IODP Proposal Cover Sheet

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Title:	Mission Moho		
Proponent(s):	Benoît Ildefonse, Natsue Abe, Peter Kelemen, Hidenori Kumagai, Damon Teagle, Doug Wilson, and the Mission Moho proponents		
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Permission to post abstract on IODP Web site: ☑ Yes ☐ No

Abstract: (*400 words or less)*

Mission Moho is an integrated campaign to understand the formation of the oceanic lithosphere with the ultimate goal of drilling a complete section through intact ocean crust, across the Moho and into peridotites of the upper mantle. This proposal elaborates on the outcomes of an international workshop held in September 2006 (www.iodp.org/lithosphere). Mission Moho is the culmination of a four-decade quest by IODP and its predecessors (ODP, DSDP) to increase our understanding of the oceanic lithosphere through deep scientific drilling.

Our scientific objectives are to: 1) determining the geological nature of the Mohorovičić seismic discontinuity, 2) understand upper mantle dynamics and melt migration processes; 3) test competing hypotheses of the accretion of igneous crust at mid-ocean ridges; and 4) estimate the extent, location and intensity of hydrothermal exchanges between seawater and the oceanic lithosphere that control crustal cooling, global chemical fluxes, and sub-seafloor biological activity.

The “MoHole” will be the final stage of Mission Moho that will require non-riser and riser drilling, geophysical site surveys and the development of new technology including the construction of a +4000 m riser. The initial expeditions will utilize the existing capabilities of both the SODV and the Chikyu to drill shallow and then deeper targets in increasingly hostile conditions. We will thus be able to deliver major short-term science returns whilst we develop the equipment, technology and experience to tackle a full crustal penetration. Although Site 1256 in the eastern equatorial Pacific has many of the desirable attributes for a MoHole, alternative sites in the Pacific must be identified and thoroughly evaluated before a final MoHole site is identified.

Along the road to the Moho, we will progressively advance our scientific understanding, and gain experience in drilling deep in high-temperature basement, through 1) non-riser drilling as deeply as possible into intact crust at Site 1256, 2) conduct non-riser drilling of fast spread lithosphere in the Hess Deep tectonic window in the eastern Pacific, 3) deepen Hole U1309D in the North Atlantic slow-spread crust, possibly into rocks with mantle seismic velocities, and 4) test whether the Moho can be a serpentinization front through a combination of non-riser and riser deep drilling at Atlantis Bank, on the slow-spreading Southwest Indian Ridge. Mission Moho requires a 10- to 15-year commitment by IODP to operation at five sites through multiple expeditions.

Scientific Objectives: (*250 words or less*)

Drilling and recovering an intact and tectonically undisrupted section of ocean crust and upper mantle generated at a fast-spreading ridge is the main goal of the 21st Century Mohole Initiative of the IODP Science Plan, that echos a long term goal of Earth scientists since the initiation of Project Mohole in the late 50's through DSDP and ODP. Only by drilling a suite of increasingly deep holes, with the ultimate goal of full-crustal penetration, will we be able to address primary questions related to the formation of oceanic crust, the geological nature of the Moho, and the geodynamics of the convecting upper mantle. Specific science objectives are to:

- Determine the geological meaning of the Moho in different oceanic settings, determine the in situ composition, structure and physical properties of the uppermost mantle, and understand mantle melt migration,
- Determine the bulk composition of the oceanic crust to establish the chemical links between erupted lavas and primary mantle melts, understand the extent and intensity of seawater hydrothermal exchange with the lithosphere, and estimate the chemical fluxes returned to the mantle by subduction,
- Test competing hypotheses of the ocean crust accretion at fast spreading mid-ocean ridges, and quantify the linkages and feedbacks between magma intrusion, hydrothermal circulation and tectonic activity,
- Calibrate regional seismic measurements against recovered cores and borehole measurements, and understand the origin of marine magnetic anomalies,
- Establish the limits of life in the ocean lithosphere.

Please describe below any non-standard measurements technology needed to achieve the proposed scientific objectives.

Logging (geophysical measurements and borehole imaging) and fluid/gas sampling in High Temperature (≥ 200°C) basement.

Proposed Sites:

Site Name	Position	Water Depth (m)	Penetration (m) Sed	Penetration (m) Bsm	Penetration (m) Total	Brief Site-specific Objectives
East Pacific : 1256 (Pr. 522-Full5)	6°44.2'N - 91°56.1'W	3635	n/a	>1700	As deep as possible	Non-riser deepening of Hole 1256D, igneous crust. Site 1256 is currently the best known "MoHole" site.
Hess Deep : HD-01A	2°15.8'N - 101°31.8'W	4400	<30	<500	<500	Middle crust plutonic rocks
HD-02A	2°15.5'N - 101°31.8'W	4600	<30	<500	<500	Lower crust plutonic rocks
HD-03A	2°15'N - 101°31.8'W	4750	<30	<500	<500	Lower crust plutonic rocks
HD-04A (Pr. 551-Full)	2°16.7'N - 101°26'W	3900	<30	<500	<500	Upper mantle ultramafic rocks
Atlantis Massif : U1309	30°6'N - 42°W	1645	n/a	>1900	As deep as possible	Non-riser deepening of hole U1309D, lower igneous crust, serpentinites?
Atlantis Bank : AtBk-1A (Pr. 535-Full5)	32°42.75'S - 57°17.1'E	700	0	~3000 ≤6000	~3000 ≤6000	Lower igneous rocks, serpentinites?, upper mantle
The MoHole	to be determined	+4000	≥50	>6000	>6000	Lavas, dikes, gabbros, cumulate gabbros, the Moho, fresh mantle peridotite

MISSION MOHO PROPOSAL

Creation of new oceanic crust by seafloor spreading is the dominant geologic process on Earth. Seafloor spreading has been operating for at least 3.8 billion years, and more than 60% of the Earth's surface today is paved by ocean crust formed in this way. Ocean crust records the Earth's origin and evolution, and exerts the primary control on mass and heat transfer between the Earth's interior and hydrosphere. It hosts an extensive biosphere, with unique chemosynthetic communities existing without recourse to the sun's energy.

Across the ocean basins there is a seismic boundary – the Mohorovičić discontinuity, or 'Moho' – that represents the transition between the crust and the mantle. Crossing this frontier has been the foremost scientific goal of ocean drilling since the advent of the plate tectonic paradigm in the late 1950s, and was one of the driving forces for the scientific ocean drilling programs of the four decades since.

With the new technologies now available to us and under development by the Integrated Ocean Drilling Program, for the first time we have the capability of realizing our long-held aspiration to sample a complete section of in situ ocean crust and shallow mantle. This is the goal of 'Mission Moho'.

To achieve this goal is to understand how the surface of the Earth is paved, its internal architecture, and the geodynamic engine of plate tectonics. Mission Moho, through IODP international partnership, will create, for generations to come, a legacy equivalent to Man's missions to the Moon.

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SUMMARY

The Mohorovičić Discontinuity, commonly known as the "Moho", is a seismically imaged acoustic interface within the Earth below which compressional wave velocities (Vp) exceed 8 km/s. In the ocean crust this step in seismic velocity occurs at ~5-8 km depth and, away from plate boundaries and transform faults, the Moho is commonly a bright reflector. It is commonly assumed that the Moho also represents the boundary between mafic igneous rocks crystallized from magmas that form the crust and the residual peridotites of the mantle. To date, however, this interpretation of the Moho as the crust-mantle boundary has never been tested and there are geologically valid scenarios in which the Moho might exist at the boundary between mafic and ultramafic cumulates within the crust or below serpentinized peridotites that were previously part of the mantle until hydrated by seawater-derived fluids. Knowledge of the Moho, the crust-mantle boundary and the rocks of the upper mantle is fundamental to understanding the geodynamics and differentiation of our planet.

The ultimate goal of Mission Moho is to drill completely through intact oceanic crust formed at a fast spreading rate into the upper mantle to understand the processes responsible for the creation of new crust, and determine the nature of the Moho and the mantle beneath. Fast spreading crust is relatively uniform, and we have well-developed theoretical models for crustal accretion at fast spreading ridges that can be tested by drilling. This will be the highest priority of an integrated "Mission" with short and long term goals, shallow and deep targets, and requiring both riserless and shallow to deep riser drilling. Throughout this Mission we will develop the scientific and technical knowledge to achieve of a full crustal penetration. Many first-order questions about the processes of crustal accretion and interaction between the lithosphere and hydrosphere will be addressed on the journey to the Moho. A first-order understanding of the nature of the Moho and the crust also requires investigation of slow-spread crust. Selected regions on slow- and fast-spreading ridges where tectonics make lower crustal and upper mantle rocks accessible with current technology are thus compelling targets.

Mission Moho is anticipated to last ~10 to 15 years, and comprises five targets:

1) To drill as deep as possible into ocean crust formed at a superfast spreading rate at Site 1256, hosted in 15 m. yr.-old crust that formed at the East Pacific Rise (Fig. 1), using riserless technology. It is possible that, because of the relatively young age of the crust at Site 1256, hot lower crustal temperatures (≥250°C) may ultimately prevent us from achieving total crustal penetration in Hole 1256D. However, this site will be the initial focus of operations;

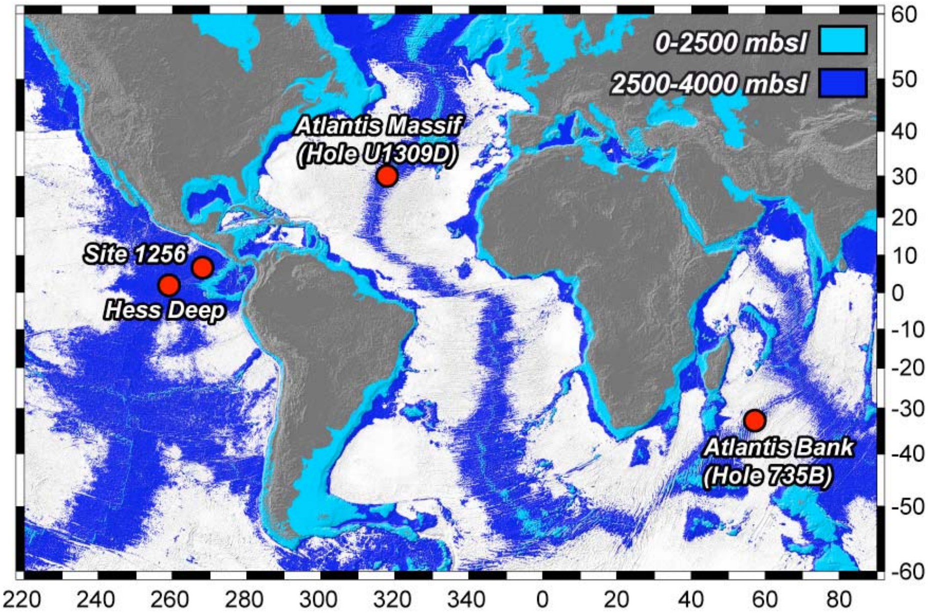

Fig. 1 - Location map of the four current known sites of Mission Moho

2) To exploit with shallow (<500 m) riserless drilling the tectonic window provided at Hess Deep (Fig. 1) as a shortcut to the lower oceanic crust and serpentinized upper mantle in fast-spread oceanic lithosphere. This will be an important complement to the deep drilling of intact fast-spread oceanic crust;

3) To drill as deep as feasible with riserless technology in Hole 1309D (Atlantis Massif, Mid-Atlantic Ridge, Fig. 1), that has already sampled ~1400 m of gabbroic rocks in young (~2 Ma), slow-spread crust. This will provide essential operational experience in drilling hot plutonic oceanic crust, and complementary knowledge of lower crustal accretion processes at slow-spreading ridges. It may also provide a short-cut to sampling *in situ* fresh mantle rocks with >8km/s compressional wave velocities, and assess the spreading-rate dependence of the nature of the Moho.

4) To drill deeply at Atlantis Bank on the Southwest Indian Ridge, using both riserless and riser drilling, to test the model that the lower crust at this site is made of serpentinized peridotite, and that the Moho may in places be a serpentinization front. This site has a proven track record of benign drilling and the shallow water depth provides an excellent opportunity for testing deep riser drilling of oceanic basement using the current capabilities of D/V Chikyu, and to address important questions about the variability of the Moho and the crust-mantle boundary.

5) The "MoHole": Full penetration and sampling of intact crust, Moho, and upper mantle in oceanic lithosphere formed at a fast spreading rate. This will provide hitherto unattainable

information on the composition and melting of the upper mantle, the construction and cooling of the oceanic crust, the chemical exchange between the crust and oceans, and the linkages between these processes. Drilling the Mohole will require development of a 4000+ m riser for D/V *Chikyu*. Although the optimal location for the MoHole has not yet been determined, the criteria for selecting a site are well established (see section 4.5). Knowledge gained from the drilling of targets 1 through 4, coupled with geophysical site surveys, will be necessary for choosing the site for full crustal penetration into the upper mantle.

1. PRIMARY MOTIVATION FOR MISSION MOHO

The formation, evolution and recycling of oceanic lithosphere is the dominant process in the chemical differentiation and physical evolution of our planet. This process encompasses the transfer and transformation of material and energy from Earth's mantle to the crust and from the crust, to the ocean and atmosphere. Independent of sunlight, the evolving ocean crust supports life in unique subsurface and seafloor habitats that may resemble the conditions that enabled the origin of life. Upon its formation at seafloor spreading centers, the oceanic lithosphere records geomagnetic field variability, providing the basis for geomagnetic polarity timescales, plate reconstructions, and estimates of plate motions. From its formation until it is subducted back into the mantle, the oceanic lithosphere interacts with seawater, sequesters surface materials (including water and CO_2) and recycles them back into the mantle.

Sampling a complete section of crust and shallow mantle was the original motivation for scientific ocean drilling. Mission Moho will be the culmination of a decades-old quest by IODP, ODP and DSDP, since Walter Munk and the AMSOC first proposed Project Mohole in 1957 (e.g., Greenberg, 1974; Shor, 1985). The goal was and remains to understand the composition, structure, and evolution of the oceanic lithosphere through deep scientific drilling, as outlined in the 21st Century Mohole Initiative of the IODP Initial Science Plan. This goal has been a core component of planning documents since the inception of scientific ocean drilling (e.g., the "Road to the Moho" chapter in Murray et al., 2000).

The Moho (Mohorovičić Discontinuity) is a seismically imaged, primary acoustic interface that represents the transition between the Earth's crust and the underlying mantle. Whereas oceanic crust is formed by a variety of igneous and metamorphic processes, and has a low seismic velocity, the oceanic mantle has a much higher seismic velocity and is largely composed of residual peridotite. Residual peridotites have lost magma to form the crust during partial melting, and although deformed and recrystallized, have remained relatively solid for more than 4 billion years. Thus the mantle is intrinsically different from the igneous crust.

Uncertainty about the Moho stems from questions about the relationship between the seismic boundary, on the one hand, and the geological crust-mantle transition on the other. Are there "ultramafic" igneous rocks, with high seismic velocities, emplaced below the Moho? Are there hydrothermally altered residual peridotites, with low seismic velocities, above the Moho? Is the Moho an intrusive or tectonic boundary? The floor of a magma body? How sharp is the transition, given the limitations of seismic data analysis (±50m)?

In addition to the mysteries surrounding the Moho, we also have major gaps in knowledge about the oceanic lower crust and mantle themselves. How does the igneous crust form, and how does it exchange heat and chemical components with seawater? How is melt transport focused from a broad melting region to a narrow zone of crustal accretion beneath mid-ocean ridges? What is the composition and physical state of the convecting mantle? We have no fresh, *in situ* mantle sample. A few kilograms of fresh residual peridotite from beneath intact oceanic crust would provide a wealth of new information comparable to the treasure trove obtained from the Apollo lunar samples.

To date, the elusive frontier at the Moho, and the enormous mantle domain beneath, have been symbolic, unattainable goals. However, with the recent commissioning of IODP's new riser-drilling vessel, D/V *Chikyu*, the aspirations of generations of Earth scientists of drilling completely through the oceanic crust to the Moho into the upper mantle ~5-6 km below seafloor, have moved into the realm of technical feasibility.

The wider mid-ocean ridge and oceanic lithosphere community has been involved with the establishment of the plan presented herein via the IODP-MI sponsored Mission Moho workshop held in Portland Oregon in September 2006 (Christie et al., 2006; Ildefonse et al., 2007b; full report: www.iodp.org/ocean-lithosphere). The basic strategy of Mission Moho is derived from the consensus of about one hundred representatives from the international community. Mandate was given to the writing team and co-proponents to take forward the outline plan on behalf of the wider community. The six lead proponents are willing to serve in the stage 1 core Mission Team. This Team should also comprise seismologists (of which several are included in the co-proponent list), deep drilling engineers (especially riser drilling) from USIO, CDEX and industry, logging tool specialists, and borehole management experts (to improve our control of borehole stability issues).

2. ROAD TO THE MOHO

Since the early 70's when the "Penrose" layered model for the ocean crust (Penrose Conference Participants, 1972) was widely accepted, investigations of the oceanic crust by scientific ocean drilling (Fig. 2), marine geological and geophysical techniques, complemented by ophiolite studies, have expanded our understanding of the architecture of the ocean crust (e.g., Teagle et al., 2004; Dick et al., 2006; Ildefonse et al., 2007c).

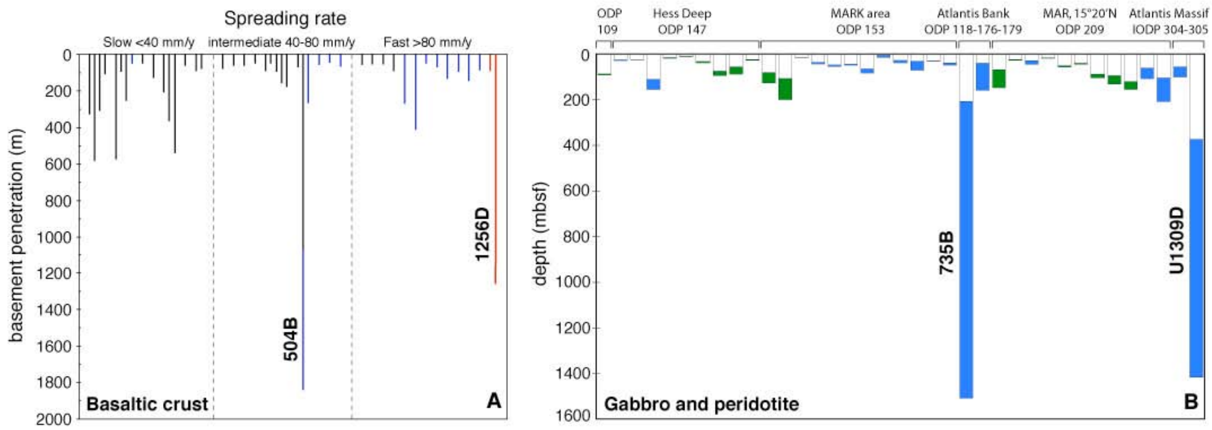

Fig. 2 - Summaries of existing scientific drill holes into oceanic crustal and mantle rocks. [A] Penetration for all holes penetrating more than 50 meters into basaltic basement, as a function of spreading rate. Hole 1256D has reached the base of the sheeted dike complex at a shallower depth than the bottom of Hole 504B, which is still in sheeted dikes. Black = DSDP holes, blue = ODP holes, red = IODP holes. After Teagle et al. (2006). [B] Depth of penetration for all ODP and IODP holes deeper than 10 meters below seafloor into gabbroic rocks or residual mantle peridotite. Blue = dominantly gabbro, green = dominantly peridotite, white = no recovery. After Blackman et al. (2006).

Away from transform faults, ocean crust formed at fast spreading rates exhibits a relatively uniform seismic stratigraphy (e.g., Canales et al., 2003). At the ridge crests continuous axial low-velocity zones interpreted to be high level, axial melt lenses are imaged, and well defined Moho reflectors are present within a few kilometers of the axis. This suggests that ocean crust formed at fast spreading rates (>80 mm/yr full rate) is layered and relatively homogeneous. Although only 20% of modern ridges are fast-spreading (>80 mm/yr), more than 50% of the present day seafloor (~30% of Earth's surface), and the great majority of crust subducted into the mantle during the past 200 Ma, was produced at fast spreading ridges. Because of the relatively uniform seismic structure and bathymetry of fast-spreading lithosphere, understanding of crust and mantle genesis and evolution at one site can be extrapolated to a significant portion of Earth's surface with some confidence. Importantly, scientists have well developed theoretical models of contrasting styles of magmatic accretion at fast-spreading ridges. Methods have been proposed to test these model using samples recovered from drilled sections of ocean basement together with complementary studies of ophiolites, in particular the Oman ophiolite. Therefore, the highest priority of Mission Moho is to obtain a continuous sample of the entire crust, the Moho and shallow mantle peridotites, in oceanic lithosphere formed at a fast-spreading rate. Scientific and technological progress towards this ultimate goal will require drilling at several additional sites, in crust formed at both fast- and slow-spreading rates.

Ocean crust formed at slow to ultra-slow rates (<40 mm/yr) is highly heterogeneous both along and across axis particularly towards the end of ridge segments where tectonic extension competes with magmatic accretion (e.g., Karson and Elthon, 1987; Dick, 1989; Cannat et al., 1995, 2006; Canales et al., 2000; Kelemen et al., 2004; Ildefonse et al., 2007a). Such is the variety of accretion on slow spreading ridges that fully characterizing the heterogeneity is beyond the scope of this Mission. However, tectonic windows at fast- and slow-spreading ridges provide exposures of deep crustal rocks, serpentinized upper mantle, and possibly fresh upper mantle peridotites that can be sampled in relatively shallow drill holes using existing technologies.

3. Scientific Objectives

By drilling an intact section of ocean crust and upper mantle generated at a fast-spreading ridge, we will address first-order questions about the formation of oceanic crust, the nature of the Moho, and the composition of the Earth's convecting mantle. Specific objectives include:

- Determine the geological meaning of the Moho in a variety of tectonic settings,
- Determine the *in situ* composition of the uppermost mantle, its structure and physical properties, and the physics and chemistry of mantle melt migration processes,
- Determine the bulk composition of the oceanic crust to establish the relationship between the lavas that erupt at the seafloor and the melts that separated from their mantle sources,
- Understand the extent and intensity of hydrothermal exchange between the ocean crust and seawater and estimate the chemical flux returned to the mantle by subduction,
- Determine the mode of magmatic, crustal accretion at fast spreading mid-ocean ridges. What are the size and architecture of mid-ocean ridge magma chambers responsible for the construction of the lower ocean crust?,
- Determine the linkages and feedbacks between magma intrusion, hydrothermal circulation and tectonic activity,
- Calibrate regional seismic measurements against core samples and borehole experiments,

• Understand the origin of marine magnetic anomalies and quantify the contribution of lower crustal rocks to the magnetic signature of the ocean crust,

• Establish the limits of life in the ocean lithosphere.

Addressing these objectives requires sampling and logging in deep and so-far unexplored parts of the ocean lithosphere. Specific science questions and working hypotheses to be tested are summarized below. Details of the individual components of Mission Moho will be fully developed in the proposals hosted beneath the Mission Moho umbrella.

3.1. What is the geological meaning of the Moho and seismic layers?

Understanding the seismic structure of the ocean lithosphere requires calibration of remotely obtained regional geophysical data against physical properties and petrological measurements of geological samples. There is a well established terminology for seismic layering in fast-spread oceanic crust. Layer 1 is locally absent, but present where sediment thickness exceeds a few tens of meters, and has Vp <3 km/s. Layer 2 is a band with a high gradient in Vp with depth, ranging from ~3-5 to ~6.7 km/s, and Layer 3 is a band with nearly uniform Vp ranging from ~6.7 to ~7.1 km/s. The Layer 2/3 boundary is an inflection point, between seismic velocities that increase with depth through Layer 2 and nearly uniform seismic velocity through Layer 3. Below Layer 3, in the “classical” Pacific seismic profiles a sharp transition from ~7 to ~ 8 km/s occurs within <500 m. By analogy with ophiolites and geological samples from the Pacific, these layers are commonly interpreted as pelagic sediment (Layer 1), lavas and fractured, sheeted dikes (Layer 2), intact sheeted dikes and plutonic rocks (Layer 3), and residual mantle peridotite ± ultramafic plutonic rocks (below Layer 3).

The only site where geological samples have been recovered from intact oceanic crust at the depth of the Layer 2/3 seismic boundary is DSDP/ODP Hole 504B where the inflection in seismic velocity gradient occurs within the sheeted dikes (Detrick et al., 1994; Alt et al., 1996; Carlson, 2001) and appears to be controlled by alteration and/or the nature and density of cracks in the formation, rather than rock type or grain size. Elsewhere, Hole 1256D data suggest that the layer 2/3 seismic transition has not been yet reached, even though the hole extends below the first appearance of gabbros at the base of the sheeted dikes (Teagle et al., 2006). Drilling deeper at Site 1256, and through the Layer 2/3 boundary in the MoHole (if not at Site 1256), will continue to reveal the geological meaning of the seismic layering of the upper ocean crust.

Seismic velocities in the lower oceanic crust are systematically lower than predicted for gabbros (Korenaga et al., 2001; Behn and Kelemen, 2003). This could be related to the presence of cracks and/or alteration phases, and/or to our poor knowledge of lower crustal composition. Direct sampling of Layer 3 will resolve this issue, and restore our ability to interpret Layer 3 velocities in terms of geologically significant rock properties.

The primary goal of Mission Moho is to sample through the base of Layer 3 and the Mohorovičić discontinuity, and into residual peridotites of the upper mantle. In contrast to the classical interpretation of the Moho as the crust-mantle boundary, Hess (1960) posited that the Moho represents a serpentinization front, i.e. a boundary between fresh peridotite and serpentinite. Partially serpentinized peridotites can have densities and velocities identical to (or even lower than) those of fresh gabbros (e.g. Horen et al., 1996; Carlson and Miller, 1997). At fast-spreading ridges, the Moho is generally sharp, which is thought to indicate that the Moho is a lithological contact between gabbro and ultramafic rock. However, Vp beneath the oceanic Moho is generally slightly lower than predicted for unaltered peridotite (Shipboard scientific party, 2004). This could indicate ~10% serpentinization, small proportions of gabbroic lenses intruding residual peridotite, or the presence of ultramafic plutonic rocks below the Moho. Until we drill through the Moho beneath fast-spread crust, this question of the petrological significance of the Moho will remain unresolved.

Laboratory-derived velocities of discrete samples cannot reflect large-scale structures within the oceanic lithosphere. Integration of seismic reflection and drilling data will require detailed wireline sonic logging coupled with vertical and multi-ship offset seismic experiments allowing the measurement of regional mantle anisotropy and crustal structure.

At slow-spreading ridges, serpentinized mantle rocks are commonly incorporated into the crust. Drilling through this type of crust, down to fresh peridotites could provide the first fresh, *in situ* mantle samples and test hypotheses regarding the

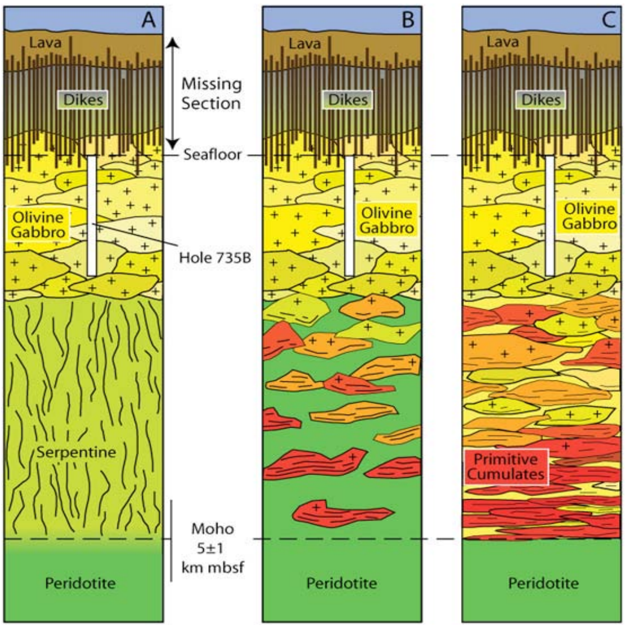

Fig. 3 - Various alternative models of crustal architecture and the Moho for the Atlantis Bank (Southwest Indian Ridge), where Hole 735B was drilled (after Dick et al., 2006). [A] After Muller et al. (1997). [B] After Cannat (1996). [C] After Dick et al. (1991).

nature of the Moho. Is it: 1) the boundary between the residual upper mantle and the igneous crust, 2) a broader zone of layered ultramafic and mafic rocks, 3) a serpentinization front, or any combination of these three (Fig. 3)? Assessing the role of serpentinization in modifying the seismic signature of the crust and the transition to typical mantle velocities is most conclusively addressed by deep drilling lower ocean crust and upper mantle unroofed at slow rates of oceanic spreading.

3.2. Obtaining the first fresh samples of the Earth's convecting mantle

Presently there are NO fresh samples of the convecting mantle. Xenoliths, inclusions brought to the surface in lavas, are (a) mainly derived from continental lithosphere, rather than the convecting mantle, and (b) contaminated by interaction with host lavas. This problem is particularly acute for understanding volatile chemical components that are modified by hydrothermal alteration in tectonically exposed samples, or by host lavas in xenoliths. As a result, hypotheses about oxygen fugacity, sulfide composition and proportion, CO_2, CH_4, graphite, H_2O, Li, B, He and other noble gas characteristics in the "MORB source" –the convecting upper mantle that partially melts to form Mid-Ocean Ridge Basalts– are sustained largely by inference and assertion. Concentrations and isotope characteristics of volatile elements in Earth reservoirs are vital tracers for global chemical cycling. Other components, such as heat-producing elements U and Th, may be concentrated on grain boundaries (Niu, 2004), but we have no fresh grain boundaries to examine.

The nature and length scale of heterogeneity in the mantle source of mid-ocean ridge basalts (MORB) remains controversial and has fundamental implications for the most basic structure of mantle convection: are ocean island basalts fed by hot plumes that cut through the upper mantle MORB source, or is the MORB source replenished from the same mantle material as ocean island basalts? Such problems remain unsolved because mantle source characteristics are largely inferred from lava compositions. Tectonically exposed peridotites sampled by dredging and shallow ocean drilling are plagued by contamination problems due to their highly reactive nature on the seafloor. Drill core from fresh, oceanic upper mantle will place constraints on the extent and scale of Sr, Nd, Pb, Hf and Os isotope vertical variability, independent of the effects of near-surface alteration and deformation.

Similarly, the grain size and deformation history of unaltered oceanic peridotite remains unknown. These parameters, essential for understanding mantle seismic data (e.g., Faul and Jackson, 2005), melt transport in the mantle (e.g., Spiegelman and Kenyon, 1992), or deformation at decreasing temperature caused by corner flow beneath the ridge, can only be addressed through the recovery of fresh samples of *in situ* mantle peridotite.

3.3. Melt focusing and extraction beneath mid-ocean ridges

One of the least constrained, fundamental problems in geodynamics is the focusing of mantle melt beneath spreading ridges. Melt is produced in tiny pores along grain boundaries within a region of the upper mantle extending to more than 100 km depth and laterally for 100's of km on either side of the locus of spreading. How is this melt extracted and crystallized to form oceanic crust within a narrow region, a few km wide, as seismically imaged along the East Pacific Rise? Several, well-defined hypotheses have been outlined, but no consensus will emerge without the direct evidence that would be provided by drilling *in situ* upper mantle.

A key element of this problem is to understand and characterize the upwelling path of partially molten mantle peridotite. Is it passive, plate-driven flow (e.g., Langseth et al., 1966; McKenzie, 1967; Bottinga and Allegre 1973, 1976; Sleep, 1975) or active, buoyancy-driven flow (e.g., Rabinowicz et al., 1984; Whitehead et al., 1984; Buck and Su, 1989; Fig. 4)?

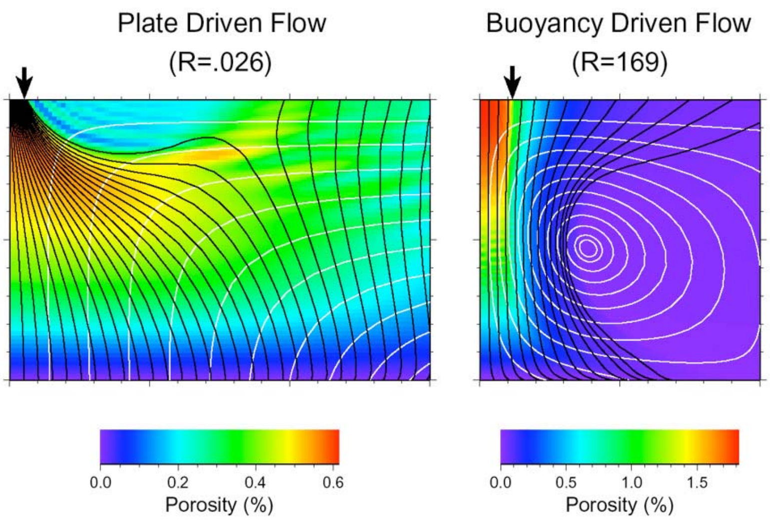

Fig. 4 - Examples of 2D (perpendicular to ridge axis) numerical models of mantle passive upwelling (left) and active, buoyant upwelling (right). Black curves: melt flow; white curves: solid flow (Spiegelman, 1996).

For samples obtained more than a few kilometers from the ridge axis, both models predict flow trajectories and lineation approximately perpendicular to the ridge axis, in a nearly horizontal foliation. However, passive vs. buoyancy driven upwelling can be distinguished from the flow kinematics recorded by olivine crystallographic preferred orientations. Active upwelling models predict that outward horizontal flow in the upper mantle is faster than plate velocity, resulting in an inversion of shear senses on a vertical section close to the Moho

(Ceuleneer et al., 1988; Nicolas et al., 1988; Nicolas et al., 1994). This has been mapped in the Oman ophiolite (Nicolas et al., 1994; Ildefonse et al., 1995) and would be apparent in drill cores.

Another key element is to understand the transport of melt through the mantle peridotite host rocks. Transport may be by diffuse porous flow (e.g., Phipps Morgan, 1987; Spiegelman and McKenzie, 1987), by focused flow in high porosity dissolution channels marked by dunites (e.g., Kelemen et al., 1995a, 1995b, 1997a), by focused flow in high porosity decompaction channels overlain by a permeability barrier at the base of the cold, overlying lithosphere (e.g., Sparks and Parmentier, 1991; Spiegelman, 1993; Ghods and Arkani-Hamed, 2000; Rabinowicz and Ceuleneer, 2005), by focused flow in high porosity shear zones (e.g., Stevenson, 1989; Kelemen & Dick, 1995; Connolly and Podladchikov, 2000; Holtzman et al., 2003), via passive transport within low permeability, partially molten, buoyant diapirs (e.g., Rabinowicz et al., 1984; Whitehead et al., 1984; Buck and Su, 1989), and/or in fractures initiated as a result of overpressure in an interconnected column of buoyant melt overlain by a permeability barrier (e.g., Nicolas 1986, 1990). All of these processes form distinctive geological features, and should be evident in drill core sampling melt transport features in mantle peridotites below the Moho.

Much of what we know about the composition and temperature of the upper mantle, and their global variability, comes from the chemistries of mid-ocean ridge basalts, which are used to infer the composition of the melt that crossed the Moho (e.g., Klein and Langmuir, 1987, McKenzie and Bickle, 1988). However, the majority of MORBs have Mg# << 70 (where Mg# = 100 x Mg/(Mg + Fe) atomic ratio) whereas primitive melts in equilibrium with mantle peridotites should have Mg# ranging from ~70 to 78 (O'Hara, 1968; Langmuir et al., 1982). Thus, we know that melts undergo partial crystallization to produce more primitive cumulates, with Mg# ≤ ~90 (equivalent to that of the mantle residues of MORB formation) before the remaining melt is extracted to erupt as MORB. On average, erupted MORBs record about 50% crystallization (see Shipboard Scientific Party, 2004). Primitive cumulate rocks have only rarely been sampled in the oceans, whereas they should be at least as abundant as erupted lavas and sheeted dikes. We believe that they must comprise much of seismic Layer 3 in fast-spread crust, and must be abundant somewhere (near ridge segment centers? as intrusions into mantle peridotite?) at slow-spreading ridges, but these hypotheses remain completely untested. In addition, because the nature of the primitive cumulates is unknown, determining the composition of unfractionated melts requires making numerous assumptions. These assumptions can only be tested by having a complete crustal section from which the integrated composition of the entire crust can be determined (e.g., O'Hara, 1982).

3.4. Mode(s) of accretion of the lower crust at fast-spreading ridges

Seismic Layer 2A, inferred to be composed mainly of lavas, constitutes less than a sixth of the total crustal thickness in fast-spread crust, so that the majority of the crust is inferred to be formed from melt that is intruded into the crust from the mantle. The nature of this process is hotly debated. Our understanding has been limited by the difficulties of geophysically imaging and directly sampling the crust, in particular *in situ* gabbroic lower crust. Consequently, the nature of the magma chambers beneath mid-ocean ridges and the magmatic processes that build the lower crust remain virtually unconstrained. Many fundamental questions remain unresolved. For example: how is melt transported from the mantle through the crust? Where do melts fractionate and crystallize? How, and how fast is heat extracted?

Multi-channel seismic (MCS) profiles across active intermediate and fast spreading ridges commonly reveal bright, low velocity reflectors ~1-2 km below the ridge axis, interpreted to be thin (20-100 m thick) axial magma lens (e.g., Morton and Sleep, 1985a; Detrick et al., 1987; Harding et al., 1989; Singh et al., 1998; Kent et al., 2000; Singh et al., 2006a). Melt lenses have also been imaged at or close to Moho depth (Garmany, 1989; Dunn et al., 2001; Crawford and Webb, 2002, Nedimovic et al., 2005; Singh et al., 2006b). These observations, combined with geological and petrological evidence from in-situ ocean crust and the Oman ophiolite, have led to two competing models of lower crustal accretion at fast-spreading mid-ocean ridges:

1. All of the crystallization occurs in a shallow melt lens, and the accumulated crystal residues subside in a "gabbro-glacier" to build the lower crust (e.g., Henstock et al., 1993; Phipps Morgan and Chen, 1993; Quick and Denlinger, 1993; Fig. 5a).
2. Crystallization of lower crustal gabbros occurs partly (Boudier et al., 1996) or essentially *in situ* (Kelemen et al., 1997b; MacLeod and Yaouancq, 2000) via injection of "sheeted sills" (Boudier et al., 1996; Kelemen et al., 1997b; Fig. 5b-c).

These two end-member models have profoundly different implications for the properties of the lower crust, including its composition, the distribution of melt, the extent of deformation, thermal history, and the geometry, temperature and intensity of hydrothermal fluid-rock exchange. Criteria for distinguishing between the two contrasting models are outlined below following tests developed from ophiolite and limited drill core studies. Drill core samples from a Pacific Ocean crustal section are essential to distinguish between these competing

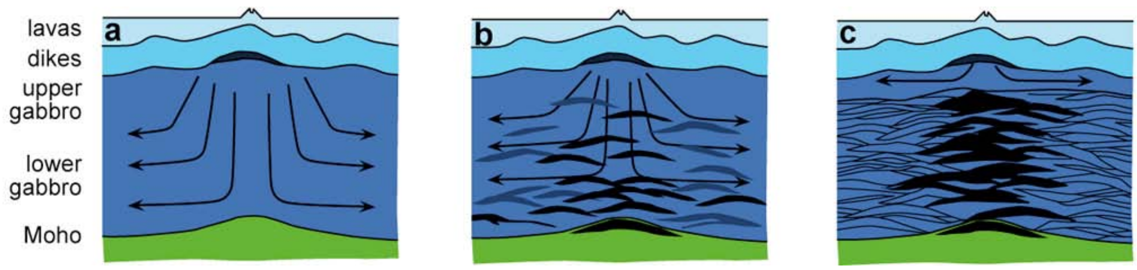

Fig. 5 - Schematic drawings of crustal accretion models (after Korenaga and Kelemen, 1998). [a] Gabbro glacier ductile flow model (e.g., Henstock et al., 1993; Quick and Denlinger, 1993). [b] A hybrid model of ductile flow with sill intrusions (e.g., Boudier et al., 1996). [c] "Sheeted sill" model of *in situ* formation of the lower crust by on-axis sill intrusions (e.g., Kelemen et al., 1997b).

models directly, through systematic measurements of compositions, textures, structures, and igneous contacts as a function of depth through the lower crustal gabbro section (Fig. 6).

Magmatic processes and architecture of the crust: The igneous stratigraphy and the nature of igneous contacts will be determined, to evaluate whether or not the lower crust comprises individual magma bodies that were intruded into the lower crust, and fractionated and crystallized *in situ*. In the sheeted sill model the bulk crustal composition will become more evolved upwards (Fig 6) and sub-Moho sills (Kelemen et al., 1997; Korenaga and Kelemen, 1997) are predicted. In contrast, in the gabbro glacier model there will be no change in bulk crustal composition with depth and sub-Moho sills are not expected (Fig 6). In addition to modal layering, vertical chemical variation is observed in ophiolite gabbros (e.g., Pallister and Hopson, 1981; Malpas et al., 1989; Bédard, 1991; Schouten and Kelemen, 2002), and in plutonic rock sections drilled along the mid-ocean ridges (e.g., Dick et al. 1991, 2000; Cannat et al., 1995; Pedersen et al., 1996; Natland and Dick, 1996; Kelemen et al., 2004; Blackman et al., 2006). The nature of this chemical layering can be used to constrain the size of individual crystallization units (Browning, 1984). Magma lenses ≤ 10 m thick crystallized layered gabbros in the Troodos ophiolite lower crust (Browning et al., 1989) and in the crust-mantle transition zone of the Oman ophiolite (Korenaga and Kelemen, 1997).

The nature of chemical layering can also be used to place constraints on the mode of melt migration from the mantle through the lower crust, to form shallow gabbros, sheeted dikes, and lavas. Korenaga and Kelemen (1998) showed how reactive porous flow of melt through chemically layered gabbros would disrupt correlations between mineral compositions formed during crystal fractionation, and gradually smooth vertical chemical variation via diffusion. The scale of measurements undertaken in drill cores is ideal to address such chemical variations.

Deformation of the ocean crust: If the lower crust is built by the subsidence of material from a high level melt lens in a gabbro glacier, increasing strain with depth is predicted (Fig. 6). In contrast, crustal construction by successive sill injections will not produce systematic gradients in strain with depth. Published data sets from the Oman ophiolite are too limited to be conclusive, and show no significant downward trend (Yaouancq and MacLeod, 2000). The intensity of deformation, manifested by crystal shape and lattice preferred orientations, and to some extent by magnetic fabrics (Gee et al., 2004) can be readily assessed in drill core samples.

Cooling the lower ocean crust: As magmas cool and crystallize, both the latent heat of crystallization and specific heat of cooling must be removed. Heat is transferred through the crust by conduction, or the advection of melt, solid material and seawater-derived hydrothermal fluids. Hydrothermal convection removes heat more rapidly than conduction. The distinct distributions of melt intrusion and crystallization with depth implicit in the two end-member models in Figure 5a and 5c yield different distributions of latent heat removal with depth (Fig. 6). Computer simulations that balance the input of magmatic heat from the mantle to the crust with heat sinks provided by conduction, advection, and hydrothermal circulation have been used to test the crustal accretion models, by constraining the input parameters to yield the best fits to geophysical or geological observations (Sleep, 1975; Morton and Sleep, 1985b; Henstock et al., 1993; Phipps Morgan and Chen, 1993; Maclennan et al., 2004). The gabbro glacier model provides the most efficient geometry for hydrothermal heat extraction, as the latent heat and specific heat of cooling can be readily advected from the lid of the melt lens (Henstock et al., 1993), and predicts a decrease in cooling rate with depth, assuming that deep cooling is predominantly by conduction. However, the sheeted sill model (Fig. 5b-c) can also be successfully simulated, provided that vigorous deep hydrothermal circulation occurs near the ridge axis and there is some crystal subsidence from the axial magma lens (Maclennan et al., 2004; Maclennan et al., 2005). The vigor of hydrothermal convection in the lower crust depends on how close to the ridge axis hydrothermal fluids are able to penetrate deeply in the crust, and on permeability. Small changes in permeability may have a huge effect on the resulting thermal structure (Cherkaoui et al., 2003), rendering thermal models uncertain until tested by data. The contrasting distribution, flux and temperatures of hydrothermal fluids predicted by each of the accretion models imply distinct alteration patterns that will be directly observed in drill cores (Fig. 6).

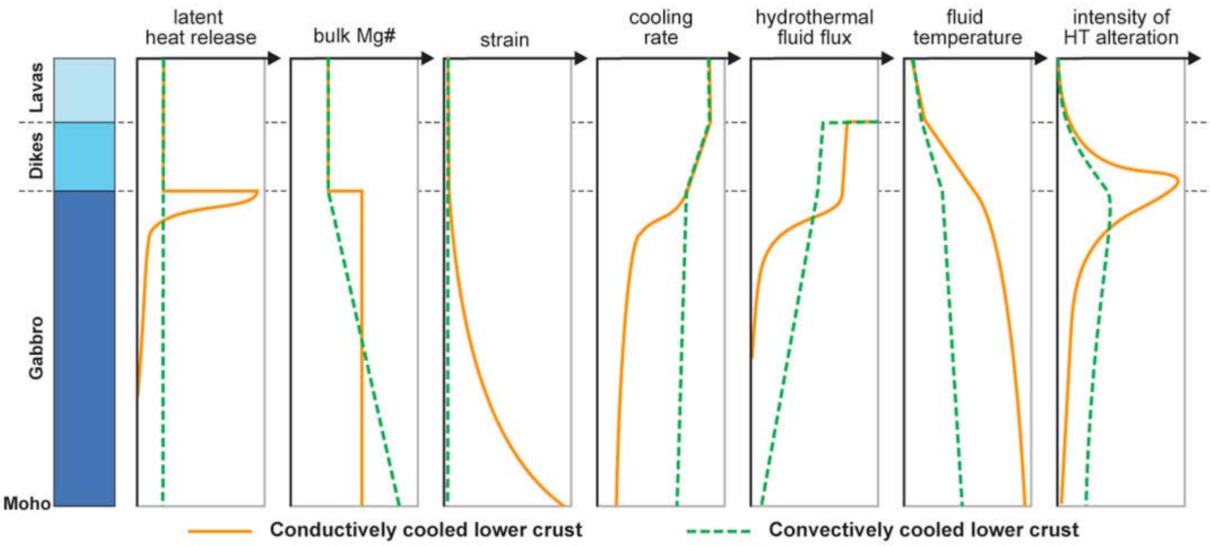

Figure 6. Schematic relative variations in the general trends of latent heat release, bulk Mg#, strain rate, cooling rate, hydrothermal fluid flux, fluid temperature, and intensity of high temperature alteration with depth predicted by end-member "gabbro glacier" (with mainly conductive cooling of the lower crust) and "sheeted sill" (with convective cooling of the lower crust) models of crustal accretion.

If hydrothermal fluids penetrate sufficiently deep close enough to the ridge axis, they may lower the melting point of newly crystallized gabbro or gabbroic mush and generate more felsic melts (e.g., Koepke et al., 2007), resulting in the intrusion of silicic veins and plutons with distinctive isotope and compositional characteristics. Silicic veins, produced via crystal fractionation or partial melting, are essential to understanding the crustal budget of many geochemically important elements such as U, Th and Pb (e.g., Hart et al., 1999).

The cooling rate of the lower crust, as a function of depth, can be estimated using (i) “geospeedometers” that exploit elemental (Fe, Ca, Li) diffusion rates in olivine, clinopyroxene, and plagioclase (Ozawa, 1986; Coogan et al., 2002, 2005a, 2005b), (ii) analysis of plagioclase crystal size distributions in gabbros (Garrido et al., 2001). Given the potential for small-scale variability in cooling rates, due to fracture-controlled heterogeneous fluid circulation (Coogan et al., 2006), drill core provides the ideal samples for such studies. In addition, the locking in of magnetic polarity in oceanic gabbros at ~500°C can provide strong constraints on cooling rate. Encountering a series of polarity reversals with increasing depth would reveal the record of the blocking isotherm moving deeper in the crust, with time intervals known separately from calibrating the polarity time scale. Uniform polarity over a great depth range would indicate rapid cooling within a time between field reversals.

Well-established petrologic and geochemical techniques can be used to characterize the nature and relative timing of hydrothermal exchange between seawater and the lower crust, the flux of fluid through the crust, and the depth to which fluid penetrates. Mineral geothermometers and cross-cutting vein mineral sequences, coupled with trace element, strontium isotope, and stable isotope compositions of whole rock samples and mineral separates can be used to establish the temperature- and chemical-evolution of the fluids in the lower crust (e.g., Gregory and Taylor, 1981; Manning et al., 1996; Teagle et al., 1998; Bach et al., 2004; Coggon et al., 2004; Gillis et al., 2005), the extent of fluid channeling along fractures and veins (Manning et al., 1996; Banerjee and Gillis, 2001; Nicolas et al., 2003; Bosch et al., 2004; Coogan et al., 2006), and time integrated fluid fluxes (Bickle, 1992; Bickle and Teagle, 1992; Teagle et al., 2003; Gillis et al., 2005).

3.5. Crustal aging and chemical fluxes: from mantle to hydrosphere and back again

The chemical evolution of the oceanic basement does not stop after the crust crystallizes. There is a discernable deficit in conductive heat flow out to 65 Ma on average and some seawater-rock exchange probably occurs in ocean crust of all ages. Geochemical and petrological constraints on water/rock ratios, time integrated fluid, chemical and isotopic fluxes and the nature of hydrothermal alteration of the crust (see section 3.4) will provide essential information on chemical and thermal exchange between the lithosphere and the oceans, key to global geochemical budgets. Stein and Stein (1994) inferred from heat flow data that 33% of the convective cooling of oceanic lithosphere occurs in crust more than ten million years old, so that drilling may actually sample an active, low temperature hydrothermal system. In any case, drilling in crust as old as possible (see section 5.2) will allow better constraints on the role of hydrothermal alteration in controlling the chemical evolution of seawater (e.g., Davis et al., 2003; Nielsen et al., 2006), and the bulk composition of the igneous crust recycled into the mantle in subduction zones.

3.6. Probing the limits of life

The upper oceanic crust is a habitat for microorganisms. Endolithic microbes colonize fractures in glassy basaltic rocks extracting energy and nutrients from the glass by dissolving it, and leaving behind biomarkers that reveal their former presence (e.g., Bach and Edwards, 2003; Banerjee and Muehlenbachs, 2003; Staudigel et al., 2006). Hydrogen and simple organic compounds can be produced abiotically where water interacts with ultramafic rocks in a variety of geotectonic settings, including portions of slow-spreading mid-ocean ridges (e.g., McCollom and Seewald, 2001; Kelley et al., 2005). Microbial activity occurring in the sub seafloor biosphere may have a profound impact on processes and chemical fluxes during water-rock reactions but the depth limits of microbiological activity in the oceanic basement have yet to be fully explored.

Exploring and characterizing the sub seafloor biosphere in the ocean crust will be pursued in all oceanic basement holes. Deep drilling will cross chemical and physical boundaries, involving energy, carbon, nutrients and porosity/permeability, which define our current understanding of habitability and may shed light on deep energy sources for microbial communities. An extraordinary diversity of microorganisms exists in high temperature environments (>120ºC; Kashefi & Lovley, 2003), and this diversity is reflected in enzymes and other molecules. Deep drilling will provide access to rocky habitats at the edge of the life envelope (Bach et al., 2006) and an opportunity to search for novel microorganisms from high-temperature sub seafloor environments, leading to discovery of new compounds with biotechnology, medical and engineering applications. These environments may also be key in the search for primordial microbial communities that may have been the earliest life forms on Earth (e.g., Furnes et al., 2004; Banerjee et al., 2006).

4. Operations to be Conducted by Mission Moho

Here we outline the specific ocean drilling experiments that will be the main components of Mission Moho. Our early priorities are scientific expeditions that can be achieved using current technology and for which the science cases have already been well formulated and endorsed by IODP and external peer-review, or are soon to be submitted. Completion of these expeditions, coupled with geophysical site survey, will equip us with the scientific knowledge and technical capabilities to embark on a full crustal penetration and sampling of the Moho and upper mantle in oceanic lithosphere formed at a fast spreading rate.

Our mission comprises five targets (Fig. 1; Table 1) :

1) Drill as deeply as possible using riserless technology into intact ocean crust formed at a superfast spreading rate at Site 1256, while developing and testing light pipe and km-scale casing technology;

2) Exploit with shallow (<500 m) riserless drilling the tectonic window provided at Hess Deep to sample lower oceanic crust and serpentinized upper mantle in fast-spread lithosphere;

3) Drill as deeply as possible using riserless technology in Hole 1309D at the Mid-Atlantic Ridge, to gain essential experience in drilling hot plutonic oceanic crust, extend our knowledge of lower crustal accretion processes at slow-spreading ridges, and possibly sample *in situ* fresh mantle rocks;

4) Deep riserless, followed by riser drilling at Atlantis Bank on the Southwest Indian Ridge to test slow-spread-crust crustal models, including a possible role for serpentinization in forming the Moho, and to test the techniques for riser drilling of oceanic lithosphere;

5) Drill an entire, intact section of crust and upper mantle in oceanic lithosphere formed at a fast spreading rate – The MoHole.

Although the optimal location for the MoHole has not yet been determined, the criteria for selecting a site are well established. Knowledge gained from drilling targets 1 through 4 coupled with regional and detailed geophysical site surveys will be integrated to refine the exact site for the MoHole, if Site 1256 is found to be unsuitable.

	Site 1256	Hess Deep	Atlantis Massif	Atlantis Bank	The MoHole
Location, age, spreading rate	EPR, 15 Ma Superfast	EPR, <1 Ma Fast	MAR, ~2 Ma Slow	SWIR, 12 Ma Ultraslow	Eastern Pac. Fast - Superfast
Previous drilling Legs / Exp.	206, 309, 312. Upper crustal section (lavas, dikes, ~100m of gabbroic rocks)	147. Upper mantle peridotites, and upper crust gabbros	304, 305. ~1.4 km of gabbroic rocks and troctolite	118, 176, 179. ~1.5 km of gabbroic rocks	
Goals	• *In situ* upper crust gabbros to cumulate gabbros • Test limits of deep riserless drilling , >500 m then as deep as possible	• Tectonically exposed lower crust, upper mantle, and crust/mantle boundary	• Slow-spread lower crust, Moho and uppermost mantle • Test limitations of drilling in hot plutonic crust	• Ultraslow-spread lower crust, Moho, and uppermost mantle • Test riser drilling in bare rocks	• Complete, *in situ* section through ocean crust, to the Moho and the uppermost mantle
Vessel	SODV	SODV	SODV	SODV + Chikyu	SODV + Chikyu
Estimated # of Expeditions	2 to 6	1 to 2	1 to 2	4 to 6? to be determined	12 to 20? to be determined
Proposal status	522-Full5 forwarded to OTF in March 2007	551-Full at IODP SAS, Scheduled site survey cruise (RRS James Cook; Jan 2008)	To be submitted Oct, 2007. Proposed geophysical project inc. 3D seismics	535-Full5/Add2 not ranked by SPC in March 2007. To be resubmitted Apr, 2007	
Readiness of drill site	Immediate Cased re-entry cone installed, Hole 1256D open to depth	2 years	Immediate Cased re-entry cone installed, Hole U1309D open to depth	Immediate New hole required	7 to 10 years
Requirements	HT coring and logging	Re-entry cones	HT coring and logging	Riserless - Riser operations	Site surveys and selection, 4500 m riser

Table 1 - Summary of Mission Moho Targets and Operations

Complementary to Mission Mohole is the Oman Drilling Project, currently in the form of a proposal to the International Continental Scientific Drilling Program to drill a series of offset holes to obtain a complete crustal section of the Oman ophiolite. Drilling in Oman has various advantages; for example, relatively inexpensive wireline diamond drilling techniques, which can rapidly obtain very high recovery within 500 meter to 2 km drill holes, can be used on land where engineering challenges such as heave compensation are not necessary. Most relevant from the point of view of Mission Mohole is the opportunity, in Oman, to directly test the reliability of inferences based on a single core sample through layered but laterally heterogeneous crust and upper mantle. In the Oman ophiolite, where there are excellent outcrop exposures through much of the crust and mantle section, we can develop statistical techniques for estimating the uncertainty of 1D measurements through 3D crust.

4.1. Non-riser drilling of intact ocean crust formed at a superfast spreading rate (Hole 1256D, eastern equatorial Pacific)

Site 1256 (Fig. 1) is in the eastern equatorial Pacific, on 15 Ma old crust of the Cocos plate that formed at superfast spreading rate (Wilson, 1996). Based on the inverse relationship between spreading rate and depth to axial low velocity zones, inferred to be axial melt lenses (Purdy et al., 1992), Site 1256 was selected to provide the best chance of reaching gabbros at the shallowest depth. After three expeditions, Hole 1256D sampled a dike-gabbro transition zone (Wilson et al., 2006). The gabbros have compositions similar to the overlying lavas and dikes. Cumulate rocks have not yet been sampled and seismic velocities are characteristic of Layer 2. Hole 1256D was left clear of debris and open to its full depth (1507 mbsf).

IODP engineers evaluated Hole 1256D as being in good condition and caution against premature attempts to install further casing. Their suggested hole deepening strategy utilizes very large mud-sweeps (100-150 bls) to clear debris and remove cuttings from the hole. ODP and IODP experience suggests that drilling through gabbro will be less challenging than the extremely hard, brittle lithologies of the lower sheeted dikes. We propose that Hole 1256D be deepened as far as possible. Should Hole 1256D fail, depending on the nature of that failure, we advocate continued deep drilling at Site 1256 following a more conservative casing strategy to define the limits of riserless drilling in intact ocean crust.

IODP proposal 522-Full5, recently evaluated by the SAS and forwarded to the OTF at the March 2007 SPC, proposes to drill >500 m further into the upper part of the gabbro section. This will be the first step of non-riser operations at Site 1256 under Mission Moho and will provide important constraints on the accretion and hydrothermal cooling of oceanic gabbros.

4.2. Shallow, non- riser drilling of lower crust outcrops in Hess Deep

Our understanding of accretion mechanisms for fast-spread lower oceanic crust is severely limited by our inability to access it directly, and by the limited number of accessible tectonic windows in fast-spread crust. Hess Deep, located at the western tip of the Cocos-Nazca ridge (Fig. 1), is the only known place on Earth where a substantial section of fast-spreading lower crust and shallow mantle is exposed. This ‘natural laboratory’ is a high priority target for future investigations. The Cocos-Nazca ridge is propagating westward at a rate comparable to the half spreading rate of the EPR (~65 mm/yr); hence young (~1Ma) lithosphere generated at the EPR is being rifted ahead of the advancing Cocos-Nazca ridge. Submersible studies have shown that tectonically dismembered crustal section is exposed. Well studied sections of intact upper crust, from the upper gabbros to the lava sequence, outcrop along the northern scarp bounding Hess Deep and reveal significant lateral variability in crustal structure and hydrothermal alteration (Francheteau et al., 1990; Karson et al. 1992; Karson et al., 2002). ODP Leg 147 (Gillis et al., 1993) recovered serpentinized upper mantle peridotite at Site 895, and gabbro from the upper plutonic section at Site 894. Further drilling will sample the middle and lower crust and uppermost mantle, to yield a composite section of fast spreading rate crust formed at the East Pacific Rise. IODP Proposal 551Full, has been externally reviewed and currently resides within IODP SAS, awaiting further site survey, which will be undertaken by a UK-funded expedition on RRS *James Cook* in Jan-Feb 2008.

4.3. Non-riser drilling in young, slow-spread crust in Hole U1309D (Atlantis Massif, Mid-Atlantic Ridge).

Two of the four deepest (>1km) holes in oceanic crust have been drilled in oceanic core complexes. These are bathymetric highs exhumed by shallow dipping detachment faults (e.g., Tucholke and Lin, 1994; Cann et al., 1997), located in relatively volcanic-poor, inside corners where transform faults intersect slow-spreading ridges (Atlantis Bank, Southwest Indian Ridge, and Atlantis Massif, Mid-Atlantic Ridge; Fig. 1).

On the Atlantis Massif, Hole U1309D penetrated 1415.5 m of the footwall of the central dome. It is dominantly gabbroic, and includes a large proportion of primitive cumulates, unlike previous ODP sites (Blackman et al., 2006). Although some olivine-rich troctolites sampled may be produced by reaction of melt with mantle peridotite (Drouin et al., 2007), the dominantly gabbroic nature of Hole U1309D (Blackman et al., 2006; Ildefonse et al., 2007a) is inconsistent with the initial hypothesis developed from seismic observations (Collins et al., 2003; Blackman et al., 2002; Canales et al., 2004) that the core of the Atlantis Massif is dominantly composed of fresh mantle peridotite at relatively shallow (~800 m) depths. Re-assessment of seismic and gravity data show that alternative interpretations are compatible with a gabbroic core (Blackman, pers. comm.). To refine the prediction that significant amounts of fresh peridotite occurs at relatively shallow depth, a proposal for further integrated geophysical experiments including 3D seismic imaging of the Atlantis Massif has been recently submitted by Blackman et al. A proposal to return to Atlantis Massif to deepen Hole U1309D, is expected to be submitted in October 2007. Hole U1309D is open and in good condition. Because of its young age (~2 My), this site may be above 300°C at depths greater than 2-3 km. Continuing this hole as far as possible with current, non-riser technology will provide valuable experience with drilling hot crust, as well as scientific rewards.

4.4. The lower crust and Moho at the slow-spreading end-member (Atlantis Bank, Southwest Indian Ridge)

The deepest hole drilled into slow-spread crust is the 1508-m ODP Hole 735B, on the Atlantis Bank (Fig. 1), adjacent to the Atlantis II transform and ~90 km south of the active Southwest Indian Ridge. Hole 735B recovered a series gabbroic rocks, dominated by olivine gabbro, gabbro, and oxide gabbro (Dick et al., 2000). Unfortunately, Hole 735B was lost through drill string failure, and deeper drilling at this site will require starting a new hole. IODP Proposal 535-Full5 is to drill ~6 km into the Atlantis Bank 2 km NE of Hole 735B (see 535-Full5, 535-Add2) to determine the crustal architecture and the nature of the Moho (see section 3.1 and Fig. 3). The shallow bathymetry (700 m) makes Atlantis Bank an accessible target for testing whether low seismic velocities deeper than 3000 mbsf result from serpentinized peridotite (Muller et al., 1997).

4.5. The MoHole – complete sampling of crust and upper mantle in ocean lithosphere formed at fast spreading rates (Site to be determined)

The desirable characteristics for deep drilling intact oceanic lithosphere were summarized by the ODP "Architecture of the Lithosphere" Proposal Planning Group (see www.iodp.org/ocean-lithosphere/#5), and refined at the Mission Moho workshop: **(1)** Water depth within riser capability (4000 to 4500 m, see below); **(2)** Age > 15 Ma, preferably >20 Ma, limiting temperature of the upper mantle to <200°C; **(3)** A weather window of at least 8-9 months (preferably all year); **(4)** Formation at fastest available spreading rate (>80 mm/yr), with continuously layered structure, limited deformation on abyssal-hill faults, and low to moderate thickness of the dike layer, where experience indicates difficult drilling conditions; **(5)** Simple and well-understood tectonic setting away from seamounts, plate boundaries or fracture zones; **(6)** Well-imaged Moho, from high-angle MCS data and wide-angle reflection-refraction data; **(7)** Sediment thickness as needed to support riser hardware (minimum thickness of ~ 50 m); **(8)** An original latitude >±15° to provide a favorable geometry for understanding marine magnetic anomalies; **(9)** Location close to major ports, preferably in international waters or the EEZ of an IODP member country; and **(10)** Slightly below-average crustal thickness (~5.5 km, minimizing temperature at depth, weight of the drill string, and total drilling time).

There are no regions that satisfy all of the desirable criteria. The key trade off is between the relatively shallow water depth (<4500 m) required for enhanced riser drilling and high temperatures in the upper mantle (>250°C) in young relatively shallow oceanic crust (Fig. 7). Site 1256 meets most of the criteria, but the age of 15 Ma implies that temperature at Moho is ~ 250°C, which is outside the experience of scientific ocean drilling in deep holes. Although Site 1256 is currently the best-known site for full penetration of the crust, the search for, and evaluation of, potential alternative sites will continue.

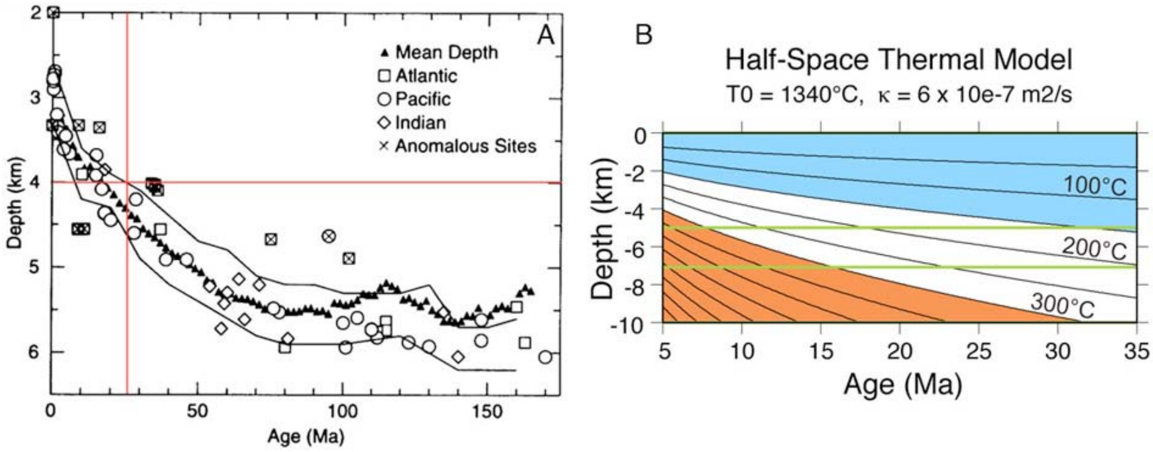

Fig. 7 - [A] Seafloor depth Vs age (Carlson and Johnson, 1994). Note that most of the crust subsides to more than 4000 m depth by ~25 Ma. [B] Half-space thermal model (Davis and Lister, 1974; Turcotte and Schubert, 1982) of impermeable ocean crust showing that at 6 km, cooling below 200°C occurs after ~25 Ma. These two diagrams illustrate the inherent difficulty for any site to be "ideal", i.e. both shallow and cold.

There are very few seismic studies that image the Moho in the potential target areas (see Fig. 8 in section 5). Most are old data collected with obsolete techniques, and the characterization of other potential MoHole sites will require additional seismic surveys.

White et al.'s (1992) review of the thickness of normal oceanic crust lists six profiles at five sites in the Pacific Ocean for ages of 10-100 Ma. Crustal thicknesses inferred from synthetic seismogram modeling at these sites range from 5.8 to 6.8 km. A long MCS transect about 300 km north of the Clipperton fracture zone (Eittreim et al, 1994) shows Moho reflections at least intermittently over most of the profile, bright and generally continuous for crustal ages 18-32 Ma, with uniform (~6 km) crustal thickness. Crustal thickness determined by recent refraction work on the Cocos plate at both Site 1256 (15 Ma; Hallenborg et al., 2003; Shipboard Scientific Party, 2003; Wilson et al., 2003) and offshore Nicaragua (23 Ma; Walther et al., 2000) is about 5.5 km.

5. TECHNOLOGICAL DEVELOPMENTS FOR MISSION MOHO

Technology development will be a key component of Mission Moho. Although many of the preliminary targets of Mission Moho can be achieved using current, non-riser technology, drilling completely through intact oceanic crust, through the Moho and into the uppermost mantle will require a drill hole in excess of 6 km. This will probably require riser drilling technology to surpass the depth limit for riserless drilling, below which maintaining borehole stability requires controlled mud circulation. This limit is unknown. The deepest penetration to date with riserless drilling is 2.2 km. IODP's riser vessel, D/V *Chikyu* is currently configured for operations to 2500 meter water depth. There are plans to construct a ~4000 meter riser as one of five domestic science and technology high priorities of the Japanese Government, and this riser will be available to IODP within the next decade. A 4500 meter riser will considerably increase the availability of potential deep crustal sites (see section 5.2, and Fig. 8). In addition, there are a host of smaller technical innovations, such as use of lighter drill pipe, which can extend the depth capability of both riser and riserless ocean drilling. The scientific rewards yielded by a successful MoHole make a compelling case for the required technological developments. Importantly, many of our sites may require drilling by both the USIO-riserless vessel and D/V *Chikyu* and technological developments are required to best utilize these vessels to accomplish the aims of Mission Moho.

5.1. Protocols for D/V Chikyu occupation of holes initiated by riserless vessel

It will often be more cost and time effective if initial drilling at some sites is undertaken by the riserless drillship before occupation and deepening by D/V *Chikyu*. This will be the case for holes started in water depths beyond the current design capability of D/V *Chikyu* (>2500 m) and most probably for holes spudded into bare-rock (e.g., Atlantis Bank). The development of the required technical protocols that allow the riserless vessel and D/V *Chikyu* to work in concert will be of great use to many ocean drilling experiments in addition to Mission Moho. Standard methods need to be developed so that such operations are routine.

5.2. Rationale for extending the RV Chikyu riser capability to 4500 meters

Sites that satisfy the deep-drilling criteria listed above are extremely rare in water depths of 4000 meters or less. In fact, no site has been identified to date. A ~20-Ma site at 4000 meters depth would, in fact, be anomalously shallow (Fig. 7). A 4500-meter riser (Fig. 8) would allow drilling in deeper water, which equates directly to drilling in older, lower temperature crust (<200°C for crust older than ~20 Ma; Fig. 7).

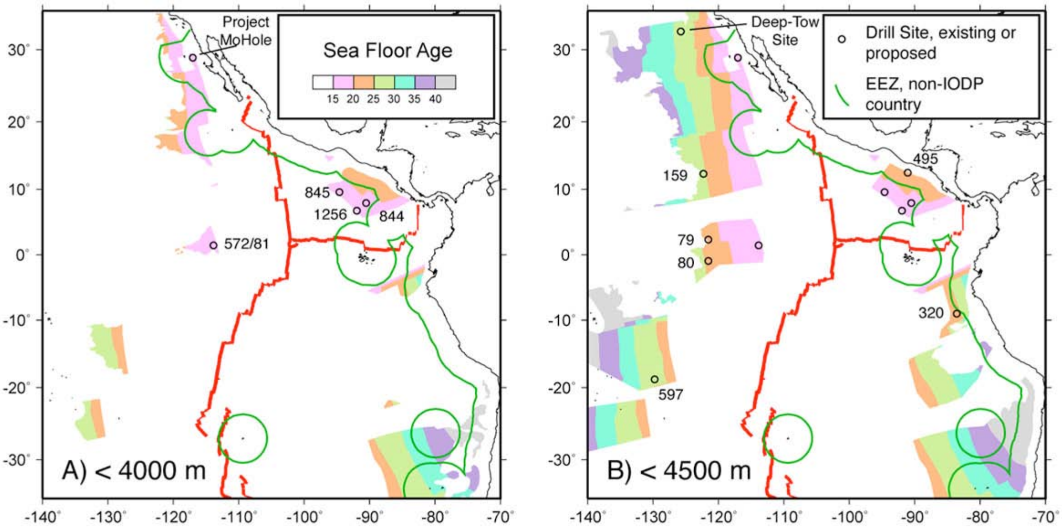

Fig. 8 - Possible drilling areas for the Chikyu in the eastern Pacific, depending on the riser depth capability. Colored areas correspond to well mapped and tectonically simple crust, older than 15 Ma, and less than 4000 meters (A) or less than 4500 meters (B). The drillable area with a 4500 m riser is about 2.6 times larger than for a 4000 m riser. Existing sites shown in the possible drilling areas all reach basement; Deep-tow site is from Larson (1996).

Drilling in older crust can also provide a longer time-integrated record of hydrothermal exchange between the oceans and the oceanic crust. This would enhance our ability to quantify the chemical and physical evolution of oceanic crust, estimate the impact of hydrothermal exchange on global chemical cycles, and estimate inputs to the mantle from subducted crust. Drilling in deeper water greatly increases the area of ocean floor available for identifying the MoHole (Fig. 8), allowing more astute site selection and maximizing chances for success.

5.3. Development of high temperature borehole measurement and sampling tools

During deep drilling of the oceanic lithosphere we will encounter temperatures beyond the tolerance of current geophysical and sampling tools. Data and samples collected from such instruments will be essential to address many of the scientific questions highlighted above.

Structural observations and measurements are imperative to answer fundamental questions about magmatic accretion and mantle flow. It is essential to be able to reorient cores in a geographic reference frame. Hard rock core orientation would be the ideal solution. However, although this goal is articulated in the IODP-USIO and EDP technology roadmaps, an effective system has yet to be designed or tested. In the absence of a core orientation system, borehole imaging provided by FMS (or equivalent) becomes critical. Borehole seismic measurements are essential to calibrate the regional geophysical data to define the crustal layering and the Moho itself. Also essential is a gyroscopically oriented wireline 3-component magnetometer to re-orient cores to the geographic reference frame and for estimating the relative contributions of various lithologies to marine magnetic anomalies.

In-situ fluid and gas sampling, to obtain deep crustal and mantle volatiles (e.g., CO_2, He) is highly desirable. This could be achieved through the development of wireline sampling tools or from the analysis of the circulating riser mud into which significant volumes of volatiles may be released by drilling-induced fracturing. Real time volatile analysis, similar to that performed during KTB or SAFOD drilling (Wiersberg and Erzinger, 2007), should be implemented during riser drilling operations in the MoHole.

Most logging tools used for hydrocarbon exploration have operational temperature limits of ~175°C although some tools are built for HPHT environments (220 to 260°C). Cable heads are routinely rated to 175°C, but can be constructed for >300°C and the cables themselves are rated to ~320°C. Beyond this, downhole measurements can only be recorded by memory tools (~400°C). Geothermal research in Iceland is pushing the temperature limits for wireline tools beyond 250°C and the new EU-sponsored HiTl 400°C memory tool is soon to be tested.

Although wireline logging in the deep holes of Mission Moho will require tool development and collaboration with industry, it seems likely that logging down to 200-300°C deep into the oceanic lithosphere will to be feasible in the near future.

Technology development will be a key component of Mission Moho planning, and the stage-1 core Mission Team will play a key role in scoping out the various aspects of the Mission, such as downhole tool development, and borehole management strategy while drilling (including monitoring and modeling) and between expeditions.

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Positions
• 1989-1991: Swiss National Fond fellowship, ETH Zürich
• 1991-1995: "Chargé de Recherches 2° classe " CNRS, France
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Main research topic :
Formation, deformation and alteration of oceanic lithosphere.

Science animation and management
• Editorial board "Visual Geosciences" (Springer) (1999-)
• Coordinator of Oceanic Lithosphere research theme in CNRS UMR 5243 (Géosciences Montpellier)
• Vice-president (2002-) of the search committee "Commission de Spécialistes des 34ème et 35ème sections du CNU" at Université Montpellier 2
• Member of the "Commission de Spécialistes de la 35ème secion du CNU" at Université Lyon 1 (2004-)
• Member of ISSEP (1999-2002), SciCom et ExCom (2003), iPC/SPC (2003-2006), OTF (2005-2006), ESSAC (2003-) in ODP & IODP
• Chairman of IODP-France (Oct 2003-); Vice-chairman of ODP-France (Oct 2001-2003)
• Chairman of InterRidge "Deep Earth Sampling" Working Group (2004-)
• Co-chairman of Steering Committee of IODP-JOI-InterRidge-R2000 workshop "Mission Moho" (2006)

Fieldwork and Cruises
• 1985 to 1990 : Fieldwork in Italian and French Alps
• 1991 to 1999, 2007 : Fieldwork in the Oman Ophiolite
• 1997 : ODP Leg 176 (R/V Joides Resolution), Return to 735B. Atlantis bank, SWIR.
• 2000 : MANAUTE cruise (R/V L'Atalante + Nautile). Manus Basin. New Starmer Program.
• 2001 : SWIFT cruise (R/V Marion Dufresne). SWIR.
• 2003 : ODP Leg 209 (R/V joides Resolution), Mid-Atlantic Ridge Peridotites.
• 2005 : IODP Expedition 305 (R/V Joides Resolution), Oceanic Core Complex, Atlantis Massif. *Co-chief Scientist*

Recent Funded Projects
• NSF-CNRS project "GEOman" (Geophysical Experiment in Oman), with W. Wilcock (Washington University, Seattle), D. Toomey (University of Oregon, Eugene) and S. Constable (Scripps Institute of Oceanography, San Diego).
• Procope/Dorsales project, on physical properties of partially molten gabbros (with N. Bagdassarov, Gesteinsphysiklabor, Institut für meteorologie und geophysik, J.W.Goethe Universität Frankfurt, Germany)
• CNRS-INSU-"Intérieur de la Terre" project on viscosity of silicate melts and attenuation in partially molten rocks (mantle and oceanic crust).
• CNRS-INSU-"DyETI" project : "Atténuation sismique et tomographie du manteau supérieur en domaines océaniques".
• Participation to CNRS-INSU-“DyETI” project on serpentines (ODP Leg 209 post-cruise research).
• CNRS-INSU-"DyETI" project : "Accrétion et subduction de la croûte océanique. Exemple de l’Atlantique Nord et de la marge active Nord Caraïbes" (IODP Expeditions 304/305 post-cruise research).

Public Outreach Activities

• Scientific program of Excursion for high-school teachers in the Oman ophiolite (1996-1997)
• Design and maintenance of web sites for the laboratoire de Tectonophysique (1997-98), ODP-France, and IODP-France (2001-)
• Participation to the french "Fête de la science" (2001, 2004, 2006. Conferences, Participation to the exhibition "Recherche en Languedoc-Roussillon, Arrêt sur Images", …)
• Conferences on Ocean Drilling (Bordeaux, 2005; Montpellier, 2006, Grenoble 2006)
• Press interviews for IODP-France/ECORD
• Project with 2 classes of elementary school (children from 8 to 10 years old) during IODP Expedition 305. Web page in IODP-France.org ("IODP à l'école")
• ECORD Distinguished lecturer, 2007

Selected publications related to Ocean drilling

• Dick, H.J.B., et al., 2000. A long in-situ section of the lower ocean crust: results of ODP Leg 176 drilling at the Southwest Indian Ridge. Earth and Planetary Science Letters. 179 : 31-51.
• Ildefonse, B. and Pezard, P.A., 2001. Electrical properties of slow-spreading ridge gabbros from ODP site 735, Southwest Indian Ridge. Tectonophysics. 330: 69-92.
• Ildefonse, B., Dick, H. and Cannat, M., 2002. Sampling the Lower Crust at the Slow-Spreading, Southwest Indian Ridge. In White, K. and Urquhart, E. (Eds.), ODP's Greatest Hits, Volume 2. Available from World Wide Web: http://www.joiscience.org/greatesthits2/pdfs/ildefonse.pdf.
• Blackman, D.K., Ildefonse, B., John, B.E., Ohara, Y., Miller, D.J., MacLeod, C.J., and the Expedition 304/305 Scientists, 2006. Proc. IODP, 304/305: College Station TX (Integrated Ocean Drilling Program Management International, Inc.). doi:10.2204/iodp.proc.304305.2006
• Bach, W., H. Paulick, C. J. Garrido, B. Ildefonse, W. P. Meurer, and S. E. Humphris (2006), Unraveling the sequence of serpentinization reactions: petrography, mineral chemistry, and petrophysics of serpentinites from MAR 15°N (ODP Leg 209, Site 1274), Geophys. Res. Lett., 33, L13306, doi:10.1029/2006GL025681.
• Ildefonse, B., Blackman, D.K., john, B.E., Ohara, Y., Miller, D.J., MacLeod, C.J., and the IODP Expeditions 304-305 Scientists, 2006. IODP Expeditions 304 & 305 Characterize the Lithology, Structure, and Alteration of an Oceanic Core Complex. Scientific Drilling, 3, 4-11, doi:10.2204/iodp.sd.3.01.2006.
• Dick, H.J.B., Natland, J.H., and Ildefonse, 2006. Past and Future Impact of Deep Drilling in the Ocean Crust and Mantle : An Evolving Order Out of New Complexity. Oceanography, 19 (4) : 72-80.
• Christie, D.M., Ildefonse, B., Abe, N., Arai, S., Bach, W., Blackman, D.K., Duncan, R., Hooft, E., Humphris, S.E., and Miller, D.J., 2006. Meeting report. Mission Moho : Formation and Evolution of Oceanic Lithosphere. Eos, Trans., AGU, 87 (48), 539.
• Ildefonse, B., Christie, D.M., Abe, N., Arai, S., Bach, W., Blackman, D.K., Duncan, R., Hooft, E., Humphris, S.E., and Miller, D.J., 2006. Meeting report : Mission Moho - Formation and Evolution of Oceanic Lithosphere. InterRidge News, 15 : 54-56.
• Christie, D.M., Ildefonse, B., et al., 2006. Mission Moho - Formation and Evolution of Oceanic Lithosphere. Full workshop Report. Portland, Sept 2006, www.iodp.org/ocean-lithosphere.
• Ildefonse, B., Christie, D.M., and Mission Moho Workshop Steering Committee, 2007. Mission Moho workshop : drilling through the oceanic crust to the Mantle. Scientific Drilling, 4:11-18. doi:10.2204/iodp.sd.4.02.2007.
• Ildefonse, B., Rona, P.A., and Blackman, D.K., 2007. Deep Sampling of the Crust formed at Mid-Ocean Ridges : Scientific Ocean Drilling provides perspective 'in-depth'. Oceanography, 20(1) : 22-33.
• Ildefonse, B., Blackman, D.K., John, B.E., Ohara, Y., Miller, D.J., MacLeod, C.J., and the Expedition 304/305 Scientists, 2007. Oceanic Core Complexes and Crustal Accretion at Slow-Spreading Ridges. Geology, in press.

CURRICULUM VITAE

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QUALIFICATIONS:

1997 Ph.D. Kanazawa University Department of Earth Sciences
1994 M.Sc. Kanazawa University Department of Earth Sciences
1992 B.Sc. Kanazawa University Department of Earth Sciences

WORK EXPERIENCES:

2003 March to present: Research Scientist, Institute for Research on Earth Evolution (IFREE), Japan Agency for Marine-Earth Science and Technology (JAMSTEC)
2001 March-2003 February: JSPS Postdoctoral Fellowships for Research Abroad, National Key Centre for GEMOC, Macquarie University
2000 March-2001 May: Macquarie University Research Fellow. National Key Centre for GEMOC, Macquarie University
1998 April-2000 March: Research Technician, Department of Earth & Planetary Sciences, Tokyo Institute of Technology
1997 April-1998 March: Part-time lecturer, Yamanashi Univ.

ODP and IODP EXPERIENCES:

2006 November SSEP in Sapporo alternate
2005 January – March: IODP Exp. 305 “Oceanic Core Complex” Igneous petrologist
2003 May – July: ODP Leg 209 “MAR Peridotite” Igneous petrologist
1997 April – June: ODP Leg 173 “Return to Iberia” Petrologist

MAIN INTEREST & CURRENT PROJECT:

Petrology and geochemistry of lithospheric mantle and its role in Earth evolution. Comprehensive study of Petitspot volcanism in the northwestern Pacific: a plate flexure induced volcanism.

SELECTED PUBLICATIONS:

Arai, S., Abe, N. and Ishimaru, S. (2007) Mantle peridotites from the Western Pacific, *Gondwana Rresearch*, 11, 180-199
Hirano, N., E. Takahashi, J. Yamamoto, N. Abe, S.P. Ingle, I. Kaneoka, T. Hirata, J.-I. Kimura, T. Ishii, Y. Ogawa, S. Machida and K. Suyehiro (2006) Volcanism in response to plate flexure. *Science*, **313**, 1426- 1429.

Michibayashi, K., N. Abe, A. Okamoto, T. Satsukawa and K. Michikura (2006) Seismic anisotropy in the uppermost mantle, back-arc region of the northeast Japan arc: petrophysical analyses of Ichinomegata peridotite xenoliths. *Geophys. Research. Lett.* **33**, L10312, doi: 10.1029/2006GL025812.

Abe, N. and S. Arai (2005) Petrography and Geochemistry of the mantle xenoliths: Implications for lithospheric mantle beneath the Japan arcs. *Japanese Magazine of Mineralogical and Petrological Sciences.*, **34** 133-142. (in Japanese with English abstract).

Abe, N., M. Takami and S. Arai (2003) Petrological feature of spinel lherzolite xenolith from Oki-Dogo Island: an implication for variety of the upper mantle peridotite beneath southwest Japan, *The Island Arc*, **12**, 219-232.

Griffin, W.L., S.Y. O'Reilly, N. Abe, S. Aulbach, R.M. Davies, N.J. Pearson, B.J. Doyle and K. Kivi (2003) The origin and evolution of Archean lithospheric mantle, *Precanbrian Research.*, **127**, 19-41.

Arai, S. and N. Abe (2003) Petrological model of sub-oceanic mantle and its bearing on the scientific strategy for IODP, *J. Geography*, **112**, 692-704. (in Japanese with English abstract).

Abe, N. and S. Arai (2001) Comments on "Garnet-bearing spinel herzburgite xenolith from Arato-yama alkali basalt, southwest Japan." By Yamamoto et al., *Japanese Magazine of Mineralogical and Petrological Sciences.*, **30** 190-193. (in Japanese with English abstract).

Uesugi, J., S. Arai, T. Morishita, K. Matsukage, K. Kadoshima, A. Tamura and N. Abe (2003) Significance and variety of mantle-crust boundary in the Oman Ophiolite, *J. Geography*, **112**, 750-768. (in Japanese with English abstract).

Abe, N. (2001) Petrochemistry of serpentinized peridotite from the Iberia Abyssal Plain (ODP Leg 173); its character intermediate between sub-oceanic and sub-continental upper mantle peridotite. *Geol. Soc. Special Publication*: Non-volcanic rifting of continental margins: a comparison of evidence from land and Sea. Eds. Whitmash & Wilson. **187**, 143-159.

Abe, N., S. Arai and H. Yurimoto (1999) Texture-dependent geochemical variations of sub-arc mantle peridotite from Japan arcs. *7th International Kimberlite Conference Proceedings.* 13-22.

Abe, N., S. Arai and H. Yurimoto (1998) Geochemical characteristics of the uppermost mantle beneath the Japanese island arcs: implications for upper mantle evolution. *Physics Earth Planet. Interiors* **107**, 1-3, 233-247.

Arai, S. and N. Abe (1996) Detrital minerals in surface sediments from Hess Deep, equatorial Pacific: implication for the lithological spread of mafic-ultramafic rock. *Proc. ODP, Sci. Results* **147**, 451-457.

Arai, S. and N. Abe (1995) Reaction of orthopyroxene in peridotite xenoliths with alkali basalt melt and its implication for genesis of alpine-type chromitite. *American Mineralogist*, **80**, 1041-1047.

WORKSHOP CONVENOR:

1. Mission Moho Workshop. September 8-10, 2006. Portland, USA
2. Mohole WS in Japan I,II &III. July 22-23, October 21-22, 2006 & March 26-27, 2007. Tokyo, Japan
3. JKOD-2006 Niigata: Japan-Korea Symposium. April 29-30, 2006. Niigata, Japan

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Education

1987 Ph.D., University of Washington. Thesis advisor: Dr. Bernard Evans. Assimilation of Ultramafic Rock in Fractionating Magma.
1985 M.Sc., University of Washington. Research Project advisor: Dr. Bernard Evans. Geology of the Big Jim Complex, Washington Cascades.
1980 A.B. cum laude, with high distinction in Earth Sciences, Dartmouth College.

Academic Employment & Awards

2006– present	Fellow, Mineralogical Society of America
2004– present	**Arthur D. Storke Memorial Professor**, Dept. of Earth & Environmental Sciences, Columbia University and Lamont Doherty Earth Observatory; **Associate Research Scientist**, Dept. of Earth and Planetary Sciences, American Museum of Natural History; **Adjunct Scientist**, Woods Hole Oceanographic Institution; **Fellow**, American Geophysical Union; **Research Fellow**, Explorer's Club
2004	Bowen Award, Volcanology, Geochemistry, Petrology Section, AGU
2003	Co-Chief Scientist, Ocean Drilling Program Leg 209 (May-June 2003)
2001-05	Charles Francis Adams Chair, Woods Hole Oceanographic Institution
2000-04	Senior Scientist, Woods Hole Oceanographic Institution
1997-00	Tenured Associate Scientist, Woods Hole Oceanographic Institution
1994-97	Associate Scientist, Woods Hole Oceanographic Institution
1993	Visiting Scientist, CNRS Centre Géologique et Géophysique, Montpellier, France
1990-94	Assistant Scientist, Woods Hole Oceanographic Institution
1990	Postdoctoral Investigator, Woods Hole Oceanographic Institution
1990	Visiting Assistant Professor of Earth Sciences, Dartmouth College
1988-90	Postdoctoral Scholar, Woods Hole Oceanographic Institution
1986-87	Research Assistant, University of Washington
1982-86	NSF Graduate Fellow, University of Washington

Selected publications, 2001-present

Behn, MD, G Hirth, PB Kelemen, Lower crustal foundering as a mechanism for trench parallel seismic anisotropy below volcanic arcs, Science, submitted.
Kelemen, PB, E Kikawa, DJ Miller, Shipboard Scientific Party, Igneous crystallization and localized deformation in a thick thermal boundary layer beneath the Mid-Atlantic Ridge: Major results from ODP Leg 209, Nature, in revision.
Kelemen, PB, E Kikawa, DJ Miller, Shipboard Scientific Party, Summary of post-cruise scientific research, ODP Leg 209: Processes in a 20 kilometer thick conductive boundary layer beneath the Mid-Atlantic Ridge, 14 to 16°N, ODP Scientific Results, submitted.
Bernstein, S, PB Kelemen, K Hanghøj, Depleted cratonic mantle is residue from melting of upwelling mantle in the Archaean, Geology, in press.
Grimes, CB, BE John, PB Kelemen, FK Mazdab, JL Wooden, MJ Cheadle, K Hanghøj, The trace element chemistry of zircons from oceanic crust: A method for distinguishing detrital zircon provenance, Geology, in press.
Kelemen, PB, G Hirth, A periodic shear-heating mechanism for intermediate depth earthquakes in the mantle, Nature, in press.
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Behn, MD, PB Kelemen, The stability of arc lower crust: Insights from the Talkeetna Arc section, south-central Alaska and the seismic structure of modern arcs, J. Geophys. Res. 111, B11207, doi:10.1029/2006JB004327.

Bernstein, S, K Hanghøj, PB Kelemen, CK Brooks, Ultra-depleted, shallow cratonic mantle beneath West Greenland: Dunitic xenoliths from Ubekendt Ejland, Contrib. Mineral. Petrol., 152, 335-347 (2006)

Greene, AR, SM DeBari, PB Kelemen, J Blusztajn, PD Clift, A detailed geochemical study of island arc crust: The Talkeetna Arc section, South-central Alaska, J Petrol. 47, 1051-1093, 2006.

Clift, PD, AE Draut, PB Kelemen, J Blusztajn, A Greene, J Trop, Stratigraphic and geochemical evolution of the Jurassic Talkeetna Volcanic Formation, south central Alaska, GSA Bull. 117, 902-925, 2005.

Kelemen, PB, Kikawa, E, Miller, DJ, et al., 2004. Proc. ODP, Init. Repts., 209 [Online]. http://www-odp.tamu.edu/publications/209_IR/209ir.htm, 2004.

Behn, MD, PB Kelemen, Relationship between seismic velocity and the composition of anhydrous igneous and meta-igneous rocks, Geochemistry, Geophysics, Geosystems (G-cubed), 2002GC000393, 2003.

Kelemen, PB, K Hanghøj, AR Greene, One view of the geochemistry of subduction-related magmatic arcs with an emphasis on primitive andesite and lower crust, in The Crust, (R.L. Rudnick, ed.), Vol. 3, Treatise on Geochemistry, (H.D. Holland, K.K. Turekian, eds.), Elsevier-Pergamon, Oxford, 593-659, 2003.

Kelemen, PB, GM Yogodzinski, DW Scholl, Along-strike variation in lavas of the Aleutian island arc: Implications for the genesis of high Mg# andesite and the continental crust, in Inside the Subduction Factory, AGU Monograph 138, (J. Eiler, ed.), 223-276, 2003.

Kelemen, PB, JL Rilling, EM Parmentier, L. Mehl, B.R. Hacker, Thermal structure due to solid-state flow in the mantle wedge beneath arcs, in Inside the Subduction Factory, AGU Monograph 138, (J. Eiler, ed.), 293-311, 2003.

Mehl, L, BR Hacker, G Hirth, PB Kelemen Arc-parallel flow within the mantle wedge: Evidence from the accreted Talkeetna arc, south central Alaska, J Geophys Res 108, 2002JB002233, 2003

Spiegelman, M, PB Kelemen, Extreme chemical variability as a consequence of channelized melt transport, Geochemistry, Geophysics, Geosystems (G-cubed), 2002GC000336, 2003

Braun, MG, PB. Kelemen, Dunite distribution in the Oman ophiolite: Implications for melt flux through porous dunite conduits, Geochemistry, Geophysics, Geosystems (G-cubed), 2001GC000289, 2002.

Jull, M, PB Kelemen, K Sims, Consequences of diffuse and channelled porous melt migration on U-series disequilibria, Geochim. Cosmochim. Acta 66, 4133–4148, 2002.

Korenaga, J, PB Kelemen, WS Holbrook, Methods for resolving the origin of large igneous provinces from crustal seismology, J. Geophys. Res., 107, 2001JB001030, 2002.

Schouten, H, PB Kelemen, Evidence for a process of lava segregation by viscosity on the upper flanks of the Paleo-Troodos Rise, Cyprus, Earth Planet. Sci. Lett.201, 337-352, 2002.

Garrido, CJ, PB Kelemen, G Hirth, Variation of cooling rate with depth in lower crust formed at an oceanic spreading ridge: Plagioclase crystal size distributions in gabbros from the Oman ophiolite, Geochemistry, Geophysics, Geosystems (G-cubed), 2000GC000136, 2001.

Hanghøj, K, P Kelemen, S Bernstein, J Blusztajn, R Frei, Osmium isotopes in the Wiedemann Fjord mantle xenoliths, a unique record of cratonic mantle formation by melt depletion in the Archaean, Geochemistry, Geophysics, Geosystems (G-cubed), 2000GC000085, 2001

Jull, M, PB Kelemen, On the conditions for lower crustal convective instability, J. Geophys. Res. 106, 6423-6446, 2001.

Koga, K, PB Kelemen, N Shimizu, Petrogenesis of the crust-mantle transition zone (MTZ) and the origin of lower crustal wehrlite in the Oman Ophiolite, Geochemistry, Geophysics, Geosystems (G-cubed), 2000GC000132, 2001.

Korenaga, J, WS Holbrook, R Detrick, PB Kelemen, Gravity anomalies and crustal architecture at the southeast Greenland margin, J. Geophys. Res. 106, 8853-8870, 2001.

Müntener, O, PB Kelemen, TL Grove , The role of H_2O and composition on the genesis of igneous pyroxenites: An experimental study, Contrib. Mineral. Petrol. 141, 643-658, 2001.

Spiegelman, M, PB Kelemen, E Aharonov, Causes and consequences of flow organization during melt transport: The Reaction infiltration instability, J. Geophys. Res.106 , 2061-2078, 2001.

Curriculum Vitae

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Education and Qualifications:

1999 Ph.D. Dept. Earth and Planetary Physics, University of Tokyo. Thesis supervisor: Professor Ichiro Kaneoka. "Variation of noble gas signatures controlled by tectonic conditions and magmatic processes: a case study for an area around the Rodriguez Triple Junction in the Indian Ocean."

1995 M.Sc. Dept. Earth and Planetary Physics, University of Tokyo. Thesis supervisor: Professor Ichiro Kaneoka.

1993 B.Sc. Dept. Geophysics, University of Tokyo.

Career Background/History:

2000-date Research Scientist, JAMSTEC

2002-2003 Guest Investigator, Woods Hole Oceanographic Institution

1999-2000 Contract Researcher, Earthquake Research Institute, University of Tokyo

1997-1999 JSPS Research Fellow (DC2)

Expertise:

Isotope Geochemistry, Marine Volcanology

Selected Synergistic Activity:

- Onshore isotope investigations related with IODP Leg#304 and #305
- 10 oceanographic expeditions during 1995-2006 and 2 as a chief scientist or as an associate chief scientist
- Session co-convenor of Ocean Floor Geosciences, Joint Meeting of Earth and Planetary Sciences 2001

Selected Publications:

Geshi, N., Umino, S., Kumagai, H., Sinton J. M. , White, S., Kisimoto, K. and Hilde, T. W. (2007) Multiple plumbing system of a $24km^3$ off-axis lava field on the flank of East Pacific Rise 14°S. Earth Planet. Sci. Lett., accepted.

Takai, K., Nakamura, K., Suzuki, K., Inagaki, F., Nealson, K. H., and Kumagai, H. (2006) Ultramafics-Hydrothermalism-Hydrogenesis-HyperSLiME ($UltraH^3$) linkage: a key insight into early microbial ecosystem in the Archean deep-sea hydrothermal systems. *Paleontological Res*. 10, 269-282.

White, S. M., Umino S. and Kumagai, H. (2006) Transition from Seamount Chain to Intra-plate Volcanic Ridge at the East Pacific Rise, *Geology*, 34(4), 293–296.

Kumagai, H. and Kaneoka, I. (2005) Noble gas signatures around the Rodriguez Triple Junction in the Indian Ocean - Constraints on magma genesis in a ridge system, *Geochim. Cosmochim. Acta*, 69, 5567-5583.

Sumino, H., Yamamoto, J. and Kumagai, H. (2005) Noble gas studies of mantle-derived xenoliths: mantle metasomatism revealed by noble gas isotopes - a review, *Japanese Magazine of Mineralogical and Petrological Sciences*, 34, 173-185.

Kumagai, H. Dick, H.J.B. and Kaneoka, I. (2003), Noble gas signatures of abyssal gabbros and peridotites at an Indian Ocean core complex, *G-cubed*, 4, paper # 9107, doi: 10.1029/2003GC000540.

Matsumoto, T., Miyashita, S., Arai, S., Morishita, T., Maeda, J-i., Kumagai,H., Ohtomo,Y. and Dick,H.J.B.(2003), Magmatism and "Crust-mantle boundary" on the ultra-slow spreading ridge as observed in Atlantis Bank, Southwest Indian ridge (in Japanese with English abstr.), *J. Geogr.*, 112(5), 705-719.

Kumagai, H. and Kaneoka, I.(2003), Relationship between submarine MORB glass textures and atmospheric component of MORBs, *Chem. Geol*., 200,1-24.

Kumagai, H. and Kaneoka, I.(1998), Variations of noble gas abundances and isotope ratios in a single MORB pillow, *Geophys. Res. Lett.*, 25, 3891-3894.

Kumagai, H., Kaneoka, I. and Ishii, T.(1996), The active period of the Ayu Trough estimated from K-Ar ages: the southeastern spreading center of Philippine Sea Plate, *Geochem. J.*, 30, 81-87.

BIOGRAPHICAL SKETCH

DAMON A.H. TEAGLE

PLACE AND DATE OF BIRTH:

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CURRENT POSITION: (SINCE FEB 2004)

University Reader in Geochemistry and Mineralization.
School of Ocean and Earth Science, National Oceanography Centre,
University of Southampton, SO14-3ZH, Southampton, UK.

POSTS HELD:

1999-2004 University Lecturer, School of Ocean and Earth Science, Southampton Oceanography Centre, University of Southampton
1997-1999 Assistant Research Scientist, Dept. Geological Sciences, Univ. Michigan
1993-1997 Post-doctoral Research Fellow, Dept. of Geological Sciences, Univ. Michigan

DEGREES HELD:

1993 Ph.D., Earth Sciences, University of Cambridge, UK.
1987 M.Sc (with Distinction), Geology, University of Otago, New Zealand
1985 B.Sc (Hons.), Geology, University of Otago, New Zealand

SHIPBOARD/OCEAN DRILLING PROJECT EXPERIENCE:

CO-I RRS *James Cook* JC021 – Hess Deep Site Survey, Jan-Feb, 2008
Co-I RRS *James Cook* JC018 – Monserrat – Ash-Seawater Interactions, Dec, 2007
Petrologist, IODP Expedition 312, Superfast 3
Co-chief Scientist on IODP Expedition 309, Superfast 2
Co-chief Scientist on ODP Leg 206 Superfast Spreading Rate Crust
Petrologist, ODP Leg 183, Kerguelen Plateau
Petrologist, ODP Leg 169, Sedimented Ridges II; Middle Valley, Escanaba Trough.
Low-T. Geochemist/Alteration Petrologist, ODP Leg 163, SE Greenland Margin
Shore-based scientist, ODP Leg 158, TAG Hydrothermal Mound
Metamorphic petrologist, Ocean Drilling Program Leg 148, Costa Rica Rift
2000 – 2006: UK representative on ODP/IODP Science Steering Evaluation Panel
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PROFESSIONAL SOCIETIES:

American Geophysical Union
Geological Society of New Zealand
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RESEARCH INTERESTS:

Hydrothermal alteration in mid-ocean ridges and ophiolites; Modeling of fluid-rock tracer exchange; Global chemical cycles; Radiogenic isotope and trace element analysis.; Metamorphogenic gold deposits.

AWARDS, PRIZES AND SCHOLARSHIPS:

1995 Sokol Postdoctoral Fellowship, University of Michigan.
1991 Cambridge Philosophical Society Research Studentship.
1988 William Georgetti Scholarship for Social, Cultural and Economic Development of New Zealand
1988 Commonwealth Scholarship (Cambridge).
1987 Kendall Postgraduate Bursary of Science, Churchill College, Cambridge.
1987 Cambridge Commonwealth Trust Overseas Student Bursary.
1987 Overseas Research Student Award - Committee of Vice-Chancellors and Principals of the Universities of the United Kingdom.
1986 James Park Scholarship in Economic Geology (University of Otago).

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POST-DOCTORAL MENTORS:

Prof. Jeffrey C. Alt,	Geological Sciences, University of Michigan.
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RECENT PUBLICATIONS

Alt, J.C., and **Teagle**, D.A.H., 2003 Hydrothermal alteration of upper oceanic crust formed at a fast-spreading ridge: mineral, chemical, and isotopic evidence from ODP Site 801. Chem. Geol. 201:191-211.

Chan, L.H., Alt, J.C., **Teagle**, D.A.H., 2002. Lithium and Lithium isotope profiles through the upper oceanic crust: a study of seawater-basalt exchange at ODP Sites 504B and 896A. Earth Planet. Sci. Letts. 201:187-201.

Coggon, R.M., **Teagle**, D.A.H., Cooper, M.J., Vanko, D.A., 2004. Linking basement carbonate vein compositions to porewater geochemistry across the eastern flank of the Juan de Fuca Ridge, ODP Leg 168. Earth Planet. Sci. Lett., 219:111-128.

Davis, A.C., Bickle, M.J., **Teagle**, D.A.H., 2003. Imbalance in the oceanic strontium budget. Earth Planet. Sci. Lett. 211:173-187.

Nielsen S. G., Rehkämper M., **Teagle**, D. A. H., Butterfield D. A., Alt J. C., and Halliday A. N. 2006 Hydrothermal fluid fluxes calculated from the isotopic mass balance of thallium in the ocean crust. Earth Planet. Sci Lett 251, 120-133.

Paul H. J., Gillis, K. M., Coggon, R. M., **Teagle**, D. A. H., 2006, ODP Site 1224: A missing link in the investigation of seafloor weathering, Geochem. Geophys. Geosyst., 7, Q02003, doi:10.1029/2005GC001089.

Pitcairn, I.K., **Teagle**, D.A.H., Kerrich, R., Craw, D. and Brewer, T.S., 2005. The behavior of nitrogen and nitrogen isotopes during metamorphism and mineralization: Evidence from the Otago and Alpine Schists, New Zealand. Earth Planet. Sci. Lett. 233:229-246.

Révillon S., **Teagle**, D. A. H., Boulvais, P., Shafer, J., Neal, C. R., 2007, Geochemical fluxes related to alteration of a subaerially exposed seamount: Nintoku seamount, ODP Leg 197, Site 1205, Geochem. Geophys. Geosyst., 8, Q02014, doi:10.1029/2006GC001400.

Teagle D. A. H., Alt J. C., Umino S., Miyashita S., Banerjee N. R., Wilson D. S., and Expedition 309/312 Scientists. 2006. Proc. IODP 309/312 Exp. Repts. "Superfast 2 and 3 – An intact section of ocean crust formed at a superfast spreading rate" Integrated Ocean Drilling Program Management International, Inc. (DVD)

Teagle, D.A.H., Wilson, D.S., Acton, G.D., and the ODP Shipboard Party, 2004. The "Road to the MoHole" for decades on: Deep drilling at Site 1256. EOS Trans. Am. Geophys. Union, 85(49):521,530-531.

Teagle, D.A.H. and Alt, J.C., 2004. Hydrothermal alteration of basalts beneath the Bent Hill Massive Sulfide Deposit, Middle Valley, Juan de Fuca Ridge. Econ. Geol. 99:561-584

Teagle, D.A.H., Bickle, M.J., and Alt, J.C., 2003. Recharge flux to ocean-ridge black smoker systems: a geochemical estimate from ODP Hole 504B. Earth Planet. Sci. Lett. 210:81-89.

Wilson, D.S., **Teagle**, D.A.H. and Acton, G.D., et al. 2003. An in situ section of upper oceanic crust formed at a superfast spreading rate. Proc. ODP Init. Res. 206

Wilson D. S., **Teagle** D. A. H., Alt J. C., Banerjee N. R., Umino S., Miyashita S., Acton G. D., et al., 2006 Drilling to gabbro in intact ocean crust. Science 312, 1016-1020.

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Professional Experience:
Associate Research Geophysicist, University of California, Santa Barbara, 1993-present.
Assistant Research Geophysicist, University of California, Santa Barbara, 1988-1993.
Geophysicist, U.S. Geological Survey, 1987.
Research Associate, National Research Council/USGS, 1985-1987.
Research and Teaching Assistant, Stanford University, 1981-1985.
Research Associate, Hawaii Institute of Geophysics, 1979-1981.
Teaching and Research Assistant, Stanford University, 1977-1978.
Undergraduate Research Asst, Lamont-Doherty Geological Observatory, summer, 1976.

Recent seagoing experience:
2005 D/V JOIDES Resolution, Guatemala Basin (IODP Expeditions 309 & 312)
2004 RVIB N.B. Palmer, Ross Sea (Co-chief Scientist)
2002 D/V JOIDES Resolution, Guatemala Basin (Co-chief Scientist for ODP Leg 206)
1999 R/V M. Ewing, Guatemala Basin (Chief Scientist for ODP site survey)

Selected publications:
Wilson, D. S., D. A. Clague, N. H. Sleep, and J. L. Morton, Implications of magma convection for the size and temperature of magma chambers at fast spreading ridges, *J. Geophys. Res., 93,* 11,974-11,984, 1988.
Wilson, D. S., Focused mantle upwelling beneath mid-ocean ridges: evidence from seamount formation and isostatic compensation of topography, *Earth Planet. Sci. Lett., 113,* 41-55, 1992.
Wilson, D. S. Confirmation of the astronomical calibration of the magnetic polarity time scale from rates of sea-floor spreading, *Nature, 364,* 788-790, 1993.
Wilson, D. S. and R. N. Hey, History of rift propagation and magnetization intensity for the Cocos-Nazca spreading center, *J. Geophys. Res., 100,* 10,041-10,056, 1995.
Cormier, M. H., K. C. Macdonald, and D. S. Wilson, A three-dimensional gravity analysis of the East Pacific Rise from 18° to 20°30'S, *J. Geophys. Res., 100,* 8063-8082, 1995.
Hallenborg, E., A.J. Harding, G.M. Kent, and D.S. Wilson, Seismic Structure of 15 Ma Oceanic Crust Formed at an Ultra-fast Spreading East Pacific Rise: Evidence for Kilometer-scale Fracturing from Dipping Reflectors, *J. Geophys. Res.*, *108*, B11, 2532, doi:10.1029/2003JB002400, 2003.
Wilson, D.S., D.A.H. Teagle, G.D. Acton, et al., 1. Leg 206 Summary, *Proc. ODP, Init. Repts, v. 206,* pp 1-117, D.S. Wilson, D.A.H. Teagle, and G.D. Acton, eds., 2003

Lourens, L., F.J. Hilgen, J. Laskar, N.J. Shackleton, and D. Wilson, The Neogene Period, in *A Geologic Time Scale 2004*, ed. F. Gradstein, J. Ogg, and A. Smith, Cambridge Univ. Press, pp. 409-440, 2005.

Wilson, D.S., P.A. McCrory, and R.G. Stanley, Implications of volcanism in coastal California for the Neogene deformation history of western North America, *Tectonics, 24(3),* TC3008, doi:10.1029/2003TC001621, 2005.

Wilson, D.S., D.A.H. Teagle, J.C. Alt, N.R. Banerjee, S. Umino, S. Miyashita, and 45 others, Drilling to gabbro in intact ocean crust, *Science, 312*, 1016–1020, 2006.

Synergystic activities:
Member, JOIDES (ODP) Lithosphere Panel, 1992-1995
Member, NSF review panel, Marine Geology and Geophysics, 1992-1994, 1998-2001, 2004.
Guest editor, G-cubed, Fast-spread ocean crust theme, 2005-present.

Long-term and recent collaborators (not UCSB): Patricia McCrory, Richard Stanely (USGS); Charles DeMets (U Wisconsin); Alistair Harding, Graham Kent (UCSD); Louis Bartek (UNC); John Diebold (LDEO/Columbia), Christine Siddoway (Colorado Col.); Gary Acton, Kari Cooper (UC Davis), Jeff Alt (U. Michigan), David Christie (U. Alaska); Emilio Herrero-Bervera, Stephanie Ingle (U. Hawaii); Steven Swift (WHOI), Anahita Tikku (RPI), D. Teagle (Southampton), I. Grevemeyer (Bremen); F. Hilgen, H. Abdul Aziz, L. Lourens (U. Utrecht); J Maclennan (Cambridge); J. Carlut (ENS-Paris).

Co-editors: Damon Teagle (Southampton), Gary Acton (UC Davis), Dave Vanko (Towson U.)

Graduate Advisors: Allan V. Cox (deceased), Norman H. Sleep (Stanford)
Postdoctoral Sponsor: David W. Scholl (USGS & Stanford)

Graduate Students and Postdoctoral Scholars: Primary advisor (none); Dissertation committee member (11 total) for Laura Perram (PhD. 1990; now Santa Cruz, CA), Suzanne Carbotte (PhD. 1992; LDEO), Marie-Helene Cormier (PhD. 1994; U. Missouri), Daniel Scheirer (PhD. 1994, USGS), Charles Weiland (PhD. 1995; Stanford), Scott White (PhD. 2001, U. So. Carolina), David W. Valentine (PhD. 2003; UCSD), Robert West (PhD. 2004; East L.A. Col.), Kathleen Gans (M.S. 2001; USGS), Jeff Blasius (M.S. 2003; Yale), Robert Decesari (PhD. 2006; ExxonMobil).

IODP Site Summary Forms:

Form 1 - General Site Information

Please fill out information in all gray boxes
Revised 7 March 2002

New ✓ **Revised** ☐

Section A: Proposal Information

Title of Proposal:	Mission Moho
Date Form Submitted:	1st April, 2007
Site Specific Objectives with Priority (Must include general objectives in proposal)	Hole 1256D (Proposal 522-Full5) Continued drilling as deep as feasible using non-riser technology. The hole is presently at 1507m. First stage : Proposal 522-Full5
List Previous Drilling in Area:	Sediment in ODP Holes 1256A,B, and C; 1257 m basement in Hole 1256D and 88.5 m basement in Hole 1256C (Leg 206); Sediment at Sites 83, 503, 844, and 845, Legs 9, 68, and 138

Section B: General Site Information

Site Name: (e.g. SWPAC-01A)	GUATB-03C (ODP/IODP Site 1256)	If site is a reoccupation of an old DSDP/ODP Site, Please include former Site #	Area or Location:	Guatemala Basin, Eastern Pacific Ocean
Latitude:	Deg: 6°N	Min: 44.2'	Jurisdiction:	International
Longitude:	Deg: 91°W	Min: 56.1'	Distance to Land:	700 km
Coordinates System:	WGS 84,	Other ( )		
Priority of Site:	Primary: X	Alt:	Water Depth:	3635 m

Section C: Operational Information

	Sediments	Basement
Proposed Penetration: (m)	n/a What is the total sed. thickness? 250 m	Maximum feasible penetration using non-riser drilling
		Total Penetration: m
General Lithologies:	gabbros	
Coring Plan: *(Specify or check)*	1-2-3-APC [ ] VPC* [ ] XCB [ ] MDCB* [ ] PCS [ ] RCB [x] Re-entry [x] HRGB [ ] ** Systems Currently Under Development*	

Wireline Logging Plan:

Standard Tools		Special Tools				LWD	
Neutron-Porosity	[x]	Borehole Televiewer	[x]	Formation Fluid Sampling	[x]	Density-Neutron	[ ]
Litho-Density	[x]	Nuclear Magnetic Resonance	[ ]	Borehole Temperature & Pressure	[x]	Resistivity-Gamma Ray	[ ]
Gamma Ray	[x]	Geochemical	[x]	Borehole Seismic	[x]	Acoustic	[ ]
Resistivity	[x]	Side-Wall Core Sampling	[ ]				
Acoustic	[x]						
Formation Image	[x]			Others ( )		Others ( )	

Max.Borehole Temp. : *Expected value (For Riser Drilling)* ≥250 °C

Mud Logging: *(Riser Holes Only)*

Cuttings Sampling Intervals

from ________ m to ________ m, ________ m intervals

from ________ m to ________ m, ________ m intervals

Basic Sampling Intervals: 5m

Estimated days:	Drilling/Coring:	Logging:	Total On-Site: unknown

Future Plan: *Longterm Borehole Observation Plan/Re-entry Plan*

Hazards/ Weather:

Please check following List of Potential Hazards

Shallow Gas	[ ]	Complicated Seabed Condition	[ ]	Hydrothermal Activity	[ ]
Hydrocarbon	[ ]	Soft Seabed	[ ]	Landslide and Turbidity Current	[ ]
Shallow Water Flow	[ ]	Currents	[ ]	Methane Hydrate	[ ]
Abnormal Pressure	[ ]	Fractured Zone	[ ]	Diapir and Mud Volcano	[ ]
Man-made Objects	[ ]	Fault	[ ]	High Temperature	[x]
H_2S	[ ]	High Dip Angle	[ ]	Ice Conditions	[ ]
CO_2	[ ]				

What is your Weather window? (Preferable period with the reasons)

The weather window is open all year.

IODP Site Summary Forms:

Form 1 - General Site Information

Please fill out information in all gray boxes
Revised 7 March 2002

New ✓ **Revised** ☐

Section A: Proposal Information

Title of Proposal:	Mission Moho
Date Form Submitted:	1st April, 2007
Site Specific Objectives with Priority (Must include general objectives in proposal)	Hess Deep (Proposal 551-Full) To sample middle-crust plutonic rocks that formed at the fast-spreading East Pacific Rise
List Previous Drilling in Area:	ODP Leg 147; Site 894 drilled ~4.5 km NNE

Section B: General Site Information

Site Name: (e.g. SWPAC-01A)	HD-01A	If site is a reoccupation of an old DSDP/ODP Site, Please include former Site #	Area or Location:	Hess Deep, eastern equatorial Pacific Ocean
Latitude:	Deg: 2°N	Min: 16.2'	Jurisdiction:	International
Longitude:	Deg: 101°W	Min: 31.8'	Distance to Land:	~1400 nm (Panama City)
Coordinates System:	WGS 84,	Other ( )		
Priority of Site:	Primary: X	Alt:	Water Depth:	4400 m

Section C: Operational Information

	Sediments	Basement
Proposed Penetration: (m)	<30 m What is the total sed. thickness? <30 m	< 500 m
		Total Penetration: <500 m
General Lithologies:	Pelagic ooze, gabbroic rocks	
Coring Plan: *(Specify or check)*	1-2-3-APC □ VPC* □ XCB □ MDCB* □ PCS □ RCB ■ Re-entry ■ HRGB □ ** Systems Currently Under Development*	

Wireline Logging Plan:

Standard Tools		Special Tools				LWD	
Neutron-Porosity	■	Borehole Televiewer	□	Formation Fluid Sampling	□	Density-Neutron	□
Litho-Density	■	Nuclear Magnetic Resonance	□	Borehole Temperature & Pressure	□	Resistivity-Gamma Ray	□
Gamma Ray	■	Geochemical	□	Borehole Seismic	□	Acoustic	□
Resistivity	■	Side-Wall Core Sampling	□				
Acoustic	■						
Formation Image	■			Others ( )		Others ( )	

Max.Borehole Temp. : *Expected value (For Riser Drilling)* ______________ °C

Mud Logging: *(Riser Holes Only)*

Cuttings Sampling Intervals

from __________ m to __________ m, ___________ m intervals

from __________ m to __________ m, ___________ m intervals

Basic Sampling Intervals: 5m

Estimated days:	Drilling/Coring: 16	Logging: 1.5	Total On-Site: 17.5

Future Plan: *Longterm Borehole Observation Plan/Re-entry Plan*

Hazards/ Weather:

Please check following List of Potential Hazards

Shallow Gas	□	Complicated Seabed Condition	■	Hydrothermal Activity	□
Hydrocarbon	□	Soft Seabed	□	Landslide and Turbidity Current	□
Shallow Water Flow	□	Currents	□	Methane Hydrate	□
Abnormal Pressure	□	Fractured Zone	■	Diapir and Mud Volcano	□
Man-made Objects	□	Fault	□	High Temperature	□
H_2S	□	High Dip Angle	□	Ice Conditions	□
CO_2	□				

What is your Weather window? (Preferable period with the reasons)

The weather window is open all year.

IODP Site Summary Forms:

Form 1 - General Site Information

Please fill out information in all gray boxes
Revised 7 March 2002

New ✓ Revised

Section A: Proposal Information

Title of Proposal:	Mission Moho
Date Form Submitted:	1st April, 2007
Site Specific Objectives with Priority (Must include general objectives in proposal)	Hess Deep (Proposal 551-Full) To sample lower-crust plutonic rocks that formed at the fast-spreading East Pacific Rise
List Previous Drilling in Area:	ODP Leg 147; Site 894 drilled ~4.5 km NNE

Section B: General Site Information

Site Name: (e.g. SWPAC-01A)	HD-02A	If site is a reoccupation of an old DSDP/ODP Site, Please include former Site #	Area or Location:	Hess Deep, eastern equatorial Pacific Ocean
Latitude:	Deg: 2°N	Min: 15.5'	Jurisdiction:	International
Longitude:	Deg: 101°W	Min: 31.8'	Distance to Land:	~1400 nm (Panama City)
Coordinates System:	WGS 84,	Other ( )		
Priority of Site:	Primary: X	Alt:	Water Depth:	4600 m

Section C: Operational Information

	Sediments	Basement
Proposed Penetration: (m)	<30 m What is the total sed. thickness? <30 m	< 500 m
		Total Penetration: <500 m
General Lithologies:	Pelagic ooze, gabbroic rocks	
Coring Plan: (Specify or check)	1-2-3-APC ☐ VPC* ☐ XCB ☐ MDCB* ☐ PCS ☐ RCB ■ Re-entry ■ HRGB ☐ * Systems Currently Under Development	

Wireline Logging Plan:

Standard Tools		Special Tools				LWD	
Neutron-Porosity	■	Borehole Televiewer	☐	Formation Fluid Sampling	☐	Density-Neutron	☐
Litho-Density	■	Nuclear Magnetic Resonance	☐	Borehole Temperature & Pressure	☐	Resistivity-Gamma Ray	☐
Gamma Ray	■	Geochemical	☐	Borehole Seismic	☐	Acoustic	☐
Resistivity	■	Side-Wall Core Sampling	☐				
Acoustic	■						
Formation Image	■			Others ( )		Others ( )	

Max.Borehole Temp. : *Expected value (For Riser Drilling)* ___________ °C

Mud Logging: *(Riser Holes Only)*

Cuttings Sampling Intervals

from _________ m to _________ m, __________ m intervals

from _________ m to _________ m, __________ m intervals

Basic Sampling Intervals: 5m

Estimated days:	Drilling/Coring: 16	Logging: 1.5	Total On-Site: 17.5

Future Plan: *Longterm Borehole Observation Plan/Re-entry Plan*

Hazards/ Weather:

Please check following List of Potential Hazards

Shallow Gas	☐	Complicated Seabed Condition	■	Hydrothermal Activity	☐
Hydrocarbon	☐	Soft Seabed	☐	Landslide and Turbidity Current	☐
Shallow Water Flow	☐	Currents	☐	Methane Hydrate	☐
Abnormal Pressure	☐	Fractured Zone	■	Diapir and Mud Volcano	☐
Man-made Objects	☐	Fault	☐	High Temperature	☐
H_2S	☐	High Dip Angle	☐	Ice Conditions	☐
CO_2	☐				

What is your Weather window? (Preferable period with the reasons)

The weather window is open all year.

IODP Site Summary Forms:

Form 1 - General Site Information

Please fill out information in all gray boxes
Revised 7 March 2002

New ✓ **Revised** ☐

Section A: Proposal Information

Title of Proposal:	Mission Moho
Date Form Submitted:	1st April, 2007
Site Specific Objectives with Priority (Must include general objectives in proposal)	Hess Deep (Proposal 551-Full) To sample lower-crust plutonic rocks that formed at the fast-spreading East Pacific Rise
List Previous Drilling in Area:	ODP Leg 147; Site 894 drilled ~4.5 km NNE

Section B: General Site Information

Site Name: (e.g. SWPAC-01A)	HD-03A	If site is a reoccupation of an old DSDP/ODP Site, Please include former Site #	Area or Location:	Hess Deep, eastern equatorial Pacific Ocean
Latitude:	Deg: 2°N	Min: 15.0'	Jurisdiction:	International
Longitude:	Deg: 101°W	Min: 31.8'	Distance to Land:	~1400 nm (Panama City)
Coordinates System:	WGS 84,	Other ( )		
Priority of Site:	Primary: X	Alt:	Water Depth:	4850 m

Section C: Operational Information

	Sediments		Basement
Proposed Penetration: (m)	<30 m		< 500 m
	What is the total sed. thickness? <30 m		
		Total Penetration:	<500 m

General Lithologies:	Pelagic ooze, gabbroic rocks	

Coring Plan: *(Specify or check)*

1-2-3-APC ☐ VPC* ☐ XCB ☐ MDCB* ☐ PCS ☐ RCB ■ Re-entry ■ HRGB ☐

** Systems Currently Under Development*

Wireline Logging Plan:

Standard Tools		Special Tools				LWD	
Neutron-Porosity	■	Borehole Televiewer	☐	Formation Fluid Sampling	☐	Density-Neutron	☐
Litho-Density	■	Nuclear Magnetic Resonance	☐	Borehole Temperature & Pressure	☐	Resistivity-Gamma Ray	☐
Gamma Ray	■	Geochemical	☐	Borehole Seismic	☐	Acoustic	☐
Resistivity	■	Side-Wall Core Sampling	☐				
Acoustic	■						
Formation Image	■			Others ( )		Others ( )	

Max.Borehole Temp. : *Expected value (For Riser Drilling)* ____________ °C

Mud Logging: *(Riser Holes Only)*

Cuttings Sampling Intervals

from ________ m to ________ m, ________ m intervals

from ________ m to ________ m, ________ m intervals

Basic Sampling Intervals: 5m

Estimated days:	Drilling/Coring: 16	Logging: 1.5	Total On-Site: 17.5

Future Plan: *Longterm Borehole Observation Plan/Re-entry Plan*

Hazards/ Weather:

Please check following List of Potential Hazards

Shallow Gas	☐	Complicated Seabed Condition	■	Hydrothermal Activity	☐
Hydrocarbon	☐	Soft Seabed	☐	Landslide and Turbidity Current	☐
Shallow Water Flow	☐	Currents	☐	Methane Hydrate	☐
Abnormal Pressure	☐	Fractured Zone	■	Diapir and Mud Volcano	☐
Man-made Objects	☐	Fault	☐	High Temperature	☐
H_2S	☐	High Dip Angle	☐	Ice Conditions	☐
CO_2	☐				

What is your Weather window? (Preferable period with the reasons)

The weather window is open all year.

IODP Site Summary Forms:

Form 1 - General Site Information

Please fill out information in all gray boxes
Revised 7 March 2002

New ✓ Revised

Section A: Proposal Information

Title of Proposal:	Mission Moho
Date Form Submitted:	1st April, 2007
Site Specific Objectives with Priority (Must include general objectives in proposal)	Hess Deep (Proposal 551-Full) To sample upper mantle ultramafic rocks from the fast-spreading East Pacific Rise
List Previous Drilling in Area:	ODP Leg 147; Site 895 drilled ~0.5 km S

Section B: General Site Information

Site Name: (e.g. SWPAC-01A)	HD-04A	If site is a reoccupation of an old DSDP/ODP Site, Please include former Site #	Area or Location:	Hess Deep, eastern equatorial Pacific Ocean
Latitude:	Deg: 2°N	Min: 16.7'	Jurisdiction:	International
Longitude:	Deg: 101°W	Min: 26.0'	Distance to Land:	~1400 nm (Panama City)
Coordinates System:	WGS 84,	Other ( )		
Priority of Site:	Primary:	Alt: X	Water Depth:	3900 m

Section C: Operational Information

	Sediments	Basement
Proposed Penetration: (m)	<30 m What is the total sed. thickness? <30 m	< 500 m
		Total Penetration: <500 m
General Lithologies:	Pelagic ooze, ultramafic rocks	
Coring Plan: *(Specify or check)*	1-2-3-APC ☐ VPC* ☐ XCB ☐ MDCB* ☐ PCS ☐ RCB ■ Re-entry ■ HRGB ☐ ** Systems Currently Under Development*	

Wireline Logging Plan:

Standard Tools		Special Tools				LWD	
Neutron-Porosity	■	Borehole Televiewer	☐	Formation Fluid Sampling	☐	Density-Neutron	☐
Litho-Density	■	Nuclear Magnetic Resonance	☐	Borehole Temperature & Pressure	☐	Resistivity-Gamma Ray	☐
Gamma Ray	■	Geochemical	☐	Borehole Seismic	☐	Acoustic	☐
Resistivity	■	Side-Wall Core Sampling	☐				
Acoustic	■						
Formation Image	■			Others ( )		Others ( )	

Max.Borehole Temp. : *Expected value (For Riser Drilling)* ____________ °C

Mud Logging: *(Riser Holes Only)*

Cuttings Sampling Intervals

from ________ m to ________ m, ________ m intervals

from ________ m to ________ m, ________ m intervals

Basic Sampling Intervals: 5m

Estimated days:

Drilling/Coring: 16	Logging: 1.5	Total On-Site: 17.5

Future Plan: *Longterm Borehole Observation Plan/Re-entry Plan*

Hazards/ Weather:

Please check following List of Potential Hazards

Shallow Gas	☐	Complicated Seabed Condition	■	Hydrothermal Activity	☐
Hydrocarbon	☐	Soft Seabed	☐	Landslide and Turbidity Current	☐
Shallow Water Flow	☐	Currents	☐	Methane Hydrate	☐
Abnormal Pressure	☐	Fractured Zone	■	Diapir and Mud Volcano	☐
Man-made Objects	☐	Fault	☐	High Temperature	☐
H_2S	☐	High Dip Angle	☐	Ice Conditions	☐
CO_2	☐				

What is your Weather window? (Preferable period with the reasons)

The weather window is open all year.

IODP Site Summary Forms:

Form 1 - General Site Information

Please fill out information in all gray boxes
Revised 7 March 2002

New ✓ **Revised**

Section A: Proposal Information

Title of Proposal:	Mission Moho
Date Form Submitted:	1st April, 2007
Site Specific Objectives with Priority (Must include general objectives in proposal)	Hole U1309D Continued drilling as deep as feasible using non-riser technology in the core of the Atlantis Massif. The hole is presently at 1415.5 m.
List Previous Drilling in Area:	Holes U1309A to H, U1310A and B, U1311A and B (IODP Exp. 304 & 305)

Section B: General Site Information

Site Name: (e.g. SWPAC-01A)	U1309 (AMFW-01A)	If site is a reoccupation of an old DSDP/ODP Site, Please include former Site #	Area or Location:	Mid-Atlantic Ridge at Atlantis Fracture Zone, north central Atlantic Ocean
Latitude:	Deg: 30°N	Min: 6'	Jurisdiction:	International
Longitude:	Deg: 42°W	Min: 0'	Distance to Land:	1500 nm to Azores
Coordinates System:	WGS 84,	Other ( )		
Priority of Site:	Primary: X	Alt:	Water Depth:	1645 m

Section C: Operational Information

	Sediments		Basement
Proposed Penetration: (m)	n/a What is the total sed. thickness? ~2 m		Maximum feasible penetration using non-riser drilling
		Total Penetration:	m
General Lithologies:	gabbros		
Coring Plan: *(Specify or check)*	1-2-3-APC ☐ VPC* ☐ XCB ☐ MDCB* ☐ PCS ☐ RCB ■ Re-entry ■ HRGB ☐ ** Systems Currently Under Development*		

Wireline Logging Plan:

Standard Tools		Special Tools				LWD	
Neutron-Porosity	■	Borehole Televiewer	■	Formation Fluid Sampling	■	Density-Neutron	☐
Litho-Density	■	Nuclear Magnetic Resonance	☐	Borehole Temperature & Pressure	■	Resistivity-Gamma Ray	☐
Gamma Ray	■	Geochemical	■	Borehole Seismic	■	Acoustic	☐
Resistivity	■	Side-Wall Core Sampling	☐				
Acoustic	■						
Formation Image	■			Others ( )		Others ( )	

Max.Borehole Temp. : *Expected value (For Riser Drilling)* ________ °C

Mud Logging: *(Riser Holes Only)*

Cuttings Sampling Intervals

from ________ m to ________ m, ________ m intervals

from ________ m to ________ m, ________ m intervals

Basic Sampling Intervals: 5m

Estimated days:

Drilling/Coring:	Logging:	Total On-Site: unknown

Future Plan: *Longterm Borehole Observation Plan/Re-entry Plan*

Hazards/ Weather:

Please check following List of Potential Hazards

Shallow Gas	☐	Complicated Seabed Condition	☐	Hydrothermal Activity	☐
Hydrocarbon	☐	Soft Seabed	☐	Landslide and Turbidity Current	☐
Shallow Water Flow	☐	Currents	☐	Methane Hydrate	☐
Abnormal Pressure	☐	Fractured Zone	☐	Diapir and Mud Volcano	☐
Man-made Objects	☐	Fault	☐	High Temperature	■
H_2S	☐	High Dip Angle	☐	Ice Conditions	☐
CO_2	☐				

What is your Weather window? (Preferable period with the reasons)

Avoid Sep-Nov

IODP Site Summary Forms:

Form 1 - General Site Information

Please fill out information in all gray boxes
Revised 7 March 2002

New ✓ Revised

Section A: Proposal Information

Title of Proposal:	Mission Moho
Date Form Submitted:	1st April, 2007
Site Specific Objectives with Priority (Must include general objectives in proposal)	Atlantis Bank Deep (Proposal 535-Full5/Add2) Nature of slow-spread lower crust, nature of the Moho at a location where it is has been suggested that, it is a serpentinization front, upper mantle
List Previous Drilling in Area:	Holes 735A and B (ODP Legs 118 & 176) Hole 1105A (ODP Leg 179)

Section B: General Site Information

Site Name: (e.g. SWPAC-01A)	AtBk-1A	If site is a reoccupation of an old DSDP/ODP Site, Please include former Site #	Area or Location:	Southwest Indian Ridge at AtlantisII Fracture Zone, Indian Ocean
Latitude:	Deg: 32°S	Min: 42.75'	Jurisdiction:	International
Longitude:	Deg: 57°E	Min: 17.1'	Distance to Land:	1380-km to Mauritius
Coordinates System:	WGS 84,	Other ( )		
Priority of Site:	Primary: X	Alt:	Water Depth:	700 m

Section C: Operational Information

	Sediments	Basement
Proposed Penetration: (m)	n/a What is the total sed. thickness? 0 m	~3000 non-riser 6000 riser
		Total Penetration: ≤6000 m

General Lithologies: Gabbroic rocks, serpentines (?), upper mantle

Coring Plan: *(Specify or check)*

1-2-3-APC ☐ VPC* ☐ XCB ☐ MDCB* ☐ PCS ☐ RCB ☒ Re-entry ☒ HRGB ☐

* *Systems Currently Under Development*

Wireline Logging Plan:

Standard Tools		Special Tools				LWD	
Neutron-Porosity	☒	Borehole Televiewer	☒	Formation Fluid Sampling	☒	Density-Neutron	☐
Litho-Density	☒	Nuclear Magnetic Resonance	☐	Borehole Temperature & Pressure	☒	Resistivity-Gamma Ray	☐
Gamma Ray	☒	Geochemical	☐	Borehole Seismic	☐	Acoustic	☐
Resistivity	☒	Side-Wall Core Sampling	☐				
Acoustic	☒						
Formation Image	☒			Others ( )		Others ( )	

Max.Borehole Temp. : *Expected value (For Riser Drilling)* ______________ °C

Mud Logging: *(Riser Holes Only)*

Cuttings Sampling Intervals

from __________ m to __________ m, ___________ m intervals

from __________ m to __________ m, ___________ m intervals

Basic Sampling Intervals: 5m

Estimated days:

Drilling/Coring:	Logging:	Total On-Site: to be determined

Future Plan: *Longterm Borehole Observation Plan/Re-entry Plan*

Hazards/ Weather:

Please check following List of Potential Hazards

Shallow Gas	☐	Complicated Seabed Condition	☐	Hydrothermal Activity	☐
Hydrocarbon	☐	Soft Seabed	☐	Landslide and Turbidity Current	☐
Shallow Water Flow	☐	Currents	☐	Methane Hydrate	☐
Abnormal Pressure	☐	Fractured Zone	☐	Diapir and Mud Volcano	☐
Man-made Objects	☐	Fault	☐	High Temperature	☐
H_2S	☐	High Dip Angle	☐	Ice Conditions	☐
CO_2	☐				

What is your Weather window? (Preferable period with the reasons)

Oct. through Feb.