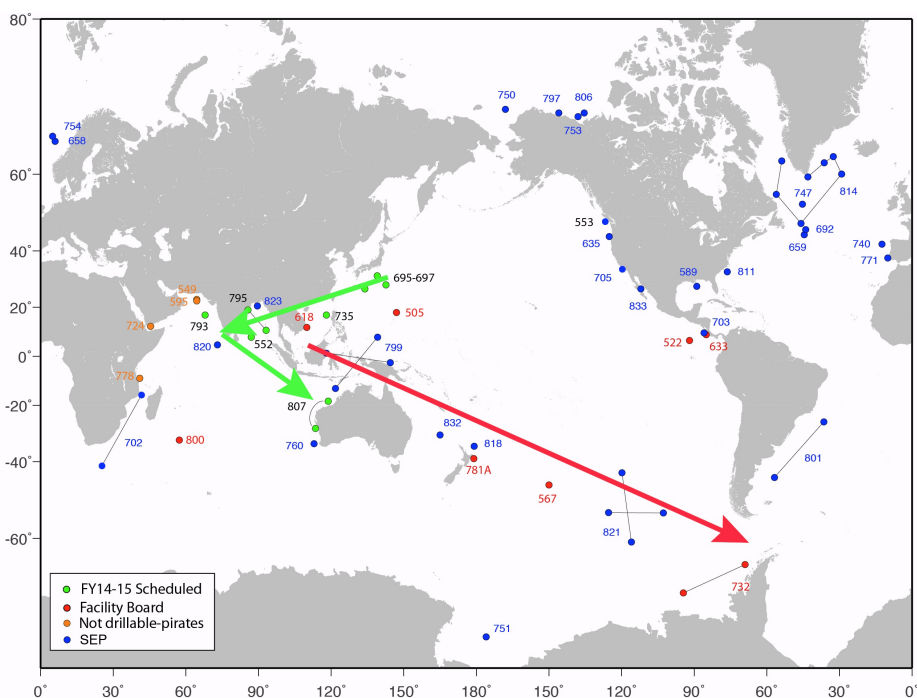
Additionally, it was suggested that the *JOIDES Resolution* transit from Keelung to Singapore could serve as a valuable opportunity to combine a microbiological training exercise with a test of new standardization techniques being developed during an IODP-ICDP-DCO workshop in Seoul, South Korea. This transit would increase efficiency of the *JOIDES Resolution* within IODP operations by training participants in microbiological sample handling and processing techniques, while acting as a test platform for feasibility of implementation of the outcomes

from the Seoul meeting. Many of these techniques are already in place on board the R/V Chikyu, which include cell enumeration, sample preservation, and contamination checking. In addition, two legacy holes from ODP 184, sites 1143 and 1147, are within the ship track for the transit. This would provide locations with past drilling activity to ensure recovery and feasibility while allowing unique science objectives to be accomplished.

### 3. Drillship transits and anticipated track for next phase of IODP

Fuel prices have doubled since 2009, resulting in annual fuel costs for the *JOIDES Resolution* increasing from ~\$4.5 million in FY09 (17,990 n. mi.), to \$7.5 million in FY11 (17,272 n. mi.), to \$6.7 million in FY13 (17,406 n. mi.). It is imperative that the program is able to conduct scientific drilling along the path of the JR rather than carrying out long and expensive transits linking highly rated drilling proposals without accomplishing science.

Figure 8 displays the likely ship track of the JR, with the opportunity for drilling in the southern and central Atlantic Ocean in 2018 and 2019, a region with few active proposals.



**Fig. 8.** JR proposed ship track presented at the workshop by Mitch Malone. Under current and anticipated proposal pressure, the Facility Board considers that the JR is likely to remain in the eastern Indian and western and southwestern Pacific oceans through 2016 and 2017. This would be followed by a likely track across the southern Pacific Ocean, with an opportunity for drilling in the southern and central Atlantic Ocean in 2018 and 2019.

### 4. Transect Drilling MDP: An Umbrella Proposal For Transit Drilling

Numerous ideas for feasible sites along or near the likely *JOIDES Resolution* ship track were generated in discussions by the Workshop attendees. For some regions, like the South Atlantic, scientific objectives could be met via a traditional 2-month leg and a standard (albeit multidisciplinary) drilling proposal. However, other non-traditional drilling strategies emerged. One idea was to assemble a suite of sites that could fill in key age or geographic gaps in existing datasets. The JR Facility Board could then have the ability to choose one or more of these sites when building the expedition schedule. Alternately, progress towards some scientific questions

could be advanced by drilling for 1-2 weeks at a single site, which would not require a full expedition, but could be carried out during part of a transit. Unfortunately neither of these drilling strategies is easily proposed in a traditional full-leg drilling proposal or 3-day ancillary planning letter. We recognize, however, that more flexible cruise lengths may be at odds with the rotation schedule of the crews.

Workshop discussions coalesced around developing a mechanism to allow the submission of umbrella proposals that describe the objectives and strategies of transit drilling. The fundamental idea is that the hypotheses driving the drilling program require numerous drill sites worldwide, and no single 2-month expedition can achieve this. However, individual and carefully planned holes taken during a transit, or when the ship is in a particular region, can have a transformative impact on our understanding of multiple Challenges. A transect-drilling umbrella proposal would be submitted as a multi-phase drilling project (MDP), and site-specific transit drilling proposals could then be submitted under the MDP.

The official description of an MDP is: “A multi-phase drilling project (MDP) can take different forms, but the unifying concept is that the project cannot be done in a single, 60-day drilling expedition. Examples of an MDP include, but are not limited to, a project that requires a long site occupation in one location, a series of scientifically related projects located in close proximity, or a project that addresses a large, overarching scientific question(s) requiring data from geographically distant sites. The initial proposal of a potential MDP should define the overall scientific objectives of the entire project and justify the need for a multiplatform or multi-phased drilling strategy to achieve those objectives; this may not require site-specific information beyond some generic site description.”

The Transit proposal concept must be opened up to the wider scientific community but workshop discussions identified holes and transects of holes consisting of multi-disciplinary targets along the likely path the ship would take from the South Pacific into the South Atlantic (as well as other potential ship tracks). Each hole could consist of piston coring the sediments (triple coring ideally), drilling basement until bit destruction (although this might not be feasible at all sites), and a curation protocol in place for dedicated microbiological sampling. All of these holes could contribute substantially to all of the 2013-2023 Science Plan Challenges:

Challenge 1: How does Earth’s climate system respond to elevated levels of atmospheric CO<sub>2</sub>?

Challenge 2: How do ice sheets and sea level respond to a warming climate?

Challenge 3: What controls regional patterns of precipitation, such as those associated with monsoons or El Niño?

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

Challenge 5: What are the origin, composition, and global significance of subseafloor communities?

Challenge 6: What are the limits of life in the subseafloor?

Challenge 7: How sensitive are ecosystems and biodiversity to environmental change?

Challenge 8: What are the composition, structure, and dynamics of Earth’s upper mantle?

Challenge 9: How are seafloor spreading and mantle melting linked to ocean crustal architecture?

Challenge 10: What are the mechanisms, magnitude, and history of chemical exchanges between the oceanic crust and seawater?

Challenge 11: How do subduction zones initiate, cycle volatiles, and generate continental crust?

Challenge 12: What mechanisms control the occurrence of destructive earthquakes, landslides, tsunami?

Challenge 13: What properties and processes govern the flow and storage of carbon in the subseafloor?

Challenge 14: How do fluids link subseafloor tectonics, thermal, and biogeochemical processes?

## **5. Possible transect targets and priorities as part of the MDP**

### **5.1 South Pacific**

The South Pacific Paleogene Latitude Transect drilling proposal (SPLAT) is a candidate for being scheduled as the “transit” of the drill ship from the southwestern Pacific into the southwestern Atlantic during FY16 or FY17. Because the proposed SPLAT sites address paleoceanographic objectives and Expedition 329 was drilled in the region to test deep biosphere hypotheses, discussions for the South Pacific region during the transect workshop focused on crustal targets and objectives. The South Pacific is generally a remote area of seafloor with very thin sediment cover characterized by abyssal hill topography. These features suggest that the region would be useful for crustal aging targets of 20, 50, 70Ma. One target specifically identified was a redrill of Site U1371 (westernmost site drilled during Expedition 329) on 73Ma crust for crustal and paleomagnetic investigations. Such a target would benefit from existing seismic data, including profiles acquired in 2005 and 2006.

### **4.2 Southern Ocean**

The likely ship track will position the *JOIDES Resolution* to potentially drill sites in the Ross Sea and Weddell Sea regions prior to sailing northward into the Atlantic basins. Drill sites in the Ross Sea region would complement ANDRILL sub-ice drilling, ostensibly forming the offshore portion of onshore-offshore marine transects that are crucial for testing hypotheses regarding ice sheet history and the associated climate impacts. Southern Ocean sites would also be useful for investigating crustal alteration and microbiology when the sediment cover is siliceous ooze. High Southern latitude sites are also key targets for geomagnetic investigations.

### **4.3 South Atlantic**

The South Atlantic emerged as the primary target for a full transect drilling proposal that would address significant outstanding questions in numerous disciplines. The slow-spreading southern Mid Atlantic Ridge is an ideal place to recover a section of “Penrose” oceanic crust for comparison with previously drilled crust produced on faster spreading ridges/rises (e.g., Sites 504B, 1256D, etc). Sites drilled toward the center of the basin could address significant questions regarding the limits of life in low carbon environments and provide the deep biosphere community with sites to compare to the equivalent gyre locations in the South

Pacific. The paleomagnetic community would benefit from high-quality cores to refine the Geomagnetic Polarity Time Scale (GPTS) – the classic GPTS stack sections derived from DSDP Leg 3 in the South Atlantic. A new transect of sites situated near the original Leg 3 sites would essentially form a paleo-WOCE line near the modern A10 line. Sediments recovered along the paleo-A10 line would enable the reconstruction of the history of the deep western boundary current, and hence deep-water formation in the Atlantic basins. The potential science from a redrill of Leg 3, including triple coring the sediment sequence and drilling basement to drill bit destruction, likely would demand more than one 2-month expedition. Such a proposal epitomizes the need for more flexible drilling models that will form the basis of the MDP. Furthermore, proposals emerging from the Brazilian Equatorial Margin and Deep Drilling of the Amazon Continental Margin workshops may fit well under the MDP idea we propose.

#### **4.4 North Atlantic**

The discussion of potential questions that could be addressed by holes in the North Atlantic raised a diversity of targets. The collective group of targets did not lend itself to a single transect, but rather a collection of holes that could be proposed as “targets of opportunity” to drill when the ship was in the vicinity. This model of drilling and drilling proposal fits perfectly into the MDP umbrella, reemphasizing the need for flexibility in scheduling the ship to accomplish transformative science. There are targets, particularly in the Labrador Sea region that would enable better characterization of paleoceanographic conditions between the Early Pliocene and Late Cretaceous. The North Atlantic also presents a unique opportunity to investigate the causes and consequences of serpentinization, including how prevalent this process was throughout the geologic evolution of the North Atlantic, and the influence of serpentinization on crustal hydrogeology and biology processes over time. How much serpentinization has occurred? How much carbonate is present in serpentinized crust? Is it possible to date alteration? Has fluid influenced the sediments (diagenesis with alkaline fluid)? Is serpentinization feeding microbes? These are key questions pressing the community.

#### **6. Site Survey Considerations**

Site surveys for IODP drilling are essential for determining whether 1) The site is an appropriate location to answer the scientific questions which have been posed; 2) The site is a feasible place for drilling; 3) There is sufficient information to support both the science and drilling operations at each site; and 4) There are no natural or manmade hazards near the proposed drill site that might endanger the ship, its crew, or the environment. The August 2013 Science Evaluation Panel (SEP) guidelines state that the guiding statement for SEP review is to ensure that IODP expeditions will have a high probability of success and that ship time, researcher time, and funds are not wasted by drilling in the wrong location or to the wrong depth, or recovering sediments or rocks that will not achieve the objectives of the proposal. The SEP idealized survey includes high-resolution multi-channel seismic (MCS) data with cross lines at proposed sites; single channel seismic data will be considered on a case-by-case basis. All data should be digital.

Useful websites to search for site survey data:

- UTIG Academic Seismic Portal [www.ig.utexas.edu/sdc](http://www.ig.utexas.edu/sdc)

- USGS National Archive of Marine Seismic Surveys (NAMSS) <http://walrus.wr.usgs.gov/NAMSS/>
- JAMSTEC Crustal Structural Database Site [http://www.jamstec.go.jp/jamstec-e/IFREE\\_center/index-e.html](http://www.jamstec.go.jp/jamstec-e/IFREE_center/index-e.html)
- NGDC <http://www.ngdc.noaa.gov/mgg/seismicreflection/index.html>
- GeoMapApp <http://www.geomapapp.org/>
- IODP Site Survey Data Bank <http://ssdb.iodp.org/>

Many regions on the upcoming *JOIDES Resolution* ship track in the south Pacific and south/central Atlantic have little existing MCS data and low probability of new acquisition in the next few years owing to the remote location. Hence, workshop attendees discussed pros and cons of sites with no crossing lines, or sites where only older analog single channel data is available. The consensus was that it would be better to drill using older data, if the target is imaged and satellite gravity/bathymetry/magnetic data suggests that the region is relatively homogeneous, rather than transit the ship conducting no science because modern MCS profiles with cross lines are lacking. Very rigid site survey requirements has resulted in the clustering of scientific ocean drilling targets and the proposed re-occupation of DSDP site because sediment stratigraphies are commonly essential to develop finely honed drilling proposals. However, very large parts of the oceans remain poorly or unsampled despite these regions potentially having key roles in the Earth system or presenting unknown microbial environments. Drilling holes during transits, based on only limited site survey data that ensures safety, but possibly not to the standards usually expected for IODP science, would provide critical stratigraphic information essential for the development of more detailed full expedition proposals.

## **7. Summary**

The motivation for the Transect Drilling workshop was that recently the *JOIDES Resolution* has traversed significant spans of the ocean basins, much of it extremely remote and unsampled, at great fuel cost but without accomplishing any science (the transit distances for FY09 – 17,990 nmi, FY10 – 25,019 nmi, FY11 – 17,272 nmi, and FY13 – 17,406 nmi were profligate examples, in contrast to FY14 projections of ~8,000 nmi). With planning, coordination, and a community desire to more efficiently use transits through rarely visited sectors of the oceans, these necessary ship movements could be exploited to yield important cores and observations. Despite more than 40 years of scientific ocean drilling there remain many major gaps in our knowledge, be they high sedimentation rate samples of key times in Earth’s climate and changes in ocean chemistry or magnetic field, the 15 to 110 Ma gap in ocean crust cores, or virtually unexplored biogeographic microbial provinces. Some of these targets do not warrant a full IODP Expedition and many sites are widely spread around the ocean basins. However, these targets could be tackled opportunistically throughout the next phase of ocean drilling when ship tracks allow, leading to fundamental observations essential to progress toward longstanding ocean drilling goals. Even one or two holes drilled during a transit could have an extraordinary impact on climate, ocean crust, and deep biosphere science.



The Transect workshop discussions developed a conceptual framework for the development of potential transit opportunities and identified some of the science questions that could be addressed. Using this framework we identified sites and transects of holes consisting of multi-disciplinary targets along the likely path the ship would take from the South Pacific into the South Atlantic (as well as other potential ship tracks). Preferably, each hole would consist of piston coring the sediments (triple coring ideally), drilling basement until bit destruction (or setting of a re-entry cone and casing at selected sites), and a curation protocol in place for dedicated microbiological sampling. These holes would contribute substantially to the achievement of the 2013-2023 Science Plan Challenges.

A significant outcome of the workshop will be to submit a Multiphase Drilling Proposal (MDP) that will form the mechanism to unite individual “transect drilling” efforts. The fundamental idea is that the hypotheses driving the drilling program require numerous drill sites worldwide, and no single 2-month expedition can achieve this. However, individual and carefully planned holes taken during a transit, or when the ship is in a particular region, can have a transformative impact on our understanding of multiple Challenges. Modern seismic reflection data may be sparse in some regions, and will require flexibility in evaluating the site characterization data. Many important drilling targets - targets that could simultaneously address high priority questions within each of the major drilling themes – will require drill times that fall between the traditional 3-day APL or 56-day expedition. The scientific ocean drilling community has long sought a more flexible mechanism for using the *JOIDES Resolution*, but the 2-month expedition model has been entrenched for several decades. With this MDP we hope to renew the discussion of devising more flexible and efficient ways of using the *JOIDES Resolution*, and to provide the conceptual platform for evaluating and scheduling these “mini-legs”. For example, 2 or 3 transect sites with different scientific objectives could be combined into a full 2-month crew rotation.

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