International Ocean Discovery Program
Expedition 357 Scientific Prospectus

Atlantis Massif Serpentinization and Life

Microbiological, alteration, and tectono-magmatic processes in young mafic and ultramafic seafloor

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IODP
INTERNATIONAL OCEAN DISCOVERY PROGRAM

Publisher's notes

This publication was prepared by the International Ocean Discovery Program *JOIDES Resolution* Science Operator (IODP JRSO) as an account of work performed under the International Ocean Discovery Program. Funding for the program is provided by the following implementing organizations and international partners:

National Science Foundation (NSF), United States
Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan
European Consortium for Ocean Research Drilling (ECORD)
Ministry of Science and Technology (MOST), People's Republic of China
Korea Institute of Geoscience and Mineral Resources (KIGAM)
Australian-New Zealand IODP Consortium (ANZIC)
Ministry of Earth Sciences (MoES), India
Coordination for Improvement of Higher Education Personnel, Brazil (CAPES)

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Citation

Früh-Green, G.L., Orcutt, B.N., and Green, S., 2015. *Expedition 357 Scientific Prospectus: Atlantis Massif Serpentinization and Life*. International Ocean Discovery Program. http://dx.doi.org/10.14379/iodp.sp.327.2015

ISSN

World Wide Web: 2332-1385

June 2015

Abstract

International Ocean Discovery Program (IODP) Expedition 357 will be implemented as a Mission Specific Platform (MSP) expedition that will address two exciting discoveries in mid-ocean-ridge research: off-axis, serpentinite-hosted hydrothermal activity exemplified by the Lost City hydrothermal field (LCHF) and the significance of tectono-magmatic processes in forming and exposing heterogeneous mafic and variably serpentinized ultramafic lithosphere that are key components of slow- and ultraslow-spreading ridges. Serpentinization is a fundamental process that controls rheology and geophysical properties of the oceanic lithosphere and has major consequences for heat flux, geochemical cycles, and microbial activity in a wide variety of environments. However, we currently have no constraints on the nature and distribution of microbial communities in ultramafic subsurface environments. Our planned drilling focuses on (1) exploring the extent and activity of the subsurface biosphere in young ultramafic and mafic seafloor; (2) quantifying the role of serpentinization in driving hydrothermal systems, in sustaining microbiological communities, and in the sequestration of carbon in ultramafic rocks; (3) assessing how abiotic and biotic processes change with aging of the lithosphere and with variations in rock type; and (4) characterizing tectono-magmatic processes that lead to lithospheric heterogeneities and the evolution of hydrothermal activity associated with detachment faulting. This expedition will be the first IODP expedition to utilize seafloor drill technology (MeBo and BGS Seafloor Rockdrill 2) to core a series of shallow (50–80 m) holes across Atlantis Massif—an oceanic core complex (30°N, Mid-Atlantic Ridge), where detachment faulting exposes mafic and ultramafic lithologies on the seafloor. We aim to recover in situ sequences of sediments, hydrothermal deposits/veins, and basement rocks that comprise a broad zone of detachment faulting across (1) a spreading-parallel (east–west) profile along the southern wall and at varying distances from the LCHF and (2) a ridge-parallel (north–south) profile into the center of the massif, where the dominant rock type changes from ultramafic to mafic. Drilling the east–west profile will allow us to evaluate how microbial communities evolve with variations in hydrothermal activity and with age of emplacement on the seafloor. We aim to compare microbial activity and diversity in areas of diffuse, H_2-rich fluid flow and carbonate precipitation with communities in areas away from the active hydrothermal system and with variable substrates and crustal ages. By quantifying the extent and evolution of carbonate precipitation we will evaluate the potential for natural CO_2 sequestration in serpentinizing peridotites. Drilling the north–south profile will allow us to evaluate the nature of the deep biosphere in varying lithologies and to assess the role of the differing rheologies of gabbros and serpentinized ultramafic rocks in localizing detachment faults. This expedition will also include engineering developments to sample bottom waters before and after drilling and to monitor methane, dissolved oxygen, redox, conductivity, temperature, and depth while drilling. In addition, seafloor operations will include deploying borehole plugs and swellable packers to seal the holes at high-priority sites after drilling to provide opportunities for future hydrogeological and microbiological experiments.

Schedule for Expedition 357

Expedition 357 to Atlantis Massif in the Central Atlantic Ocean (Figure **F1**) is based on International Ocean Discovery Program (IODP) drilling Proposal #758-Full2. Following ranking by the IODP Science Advisory Structure, the expedition was scheduled by the European Consortium for Ocean Research Drilling (ECORD) Facility Board as a Mission Specific Platform (MSP) expedition to be implemented by the ECORD Science Operator (ESO). At the time of publication of this *Scientific Prospectus*, the expedition is scheduled for 24 October–9 December 2015, with a total of 30 days available for the drilling, coring, and downhole measurements described in this report and on the ESO Expedition 357 webpage. The Onshore Science Party is provisionally scheduled to start on 20 January 2016 and last for approximately 3 weeks (dependent on core recovery).

The following links should be used in conjunction with this *Scientific Prospectus*:

- The Expedition 357 webpage will be periodically updated with expedition-specific information on the platform, facilities, coring strategy, measurements plan, scheduling, and port call information: **http://www.eso.ecord.org/expeditions/357/357.php**
- General details about the offshore facilities provided by ESO are provided on the ESO-specific webpages on the MARUM website: **http://www.marum.de/en/Offshore_core_curation_and_measurements.html**
- General details about the onshore facilities provided by ESO are provided on the ESO-specific webpages on the MARUM website: **http://www.marum.de/Onshore_Science_Party_OSP.html**
- The supporting site survey data for Expedition 357 are archived in the IODP Site Survey Data Bank: **http://ssdb.iodp.org/SSDBquery/SSDBquery.php** (choose P758 in the Proposal Number selection box). Please note that not all site survey data associated with this expedition is publicly available.

Introduction

Drilling Atlantis Massif focuses on two important relatively recent discoveries in marine geosciences: off-axis, serpentinite-hosted fluid circulation as exemplified by the Lost City hydrothermal field (LCHF) and oceanic core complexes (OCCs) as major components of slow-spreading ridges. It is now estimated that 40% or more of the Atlantic Ocean floor has been formed by interlinked processes of asymmetric extension, magmatism, and detachment faulting that result in the exposure of mantle and lower crustal rocks in OCCs (Figure **F2**) (Dick et al., 2008; Cannat et al., 2006; Smith et al., 2006, 2008; Ildefonse et al., 2007; Escartín et al., 2008; Tucholke et al., 2008). OCCs incorporate highly reactive olivine-rich rocks that interact with seawater over a range of temperatures to produce both high-temperature (T) (Rainbow and Logatchev) and low-T (LCHF) hydrothermal systems (Douville et al., 1997, 2002; Charlou et al., 1998, 2002; Sagalevich et al., 2000; Kelley et al., 2005; McCaig et al., 2007). Chemical exchange between the mantle and the hydrosphere supports abundant microbial communities in regions of focused fluid discharge in both types of systems (Shrenk et al., 2004; Takai et al., 2004; Nercessian et al., 2005; Brazelton et al., 2006; Campbell et al., 2006; Perner et al., 2007). However, it is unknown whether active microbial communities are also sustained by fluid–rock interaction in the mantle-derived host rocks or in diffusely venting areas that surround focused-flow sites. At Atlantis Massif, we can study biogeochemical and tectono-magmatic processes related to three phases in the evolution of an OCC:

1. Serpentinization processes associated with active fluid discharge at the LCHF and the influence of serpentinization on microbial

communities in a range of environments, including carbonate sediments, alteration profiles in both ultramafic and mafic rocks, and zones of subsurface fluid flow of various intensities.

2. The evolution of the massif and the effects of alteration processes on microbial activity as it was progressively denuded to the seafloor and rapidly cooled from around 1 Ma onward. This includes understanding the longevity of and possible precursors to the LCHF, determining the evolution of serpentinization with progressive denudation, and evaluating the variations in microbial communities with age of the seafloor and as the dominant lithology changes from ultramafic to mafic in composition.
3. The early history of the detachment fault (Figure **F2**), which localized high strain deformation and fluid flow at 300°–400°C (Schroeder and John, 2004; Boschi et al., 2006; Karson et al., 2006; Escartín et al., 2003), possibly up to several kilometers below the seafloor.

Background

Active serpentinite-hosted hydrothermal systems and chemical exchange between the mantle, biosphere, and hydrosphere

Approximately 30,000 km or roughly 50% of the global mid-ocean ridges are spreading at rates <40 mm/y and extend from the Arctic Ocean, along the entire Mid-Atlantic Ridge (MAR), and into the southwest Indian Ocean. The recognition that ultramafic rocks are tectonically emplaced along major normal faults (Figure **F2**) at these slow-spreading ridge environments (Cannat, 1993; Dick et al., 2003, 2008; Smith et al., 2006; Escartín et al., 2003) has led to new considerations of the geophysical, geochemical, and biological consequences of serpentinization for the global marine system. Serpentinization is associated with the uptake or release of many major and minor components, such as H_2O, Mg, Ca, Si, Cl, Li, B, C, and S, with important consequences for long-term global geochemical fluxes and biogeochemical cycles (Alt and Shanks, 1998, 2003, 2006; Früh-Green et al., 2004; Boschi et al., 2008; Delacour et al., 2008a, 2008b, 2008c). In addition, serpentinization reactions lead to the production of highly reduced fluids and result in high concentrations of H_2 and reduced C-species including methane, ethane, propane, and straight chain hydrocarbons (Proskurowski et al., 2006, 2008; Konn et al., 2009; Holm and Charlou, 2001; Foustoukos and Seyfriend, 2004). These reduced species are believed to form through Fischer-Tropsch type (FTT) reactions, catalyzed by Fe-, Ni-, and Cr-bearing minerals, and have important consequences for biological activity on and within the seafloor and for global carbon cycling (Kelley et al., 2005; Takai et al., 2004; Brazelton et al., 2006; Perner et al., 2007; Proskurowski et al., 2008; Kohn et al., 2009; Holm and Charlou, 2001).

Six sites along the MAR—the high-temperature Rainbow, Logatchev, Ashadze and Nibelungen fields, and the lower temperature Lost City and Saldanha hydrothermal fields—are known to be hosted in mafic and ultramafic basement rocks, but more are likely to be found. Studies of the Lost City system suggest that low- to moderate-T ultramafic-hosted hydrothermal systems are long lived and occur in seafloor up to 2 Ma (Ludwig et al., 2006, 2011; Früh-Green et al., 2003). Serpentinization reactions at less than ~200°C play a key role in the production of high-pH fluids, which control carbonate precipitation and have important consequences for the sequestration of CO_2 from seawater. Diffuse high-pH fluids also directly promote lithification of overlying sedimentary deposits (Früh-Green et al., 2003), which in turn affect heat flow and fluid circulation pathways. In contrast to basalt-hosted hydrothermal systems, where conceptual models of the fluid pathways, alteration reactions and element uptake are relatively well constrained (Wheat and Fisher, 2008; Wheat et al., 2003; Fisher, 1998; Fisher and Becker, 2000), little is known of the fluid pathways and degree of heat and mass transfer that can support a subsurface biosphere in such moderate-T, serpentinite-hosted hydrothermal systems.

The impact of serpentinization on the subsurface biosphere

One goal of our planned drilling is to explore the subsurface environment and the potential for a hydrogen-based deep biosphere in an area undergoing active serpentinization. Lost City is characterized by extreme conditions never before seen in the deep marine environment. Carbonate-brucite structures are venting up to 91°C, high pH (from 9 to 11) hydrothermal fluids, which are, metal- and CO_2-poor and have high concentrations of H_2 (up to 15 mmol/kg), CH_4 (1–2 mmol/kg), organic acids, and low molecular weight hydrocarbons (Kelley et al., 2005; Proskurowski et al., 2006, 2008; Konn et al., 2009). Formate and low molecular weight hydrocarbons are believed to be formed abiologically during serpentinization reactions at depth (Lang et al., 2010, 2012). Foustoukos and Seyfried (2004) indicate that even small amounts of Cr-bearing phases typical of ultramafic rock types can enhance the synthesis of short-chain alkanes, providing an abiotic mechanism for hydrocarbon production in ultramafic-hosted hydrothermal systems (McCollom and Seewald, 2001, 2003, 2006; McCollom, 2007). The production of H_2, abiotic hydrocarbons, and possibly formate during serpentinization reactions and mixing with oxidized seawater provide metabolic energy for chemolithoautotrophic and heterotrophic organisms (McCollom, 2007; McCollom and Shock, 1997). Development of an ecosystem depends on the availability and renewal of a carbon source, electron donors (such as H_2, CH_4, H_2S, and Fe^{2+}) and electron acceptors (particularly O_2, NO_3^-, and SO_4^{2-}) (Table **T1**). In ultramafic environments, electron donors are generally unlimited in the form of H_2 and CH_4, whereas electron acceptors will depend greatly on the fate of sulfate (which is 1–4 mM in Lost City fluids) (Kelley et al., 2005), as well as seawater recharge and mixing with serpentinizing fluids. Numerical models show that ultramafic-hosted systems may be capable of supplying about twice the metabolic energy as analogous deep-sea hydrothermal systems hosted in basaltic rocks (McCollom, 2007).

Considering the extent of ultramafic environments on the seafloor and the longevity of seawater circulation during serpentinization, the total biomass of the ultramafic-hosted subsurface biosphere may be substantial. Some researchers also propose that organic compounds produced abiotically in serpentinites may contribute to certain oil and gas reservoirs (Gold, 1979, 1999; Szatmari, 1989) and that similar reactions may have been the source of prebiotic organic compounds on early Earth (Holm and Andersson, 1998; Shock and Schulte, 1998; Sleep et al., 2004). Conditions of early Earth were likely similar to the hydrogen-rich, anaerobic environment within the subsurface of Lost City, and the alkaline conditions are favorable for some aspects of prebiotic chemistry, such as formation of RNA-bearing vesicles (Russell, 2003). Despite the potential importance of a subsurface hydrogen-based biosphere, it has not been well studied. Previous studies of ultramafic-hosted hydrothermal systems have concentrated on active vent areas and their hydrothermal deposits (Schrenk et al., 2004; Takai et al., 2004; Nercessian et al., 2005; Brazelton et al., 2006, 2009, 2010; Perner et al., 2007; Brazelton and Baross, 2009). Because of the significant difference in volatile compositions and limited CO_2 stability at high pH, one can expect that biotopes hosted in serpentinizing environments will differ significantly from axial, basaltic-hosted vent systems in which CO_2 is a dominant volatile species (Perner et al., 2007; Proskurowski et al., 2004, 2006, 2008; McCollom and Seewald, 2006; McCollom, 2007). In addition, the mixing of oxidized seawater with highly reduced fluids leads to complex 3-D gradients in fluid chemistry and temperature, which may influence microbial distribution and activity. Substantially different habitats harboring various types of aerobic and anaerobic metabolisms may thus occur over a narrow spatial scale. However, essentially nothing is known from in situ studies of the nature—and importance—of microbial communities in serpentinizing basement rocks and in areas of diffuse flow, or how these vary with lithology and age of the seafloor. In addition, little is known about the role microbes play in controlling fluid compositions and carbonate precipitation (Dupraz et al., 2008; Ehrlich, 2009).

The carbon budget of hydrothermal circulation

Large-amplitude anomalies exhibiting very low total dissolved manganese/methane (TDM/CH_4) ratios in the water column above fault-bounded peridotite bodies confirm that seawater-peridotite interactions generate extensive CH_4 plumes (Charlou et al., 1991, 1998; German et al., 2009; Bougault et al., 1993; Rona et al., 1992). Additional evidence that considerable volumes of hydrocarbons may be generated during serpentinization processes is provided by pore waters sampled during Ocean Drilling Program (ODP) Leg 125 at a serpentinized seamount in the Mariana fore arc, where high concentrations of CH_4 and C_2H_6 were measured (Haggerty, 1991; Mottl and Haggerty, 1989). These studies imply that a significant amount of carbon is transferred from the upper mantle to the hydrosphere through serpentinization processes.

Stable isotope and radiocarbon measurements on methane venting at Lost City demonstrate that it is ultimately derived abiotically from mantle CO_2 as opposed to seawater bicarbonate (Proskurowski et al., 2008) and imply that seawater bicarbonate carried with recharge fluids is largely removed, presumably in carbonate minerals, before the abiotic reactions that form methane occur. This is consistent with similar studies of CO_2 in high-temperature fluids from the Endeavour segment of the Juan de Fuca Ridge (Proskurowski et al., 2004), which indicate a magmatic source of carbon to the hydrothermal system after a 1999 earthquake and require that a large fraction of seawater bicarbonate originally present in downwelling fluids is removed during hydrothermal circulation. Extraction of seawater bicarbonate during recharge processes at the LCHF is substantiated by stable isotope compositions of calcite veins in the basement rocks (Früh-Green et al., 2003) that point to a dominant seawater component in the fluids at the time of calcite precipitation. Thus, the calcite vein networks in the footwall of Atlantis Massif give an indication of seawater recharge pathways during the lifetime of the system, which provide local domains for mixing of oxidizing seawater and reduced hydrothermal fluids with important consequences for the existence of a deep biosphere. Because of the unique relationship between CO_2 and CH_4 in serpentinizing systems, understanding the controls on the production and consumption of CO_2 and CH_4 are fundamental to understanding carbon biogeochemical cycles in these systems. At Lost City, significant quantities of CO_2 are also removed from seawater in forming the chimneys themselves. In addition, oceanic serpentinites may be a previously unrecognized reservoir of organic carbon, possibly originating from dissolved organic carbon in seawater (Delacour et al., 2008c). However, it is still uncertain whether there is net fixation of carbon from the hydrosphere into the solid Earth during these processes.

When considering global carbon budgets and the potential for CO_2 sequestration through carbonate precipitation in peridotites (Kelemen and Matter, 2008; Andreani et al., 2009; Boschi et al., 2009), it is important to constrain the source of carbon, the volume of carbonate, and rate of precipitation in ultramafic-hosted hydrothermal systems and the longevity of hydrothermal circulation. In this system, there may be positive feedback in which high reaction rates are enhanced by exothermic heating during serpentinization, where permeability and reactive surface area are maintained or enhanced by cracking in response to volume expansion (Kelemen and Matter, 2008). If so, quantifying carbonate precipitation during serpentinization has direct implications for evaluating the potential of in situ peridotites for CO_2 capture and storage. In the case of the LCHF, although we can constrain the current focused output of the system, we do not know the large-scale patterns of recharge and more diffuse discharge or the volume of carbonate veining in the footwall and have only a minimum estimate of the longevity of the system (Früh-Green et al., 2003; Ludwig et al., 2011). To evaluate how widespread Lost City–type intermediate-T systems are in slow-spreading environments and to what distance from the ridge axis seawater circulation and serpentinization persist, we need a better understanding of the controls on the location of the LCHF as well as spatial and temporal constraints on serpentinization and carbonate precipitation. Much remains to be understood about the necessary conditions (P, T, mineral reactions, and fluid fluxes) to form carbonate deposits and the controls on fluid circulation and its role in supporting a subsurface biosphere.

The evolution of hydrothermal circulation associated with detachment faulting

Another important question that we plan to address through drilling concerns the links among detachment faults, deformation, and hydrothermal circulation that can feed high-temperature mid-ocean-ridge vent fields. Research on detachment faulting and OCCs indicates that this style of oceanic spreading is intimately linked to hydrothermal circulation and encompasses a wide variety of fluid flow and hydrothermal regimes (McCaig et al., 2007). High-T fluid circulation is well documented mineralogically and geochemically (Schroeder and John, 2004; Boschi et al., 2006; McCaig et al., 2010), and uplift along detachments may promote circulation and alteration within the footwall (Andreani et al., 2007). McCaig et al. (2007) propose a temporal evolution in the style of hydrothermal circulation associated with the development of OCCs: from high-T systems hosted in the basaltic hanging wall within the rift valley (e.g., TAG-type), to high-T ultramafic-hosted systems within the footwall (Rainbow-type), and ultimately to off-axis ultramafic-hosted systems within the footwall (Lost City–type). At Atlantis Massif we can study the first and third of these circulation types.

Recent estimates suggest that focused flow in large, high-T hydrothermal fields may dominate the transfer of much of the total heat from the ridges to the oceans in slow-spreading environments (German et al., 2009) and are therefore fundamental in the thermal evolution of our planet. Sampling at different locations along the former detachment fault will allow us to evaluate records of fluid-rock interaction and metasomatism and isotopic interaction and to test the hypothesis that exhumation faults serve as long-lived permeable pathways for hydrothermal flow that can feed moderate- to high-T hydrothermal vents (McCaig et al., 2007). In ultramafic/mafic systems, assemblages of talc-tremolite-chlorite form at >350°C (Boschi et al., 2006, 2008; McCaig et al., 2010), typical of black smoker discharge zones, whereas serpentine-prehnite-hydrogarnet assemblages form at lower T vents (Frost et al., 2008; Bach and Klein, 2009). Spatially constrained sampling of the Atlantis Massif detachment system gives us an opportunity to map these variations in metamorphic assemblages as well as Sr, O, and Nd isotope compositions to constrain temperatures and fluid-rock ratios (Delacour et al., 2008d).

Tectono-magmatic processes at asymmetric slow spreading ridges

Oceanic core complexes are exposed in volcanic-poor areas where detachment faults remain active over periods of 1 to 3 My. These faults accommodate slip of up to 125 km (e.g., the Godzilla Mullion [Ohara et al., 2001, 2002]), implying that an extremely weak zone of localized strain is maintained for significant periods of time. The envisaged mechanisms controlling long-lived stretching of the lithosphere along oceanic detachment faults call for feedback with hydrothermal fluid flow along the fault and the growth of weak hydrous minerals (notably serpentine and talc) that favor localization of ongoing deformation (Escartín et al., 2008). This process involves a crack-seal mechanism associated with fluid circulation and mineral precipitation and could be a candidate for the generation of low-magnitude microseismicity.

Numerous recent geophysical and geological studies, as well as drilling of ODP and Integrated Ocean Drilling Program Sites 735B, 1275, and U1309 (Ildefonse et al., 2007; Dick et al., 2000; Kelemen, Kikawa, Miller, et al., 2007; Blackman, Ildefonse, John, Ohara, Miller, MacLeod, and the Expedition 304/305 Scientists, 2006) have changed our view of how slow-spreading ridges operate. Magmatic activity is locally relatively high, as evidenced by an abundance of gabbros/diabase exposed and drilled in these regions. The unexpected abundance of gabbro hosted by mantle peridotite suggests that significant quantities of melt are generated beneath these volcanic-poor ridge segments, but much is trapped in the mantle as it turns into lithosphere beneath the ridge axis, rather than migrating upward to form a continuous magmatic crust (Figure **F2**). Ongoing magmatic activity associated with asymmetric normal faulting results in a heterogeneous mafic and ultramafic lithosphere with diabase intrusions exposed in the denuded footwall, whereas accretion of volcanic seafloor persists in the hanging wall (Cannat et al., 2006; Smith et al., 2006; Ildefonse et al., 2007; Karson et al., 2006). These results are consistent with recent numerical models that suggest that about 50% of ridge extension must be accommodated by magmatic accretion to allow low-angle detachment faults to develop (Tucholke et al., 2008). This magmatic activity is probably essential to initiate and maintain large high-temperature hydrothermal systems (McCaig et al., 2007; Rona et al., 1993; Lalou et al., 1995; deMartin et al., 2007; Humphris and Cann, 2000; Cannat et al., 2004) and provides crucial feedback mechanisms between hydration-promoted melting, hydration, detachment faulting, and mass transfer (Jöns et al., 2009; Escartín et al., 2008; Reinen et al., 1991; Moore and Rymer, 2007; Scruggs, 1997).

Understanding the links between faults in the brittle axial domain and deformation of the deeper ductile lithosphere (Figure **F2**) is a key parameter for determining the mechanisms accommodating plate separation at mid-ocean ridges characterized by roughly equal partitioning of tectonic and magmatic spreading. Detachment faults are thought to initiate as high-angle normal faults extending to ~8–10 km depths; hence, the exhumed footwall provides a cross section through the upper part of the lithosphere (Figure **F2**). We will sample the exposed, and therefore inactive, section of the Atlantis Massif fault system. Rocks recovered from near the breakaway (western side of the massif) originated from shallow depths, and rocks from the easternmost side originated from depths of several kilometers. We do not plan to drill deep into the footwall, as this was achieved during Integrated Ocean Drilling Program Expedition 304/305.

Scientific objectives

The need for shallow drilling across Atlantis Massif

Our drilling strategy focuses on obtaining good recovery of continuous sequences in the upper 50–80 meters below seafloor (mbsf) both along an east–west profile at the top of the Atlantis Massif southern wall and in the vicinity of the LCHF and in a north–south profile toward the central dome where the substrate is gabbroic. Currently, almost nothing is known about the existence of a serpentinite-hosted subsurface biosphere (in any setting, marine or terrestrial), let alone its variation. Drilling the east–west profile will particularly allow a better understanding of the evolution of the detachment fault and how microbial communities evolve as ultramafic rocks are emplaced on the seafloor. Drilling the north–south profile will allow us to assess the role of gabbros versus serpentinized ultramafic rocks in supporting ecosystems and in localizing detachment faults.

Specific hypotheses that we propose to test by drilling are as follows:

- An extensive subsurface hydrogen-based biosphere persists in serpentinizing lithosphere. These communities evolve and adapt to variations in diffuse fluid flow, fluid chemistry, heat flow distribution, and aging of the seafloor.
- Serpentinizing environments sustain higher biomass than gabbroic-dominated domains.
- Progressive denudation and seawater interaction with ultramafic- and mafic-dominated lithosphere lead to ultramafic-hosted hydrothermal systems that change from high-T, magmatically driven sulfide deposits to low-T hydrothermal carbonate deposits. Moderate- to low-T hydrothermal activity may last for hundreds of thousands of years, and the change to carbonate-dominated systems occurs as soon as ultramafic rocks are exposed on the seafloor in the absence of active volcanism.
- The transition from sulfide- to carbonate-dominated environments can be detected by changes in the rare biosphere of the associated microbial communities.
- Zones of intense carbonate veining underlie sites of diffuse venting and represent seawater recharge and net sequestration of CO_2 from the hydrosphere into the lithosphere. These zones are biological hotspots where microbial communities are supported by the high fluxes of H_2 mixing with CO_2.
- Strain localization on detachments results from weak serpentine-, talc-, amphibole-, and chlorite-bearing assemblages, concentrated into ultramafic rather than gabbroic rocks.

Constraining the deep biosphere in a serpentinizing environment

A major question to be addressed is whether serpentinization supports microbial communities in the basement rocks similar to those in the carbonate chimneys and fluids at the LCHF. The warmest, highest pH domains of carbonate chimneys are dominated by a single clade of Lost City Methanosarcinales archaea (Schrenk et al., 2004). Other organisms are apparently unable to succeed in the extreme (low ΣCO_2, high pH, and highly reducing) conditions of the serpentinizing fluids at temperatures approaching 100°C. Zones where CO_2 and electron acceptors such as oxygen, nitrate, and sulfate are provided by mixing of ambient seawater with hydrothermal fluid and harbor diverse bacteria including methane- and sulfur-oxidizing organisms.

Because fluid flow in the basement rocks is likely to be much more diffuse than the focused flow creating the Lost City chimneys, it is likely that these fluids will contain more CO_2 and electron acceptors mixed in from seawater and/or not yet reduced by serpentinization reactions. Therefore, we hypothesize that the microbial communities in the underlying peridotites will show a greater diversity than those in the main chimney complex. Also, because of the immense volume of Atlantis Massif expected to host hydrothermal circulation, the biomass of this subsurface community could potentially dwarf that of the Lost City chimneys. In particular, primary producers utilizing CO_2 from seawater and reduced species such as H_2 from serpentinizing fluids should flourish. Sulfate is likely to be an important electron acceptor in subsurface communities because sulfate concentrations remain high in Lost City fluids (1–4 mM) (Kelley et al., 2005). We expect that domains with sufficient concentrations of sulfate will host consortia of anaerobic methane oxidizing archaea and sulfate-reducing bacteria, as has been observed in gas hydrates and mud volcanoes (Orphan et al., 2001). Therefore, Atlantis Massif could potentially host extensive communities dominated by both methanogens and methanotrophs. Constraining the distribution and activity of these organisms is essential for understanding biological carbon cycling through slow-spreading ocean crust.

In addition to chemolithoautotrophs, heterotrophic organisms are expected to be present in the ultramafic subsurface, where they could be supported by organic compounds generated by serpentinization. Environmental DNA sequencing of Lost City fluids (Brazelton et al., 2006, 2009, 2010; Brazelton and Baross, 2009) and lipid biomarker analyses (Bradley et al., 2009a, 2009b; Méhay et al., 2009, 2013) reveal the presence of archaeal species that are absent in the carbonate chimneys. These include species from Thermococcales (Euryarchaeota), and Crenarchaeota, which are surprisingly similar to those in diffuse hydrothermal fluids of basalt-hosted hydrothermal systems (Brazleton et al., 2006). In such systems, the presence of these thermophilic archaea is indicative of an organic-rich, high-T subseafloor biotope (Summit and Baross, 2001). Although their physiology is unknown, the Thermococcales representatives are most closely related to heterotrophs, implying a source of organics in the subsurface. The proposed drill cores will allow us to directly test whether heterotrophic communities are abundant within Atlantis Massif and whether their distribution is consistent with a community supported by serpentinization-derived organic compounds.

The proposed east–west transect will also provide an excellent opportunity to explore the rare biosphere (Brazelton et al., 2010) of subsurface communities inhabiting rocks differing in age by ~1 Ma. Virtually nothing is known regarding the biogeography of subsurface communities in oceanic crust. Our sampling scheme will shed light on important questions of whether—and if yes, how—microbial communities adapted to magmatically-driven, sulfide-dominated environments are able to transition to serpentinizing, carbonate-dominated environments over a ~1 My timescale. Is there any overlap between the communities? At what point are the sulfide-adapted organisms succeeded by carbonate-adapted organisms? Are species in the westernmost, oldest rocks already present at very rare levels in the easternmost, youngest rocks, indicating that species can remain rare for up to 1 My before "blooming"?

Some microbiological results are available from Expedition 305 at Atlantis Massif to guide our efforts (Mason et al., 2009). Rocks were collected for molecular analyses from 400 to 1400 mbsf, and aerobic bacteria were cultured in variable lithologies (gabbro and olivine-bearing gabbro), with variable (10%–50%) alteration, deeper than 1300 mbsf (T > 75°C). Mason et al. (2010) had no success culturing bacteria from the troctolites, and no archaea were found. The microorganisms cultured from the central dome are most similar to organisms known to degrade hydrocarbons and are distinct from those cultured from LCHF carbonates (Schrenk et al., 2004; Brazleton et al., 2006).

Importance of recovering the carbonate cap sequences

Polymictic sedimentary breccias overlain by pelagic limestones or chalks form the 1–2 m thick, flat-lying carbonate cap that has been mapped over a large portion of the top of Atlantis Massif (Figure **F3**) (Kelley et al., 2001, 2005; Blackman et al., 2002). The diffusely percolating, high-pH fluids emanating from the underlying serpentinites have promoted rapid sediment lithification and may provide an important niche for microbial activity kilometers away from areas of focused flow. Recovery of intact sedimentary sequences was not possible during Expedition 304/305, and this remains a priority attainable with our proposed drilling strategy.

At present, we have no constraints on the presence, diversity, and abundance of microbial communities in the sediments. The carbonate cap is thus an important target for drilling to evaluate its role in microbial activity in a carbonate-dominated environment, one in which the chemistry (with precursor sedimentary organic and inorganic carbon sources), porosity, and temperature structure is different than those of the hydrothermal carbonate towers or in the basement peridotites. This environment likely supports a more diverse microbial community that may be distinct from those in the basement, carbonate chimneys, and fissure fillings. The wide lateral extent of the carbonate cap has implications for the quantification of total chemical fluxes and the diversity of ecosystems that may be supported by peridotite-hosted hydrothermal systems. If alkaline, CH_4- and H_2-rich fluids are emitted diffusely over a broad region, the sedimentary cap rocks represent an important biological niche for communities living in diffuse fluid flow and expands the amount of biomass that may be supported by these systems. Drilling in the sedimentary cap rocks also offers an important opportunity to constrain the depositional, diagenetic, and alteration history of these sediments. Determination of the mineralogies and fossil and lithic assemblages, combined with O-isotope stratigraphy and radiocarbon age dating, can provide important information on the timing of microbial community shifts in relation to the evolution of detachment faulting, exhumation, and the initiation and episodicity of hydrothermal activity.

Detachment faulting and the evolution of oceanic core complexes

Our planned drilling aims at obtaining good, continuous recovery of the talc-amphibole-chlorite schists, serpentinite mylonites, and variably altered peridotites and gabbros that comprise the zone of detachment faulting across and along isochrons. Drilling profiles into the damage zone will constrain thickness variations of the detachment fault zone, help us better understand how strain is localized at this tectonic boundary, and document discontinuities that may reflect removal by later faulting. By drilling east–west profiles along the southern wall and north–south profiles toward the central dome using Integrated Ocean Drilling Program Hole U1309D as a tie point, we will be able to document spatial and temporal heterogeneity in rock type and therefore magmatic and tectonic accommodation to plate spreading and to assess the role of rheological contrasts between competent gabbro and weaker serpentinized ultramafic rocks in localizing detachment faults. Drilling will ultimately allow a better understanding of the evolution of the massif as it was progressively uplifted to the seafloor and cooled. Although there are other OCCs where similar studies could be envisaged, Atlantis Massif is the only one currently known that also hosts a low/moderate-temperature hydrothermal system, allowing multiple objectives to be achieved within a single expedition. Thus, our study will provide a unique opportunity to evaluate the extent and activity of the subsurface biosphere within a well-defined geological and geochemical context that is representative of processes that form a large proportion of the seafloor in slow-spreading ridge environments.

Alignment with the IODP Science Plan

Expedition 357 will drill a series of shallow (~50–80 m) holes across Atlantis Massif (30°N; Mid-Atlantic Ridge) in an effort to (1) recover in situ sequences of sediments, hydrothermal deposits/veins, and variably deformed metasomatic talc-amphibole-chlorite-rich rocks and serpentinized peridotites along a spreading-parallel (east–west) profile at the top of the southern wall of Atlantis Massif and (2) obtain comparable in situ sequences along a ridge-parallel (north–south) profile on the Atlantis Massif central dome, where rock types are known to change from dominantly ultramafic to dominantly mafic.

Major scientific questions that we intend to address by drilling include the following:

- What is the nature of microbial communities hosted by serpentinizing rocks, and to what depth is microbial activity sustained? How do these vary with aging of the lithosphere? How do they differ from or interact with communities in sediments and mafic substrates in the same age crust?
- What are the consequences of serpentinization processes for global (bio)geochemical cycles?
- What are the spatial scale of lithologic and hydrothermal variability in slow-spreading lithosphere and the implications for heat and fluid fluxes and microbial life?
- How are carbon-bearing phases distributed locally and regionally? What are the rates of carbon fixation, as biomass or solid carbonate, in ultramafic rocks during low-temperature hydrothermal activity? What is the role of serpentinization in carbon sequestration?
- How do oceanic detachment faults develop and facilitate hydrothermal circulation? How do they affect the development of alteration patterns and the evolution of the deep biosphere in these environments?

Drilling Atlantis Massif provides an important opportunity to evaluate the extent and activity of the subsurface biosphere within a well-defined geological and geochemical context that is representative of processes that form a large proportion of the seafloor in slow-spreading ridge environments. The planned drilling specifically addresses fundamental questions identified in the IODP Science Plan, Exploring the Earth under the Sea (2013–2023), regarding Biosphere Frontiers, Earth Connections, and Earth in Motion:

- What are the origin, composition, and global significance of deep subseafloor communities?
- What are the limits of life in the subseafloor?
- How are seafloor spreading and mantle melting linked to ocean crustal architecture?
- What are the mechanisms, magnitude, and history of chemical exchanges between the oceanic crust and seawater?
- How do fluids link subseafloor tectonic, thermal, and biogeochemical processes?

The processes controlling fluid flow and a deep biosphere are intimately linked, and over the past years many studies have concentrated on understanding sedimentary or volcanic systems with high-temperature discharge or on areas of diffuse flow in volcanic units (D'Hondt et al., 2002, 2004; D'Hondt, Jørgensen, Miller, et al., 2003; Fisher, Urabe, Klaus, and the Expedition 301 Scientists, 2005; Nakagawa et al., 2006; Lipp et al., 2008; Parkes et al., 2005; Biddle et al., 2006; Hinrichs et al., 2006; Inagaki et al., 2006; Huber et al, 2002, 2003). In contrast, the spatial scale of lithologic variability between mafic and ultramafic seafloor at slow-spreading ridges, the implications for fluid flow paths and fluxes, and the subsurface ecosystems supported by these systems remain almost completely unconstrained. A major aim of drilling Atlantis Massif is to investigate the nature and distribution of microbial communities and their links with seawater infiltration and alteration processes in two distinct, lithologically heterogeneous domains of an oceanic core complex: (1) the serpentinizing basement at varying distances both from the ridge axis and from the active, low-temperature hydrothermal field, the LCHF; and (2) a mafic, plutonic domain sampled from Hole U1309D, which is less influenced by present-day hydrothermal activity and serpentinization. Our objectives open new opportunities for the study of abiogenic production of organic compounds and their implications for prebiotic synthesis (Holm and Andersson, 1998; Shock and Schulte, 1998; Sleep et al., 2004) and will help constrain the subsurface scale and longevity of hydrothermal circulation and hence rates of carbon fixation. This has implications both for past climate change (Kelemen and Matter, 2008; Andreani et al., 2009; Boschi et al., 2009) and possible active sequestration of CO_2 in ultramafic rocks.

Proposed drill sites

The southern wall of Atlantis Massif

The southern wall of Atlantis Massif is cut by steep normal faults, which together with mass wasting expose a cross section of the lithosphere along a near-vertical, 3800 m high scarp north of the Atlantis Fracture Zone (Figure F1). Extensive submersible and dredge sampling along this scarp recovered primarily serpentinized ultramafic rocks (~70%) with interspersed lenses of gabbroic rocks (~30%) (Kelley et al., 2005; Schroeder and John, 2004; Boschi et al., 2006; Karson et al., 2006; Blackman et al., 2002). These samples of peridotites are primarily depleted spinel harzburgites and are affected by variable but high degrees of serpentinization (in general from 70% to 100%). An approximately 100 m thick zone of heterogeneous deformation and metamorphic assemblages considered to represent the zone of detachment faulting (Karson et al., 2006) has been mapped for at least 3 km along the crest of the Atlantis Massif southern wall in the vicinity of the LCHF. Within this zone, strain localization and focused fluid flow is marked by the presence of centimeter- to decimeter-thick domains of mylonitic serpentinized peridotites and metasomatic talc-rich and/or amphibole-chlorite–rich rocks that form shear zones with anastomosing to laminated foliations surrounding less deformed peridotites and gabbro (Schroeder and John, 2004; Boschi et al., 2006; Karson et al., 2006). Fresh high-T peridotite mylonites locally preserve unaltered olivine relicts, which suggests an early, high-T history of the fault zone (Schroeder and John, 2004; Boschi et al., 2006, 2008). These observations indicate that the detachment cannot be considered a single fault boundary between deformed and undeformed rocks, but rather a broad "damage" zone with localized high strain deformation within a heterogeneous upper mantle section. Pelagic limestones and sedimentary breccias with basaltic and serpentinite clasts cover the zone of detachment faulting and form a nearly flat-lying sedimentary cap (Figure **F3**) believed to act as a barrier for heat and hydrothermal fluids (Kelley et al., 2005; Karson et al., 2006; Früh-Green et al., 2003; Schroeder et al., 2002).

The Lost City Hydrothermal Field

The LCHF extends over 400 m in length, with numerous active and inactive carbonate-brucite structures up to 60 m in height hosting dense microbial communities that show limited phylogenetic diversity (Schrenk et al., 2004; Brazelton et al., 2006; Mehta and Baross, 2006). The high-T, anoxic interior zones of the chimneys harbor biofilms dominated by a single phylotype of archaea, referred to as Lost City Methanosarcinales; whereas bacteria, phylogenetically related to CH_4- and S-oxidizers, are mostly found in the oxygenated outer walls of carbonate chimneys, where fluid chemistry is influenced by the ingress and mixing of seawater (Kelley et al., 2005; Schrenk et al., 2004; Brazelton et al., 2006; Lang et al., 2012).

Older, nonventing sites are dominated by a single phylotype belonging to the ANME-1 clade of anaerobic methane–oxidizing archaea (Brazelton et al., 2006). Organic geochemical studies identified archaeal biomarkers in the chimneys that include isoprenoid hydrocarbons, glycerol diphytanyl diethers, and glycerol dibiphytanyl glycerol tetraethers (Bradley et al., 2009a, 2009b; Méhay et al., 2009, 2013) and bacterial biomarkers that include fatty acids, alcohols, hopanoids, and nonisoprenoidal diethers. The integration of genomic data (Brazelton et al., 2006, 2009, 2010; Brazleton and Baross, 2009) and compound-specific isotope characterization of the lipid biomarkers indicate variations in metabolism involving methanogenesis, methane and sulfur oxidation, and sulfate reduction over small scales during biofilm growth. Analyses of organic carbon in the hydrothermal deposits show that up to 50% of the microbial biomass is synthesized from this mantle carbon in areas where sulfate reduction is important (Lang et al., 2012). These studies imply that a significant amount of abiogenic carbon can be transferred from upper mantle domains to the biosphere and hydrosphere through serpentinization processes. A study utilizing next-generation sequencing technology has shown that the archaeal and bacterial biofilm communities undergo dramatic changes as environmental conditions in Lost City chimneys change over time (Brazelton et al., 2010). Microorganisms that comprise a small fraction of the community in the hottest, youngest chimneys may be the dominant species in older chimneys with different mineralogy and fluid chemistry. This observation indicates that these species can remain in the rare biosphere for at least hundreds of years before they find themselves in conditions for which they were optimally adapted. Sampling the proposed Atlantis Massif transect may reveal dynamics of the rare biosphere operating on even longer timescales.

Fracture and fault networks in the basement below Lost City provide pathways for the fluids both vertically, forming the spire structures, and horizontally, forming carbonate growths parallel to the foliation in the serpentinites (Kelley et al., 2001, 2005; Ludwig et al., 2006). The nearly horizontal sheet-like style of flow is very different to the vertical conduits that typify black smoker environments (Kelley et al., 2005). Field mapping and observations indicate that fluid expulsion also occurs along steep fractures that extend into the carbonate cap sediments (Figure **F3**).

The central dome of Atlantis Massif

Expedition 304/305 targeted the central dome of Atlantis Massif. Drilling into the footwall was exceptionally successful in Hole U1309D (1656 m water depth), resulting in a stable 1415.5 m deep hole with very high average recovery (75%) (Blackman, Ildefonse, John, Ohara, Miller, MacLeod, and the Expedition 304/305 Scientists, 2006; Expedition Scientific Party, 2005a, 2005b). However, the recovered lithology was unexpected: extremely limited proportions (<0.3%) of mantle peridotite but a predominance of gabbro (91.4%; mostly very primitive), ultramafic intrusive sequences (including troctolites; 5.7%), and diabase (3%). Drilling results suggest that the gabbro body is a discrete body hosted within a mantle protolith (Ildefonse et al., 2007; Blackman, Ildefonse, John, Ohara, Miller, MacLeod, and the Expedition 304/305 Scientists, 2006). Drilling at Site U1309 was instrumental in overturning many predrilling hypotheses and has led to a need for revised paradigms regarding processes of crustal accretion in these environments, particularly magma generation and distribution.

In general, Hole U1309D gabbros are remarkably undeformed. Evidence for talc-tremolite-chlorite schists, which mark the detachment fault on the southern wall, is confined to around 5 cm of intact core, clasts in fault breccia, and loose cobbles in several holes. The thickness of fault rocks cannot be more than 15 m, as gabbros occur within 20 m of the seafloor, which suggests significant thinning compared with the south wall. However, the fault zone may also be expressed by several zones of breccia within the upper 120 m of Holes U1309B and U1309D and by a deeper zone at around 700 mbsf (Blackman, Ildefonse, John, Ohara, Miller, MacLeod, and the Expedition 304/305 Scientists, 2006; Expedition Scientific Party 2005a, 2005b; Michibayashi et al., 2008). Detailed paleomagnetic studies on cores from Hole U1309D reoriented using borehole wall imagery demonstrate that the Atlantis Massif footwall has undergone a bulk tectonic rotation of at least 46° ± 6° around a ridge-parallel (011°-trending) axis, consistent with a "rolling hinge" flexural unloading model for the detachment fault system (Morris et al., 2009). Together, these results challenge the commonly held hypothesis that the bulk rheology of slow-spreading lithosphere is primarily controlled by cooling of a simple thermal structure and instead suggest that strain localization favored by lithologic contrasts and hydrous alteration are also important, as well as perhaps highly heterogeneous cooling around large hydrothermal systems (Boschi et al., 2006; Karson et al., 2006; Escartín et al., 2003; McCaig et al., 2010).

Operational strategy

Expedition 357 will be implemented as a MSP, in which platform and coring services are normally contracted from the industry market and scientific services are provided by ESO. For this expedition, the platform will be the RRS *James Cook*, a research vessel operated by the UK's Natural Environment Research Council (NERC). Coring will be conducted using two seafloor drills provided by seafloor drill teams from the British Geological Survey and the MARUM—Center for Marine Environmental Sciences, University of Bremen (Germany).

Some operational details are given in this prospectus, but the latest platform, facilities, coring strategy, measurements plan, scheduling, and port call information will be updated on the ESO Expedition 357 webpage (**http://www.eso.ecord.org/expeditions/357/357.php**).

Drilling platform

The drilling platform will be the NERC multirole dynamically positioned research vessel, the RRS *James Cook*. This vessel is 89.2 m in length with a gross tonnage of 5401 tonnes and an average operating speed of 11 kt. The total capacity is 54 persons, and the operational endurance is 50 days. The vessel has a Kongsberg SDP11 dynamic-positioning system. Full details can be viewed at **http://noc.ac.uk/research-at-sea/ships/rrs-james-cook**. ESO will mobilize a number of containerized laboratories in addition to using the vessel's inbuilt laboratories. The laboratories are situated on the Upper Deck: a large main laboratory, a smaller wet laboratory or deck laboratory, a controlled environment laboratory which can be set to 4°C, a chemistry laboratory, a computing laboratory, and a water sampling room, which is connected to the deck lab at one end and to the working deck through a large door at the other. There are also locations around the ship (above wet laboratory; below working deck) where container laboratories/storage can be located. ESO will work with the Co-Chief Scientists and Science Party members to devise the most efficient laboratory layout and core workflow.

Coring rigs and coring methodology

This expedition will be the first IODP expedition to utilize seafloor drill technology. To maximize the ship time and reduce risks to the expedition, two seafloor drills will be mobilized: the BGS Seafloor Rockdrill 2 (RD2; **http://www.bgs.ac.uk/scienceFacilities/marine_operations/sampling_equipment.html**) and the MARUM Meeresboden-Bohrgerät (MeBo, **https://www.marum.de/en/Sea_floor_drill_rig_MARUM-MeBo.html**). The RD2 maximum penetration is 55 mbsf, and the MeBo maximum penetration is 80 mbsf. One rig will be deployed and undertake coring operations while the other rig is being unloaded, refurbished, and set up for the next site.

The seafloor drills will use plastic liners to collect the core. A second option to use split metal liners will also be made available, should it be decided at sea that a switch from plastic liners is required.

The MeBo will be deployed over the stern, and the RD2 will be deployed over the side of the vessel. These rigs are controlled in real time at the surface via a power, communication, and hoist umbilical analogous to a workhorse remotely operated vehicle (ROV).

Coring strategy

Proposed Sites AM-01 and AM-06, located close to the active Lost City hydrothermal system, are most critical for studying the links among microbial activity, fluid flow, and active serpentinization. Because of the operational hazards associated with seafloor drilling, these highest priority sites will not be drilled first but will be attempted early in the project (third and fifth sites visited). The provisional site order is given in Table **T2**. Moreover, sites in the east–west transect will have a higher drilling priority to those in the north–south transect.

Downhole logging

In all MSP expeditions, the downhole logging program, coordinated by the European Petrophysics Consortium (EPC), is an integral part of the offshore operation and is designed to meet the expedition-specific scientific objectives and maximize scientific output in general. MSP expeditions deploy variable coring technologies and pipe sizes and drill in a variety of water depths, so the type of logging tools used on MSPs consequently varies widely from expedition to expedition.

For Expedition 357, logging tools will be directly integrated with the seafloor drills and deployed by the seafloor drill engineers. New tools for dual induction and magnetic susceptibility measurements are currently being designed for compatibility with both seafloor rock drills through a collaboration of the RD2, MeBo, and EPC teams. These tools will be memory tools, collecting data during pipe tripping and prior to installation of borehole plugs. Because of tool string configuration limitations, only one of the dual induction or magnetic susceptibility tools can be run during each pipe trip; priority for tool choice will be decided by the Co-Chief Scientists in collaboration with the operational teams.

Measurements planned during Expedition 357 include spectral gamma ray, induction resistivity, magnetic susceptibility, and image logs (optical/acoustic: RD2 only). Logging data acquired during Expedition 357 will be electronically transferred to shore by ESO personnel on the ship to an ESO petrophysicist on land. This petrophysicist will provisionally process the data and provide a preliminary data summary with comments to the ship. The final set of quality assurance/quality controlled logging data will be made available to the Science Party at the commencement of the Onshore Science Party. As the downhole logging plan progresses, details will be published on the ESO Expedition 357 webpage.

EPC's coordination of Expedition 357 logging will include data processing, quality assurance/quality control of data, as well as providing ongoing scientific support for data interpretation and research. Offshore EPC interfaces with the operational team, Expedition Project Manager, Co-Chief Scientists, and Science Party to manage and ensure that the downhole logging program is successfully achieved.

Core on deck

Unlike traditional coring from drill ships, all of the core (up to 80 m) from the complete hole will arrive on deck at the same time (i.e., once the drill has been recovered to deck). It takes approximately 15–20 min for the first core to be unloaded from the rig and 1.5 h for the last core. Cores can be unloaded in reverse order, so that the deepest and most recent core drilled is the first to be unloaded. The seafloor drill engineers will work to deploy the second seafloor drill as soon as possible after the first is recovered to the deck.

Cores will be unloaded from the seafloor drill and delivered to the core bench to commence the curation procedure. As the cores will be collected in a plastic liner, the usual IODP curation procedures will be followed, although to a limited degree, small sections of whole-round core from the deepest cores will be immediately removed from core sections and transferred directly to deep freezers for time-critical microbiological analysis (**http://www.marum.de/en/Offshore_core_curation_and_measurements.html**). After curation, core materials are passed to the Science Party members for onboard analysis and sampling as described in **Science operations** below.

Borehole plugging and other measurements

An ongoing ESO engineering activity is to develop a method to seal a borehole using a seafloor drill–deployed borehole plug and swellable packer. This incorporates a removable cap to allow sampling integrated borehole fluids by ROV at some point in the future. The aim is to deploy a borehole plug system at all high-priority sites and most mid-priority sites.

The expedition will also take advantage of attaching additional instruments and sensors to the seafloor drills, specifically sensors for methane, dissolved oxygen, pH, redox (limited to sites in less than 1200 m water depth), conductivity, temperature, and depth. Bottom water samples will also be taken upon completion of the borehole to assess bottom water changes potentially due to borehole fluids. The collected data from these seabed rock drill tools will be added to the expedition data set.

A separate baseline hydrocast with conductivity-temperature-depth sensors and bottom seawater sample operation will be conducted prior to drilling at each site.

A tracer injection system is being developed to operate from both seafloor drills to aid confidence in microbiology samples taken against contamination.

Science operations

A Sampling and Measurements Plan (SMP) for Expedition 357 will be prepared by ESO and the Co-Chief Scientists to meet the scientific objectives of IODP Proposal #758.

Offshore science activities

It is the nature of MSP expeditions that there is limited laboratory space and accommodation on board platforms compared to the larger research drilling vessels *JOIDES Resolution* and *Chikyu*, and as such, there is no splitting of the cores at sea and only selected scientific analysis carried out onboard by a subset of the Science Party. Science activities on the platform are confined to those essential for core curation, measurement of ephemeral properties, securing of proper samples for pore water chemistry and microbiology, downhole logging, and safety. Most of the scientific analysis is carried out during the Onshore Science Party in Bremen, when the cores are split.

The following is a summary of the offshore scientific activities (please refer to SMP link, which will be made available at **http://www.eso.ecord.org/expeditions/357/357.php**, and the online tutorial at **http://www.marum.de/en/Offshore_core_curation_and_measurements.html**):

- Basic curation and labeling of cores will be performed.
- The fast-track multisensor core logger (MSCL) will be used to capture magnetic susceptibility measurements prior to the core being sampled to be able to link subsequent measurements into their wider context.
- All cores will be run on the MSCL (gamma density, *P*-wave velocity [where possible], electrical resistivity, and magnetic susceptibility).
- Core catcher (if available) description and sampling for initial structural and petrophysical or sedimentological and micropaleontological characterization, including taking a core catcher image.
- Taking and proper storage of samples for gas analyses, pore water, and microbiology contamination tests (perfluorocarbon tracer analysis).
- Interstitial water analysis and any other ephemeral properties agreed in the SMP.
- Core storage will be provided.
- Downhole logging will be completed.
- Associated data management of all activities will be performed (see below).

A staffing plan will be devised to carry out the science requirements on the platform with a subset of the Science Party. The plan will require flexibility of approach from all participants, with priorities of safety, core recovery, curation, and procedures for the measurement of ephemeral properties, including sampling for microbiology.

Report preparation will take place on board as required; reports to be compiled include the following:

- Daily and weekly operations and science reports to the management and panels of ECORD and IODP, Science Party members, and any other relevant parties. Scientific reports are provided by the Co-Chief Scientists. Summarized daily reports will be publicly available on the ESO website for any interested parties.
- Offshore sections of the *Expedition Reports* (primarily the Methods chapter).
- Press releases in line with ECORD outreach policy.
- Information for posting on the ESO expedition web site.

Onshore science activities

The Onshore Science Party will be held at the IODP Bremen Core Repository (BCR) of the MARUM, University of Bremen, Germany. The scientific work will follow the SMP to be developed in due course in conjunction with the Co-Chief Scientists.

Details of the facilities that will be available for the Onshore Science Party at the IODP Bremen Core Repository and MARUM laboratories can be found at the Expedition 357 SMP link. Additional facilities can be made available through continuing close cooperation with additional laboratories at the MARUM—Center for Marine Environmental Sciences and the Department of Geosciences at Bremen University, as well as the Max Planck Institute for Marine Microbiology, all of which are situated nearby on campus.

The following briefly summarizes the Onshore Science Party scientific activities (please see the SMP link, which will be made available at **http://www.eso.ecord.org/expeditions/357/357.php**, and the online tutorial at **http://www.marum.de/Onshore_-Science_Party_OSP.html**):

- Prior to the Onshore Science Party, total natural gamma radiation measurements will be taken on all cores (as appropriate) using an MSCL-XYZ in the core repository. These measurements will be undertaken by ESO staff.
- Core splitting: an archive half will be set aside per IODP procedure.

- Core description: ESO will provide a data entry system that is IODP standard. For data entry, ESO will employ the Expedition-DIS (Drilling Information System) that is entirely compatible with others being used in IODP. Please see **Data management** below.
- Digital linescan imaging.
- Color reflectance (spectrophotometry) (to be done on sediment cores).
- Core sampling for expedition ("shipboard") samples (to produce data for the *Expedition Reports*; e.g., physical properties).
- Smear slide preparation (to be done on sediment cores).
- Thin section preparation.
- Inorganic geochemistry: whole-rock and pore fluid chemistry.
- Bulk mineralogy: X-ray diffraction analysis.
- Petrophysical measurements: *P*-wave and moisture and density analyses.
- Core sampling for personal postexpedition research: a detailed sampling plan will be devised at the completion of the offshore phase and after the scientists have submitted their revised sample requests (see **Research planning: sampling and data sharing strategy** below).

A staffing plan will be developed with the Co-Chief Scientists to ensure that all required analyses and subsampling can be carried out efficiently. The measurement plan will take account of MSP specifications for QA/QC procedures.

In view of the existing geographical distribution of all Deep Sea Drilling Program/Ocean Drilling Program/Integrated Ocean Drilling Program/IODP cores, it is understood that the BCR will be the long-term location for Expedition 357 cores.

Report preparation will take place during the OSP as required by ECORD. Reports to be compiled include the following:

- Weekly progress reports to ECORD and relevant parties. Scientific reports are provided by the Co-Chief Scientists.
- *Preliminary Report* (submission to *JOIDES Resolution* Science Operator [JRSO] Publication Services 1 week after Onshore Science Party)
- Completion of the *Expedition Reports* (submission to JRSO Publication Services as soon as practically possible after the Onshore Science Party).

Staffing

Scientific staffing is decided on the basis of task requirements and nominations from the IODP Program Member Offices (**http://www.iodp.org/program-member-offices**). ESO staffing is based on the need to carry out the drilling and scientific operations efficiently and safely (Table **T3**).

Data management

A data management plan for the expedition will be developed once the data requirements and operational logistics are finalized. The outline plan:

- The primary data capture and management system will be the ExpeditionDIS (Drilling Information System). This is a relational database. It will capture drilling, curation, and geoscience metadata and data during the offshore and onshore phases of the expedition.
- The ExpeditionDIS includes tools for data input, visualization, report generation, and data export.
- The database can be accessed directly by other interpretation or decision-making applications if required.
- A file server will be used for the storage of data not captured in the database (for example, documents and image files) and the input/output of any data processing, interpretation, and visualization applications used during the expedition.
- The EPC will manage the downhole logging data, MSCL data, and physical properties data. Logging metadata and MSCL data will be stored in the ExpeditionDIS. Downhole logging data will be stored separately by EPC for processing and compositing.
- On completion of the offshore phase of the expedition, the ExpeditionDIS database and the file system will be transferred to the BCR to continue data capture during the Onshore Science Party.
- Between the end of the offshore phase and the start of the Onshore Science Party, expedition scientists will have access to the data via a password-protected website.
- On completion of the Onshore Science Party, expedition scientists will continue to have access to all data through a password-protected website throughout the moratorium period.
- During the moratorium, all metadata and data, apart from downhole log data, will be transferred to PANGAEA for long-term data archive.
- Downhole logging data will be transferred to the Lamont-Doherty Earth Observatory for long-term archive.
- Cores and samples will be archived at the BCR.
- After the moratorium, all expedition data will be made accessible to the public.

Research planning: sampling and data sharing strategy

Science Party members and third-party researchers should refer to the IODP Sample, Data, and Obligations Policy & Implementation Guidelines at **http://www.iodp.org/program-documents**. This document outlines the policy for distributing IODP samples and data to research scientists, curators, and educators. The document also defines the obligations that sample and data recipients incur. The Sample Allocation Committee (SAC; composed of Co-Chief Scientists, Expedition Project Manager, and IODP Curator or curatorial representative on board ship) will work with the entire Science Party to formulate a formal expedition-specific sampling plan for shipboard (expedition) and postcruise (postexpedition) sampling.

Every member of the science party is obligated to carry out scientific research for the expedition and publish it. Before the expedition, all shipboard scientists are required to submit research plans and associated sample/data requests via the IODP Sample and Data Request system at **http://web.iodp.tamu.edu/sdrm** before the deadline specified in their invitation letters. Based on sample requests (shore based and shipboard) submitted by this deadline, the SAC will prepare a tentative sampling plan, which will be revised on the ship as dictated by recovery and cruise objectives. All postcruise research projects should provide scientific reasons for desired sample size, numbers, and frequency. The sampling plan will be subject to modification depending upon the actual material recovered and collaborations that may evolve between scientists during the expedition. This planning process is necessary to coordinate the research to be conducted and to ensure that the scientific objectives are achieved. Modifications to the sampling plan and access to samples and data during the expedition and the 1 y postexpedition moratorium period require the approval of the SAC.

Shipboard sampling will be restricted to acquiring ephemeral data types and to low-resolution sampling for shipboard data acquisition (e.g., pore water and shipboard geochemistry) critical to the overall objectives of the expedition and plan for higher resolution sampling postcruise. Because of the time-sensitive nature of microbiological sampling, these samples will also be collected offshore, in accordance with the predefined sample plan.

The permanent archive halves are officially designated by the IODP Curator. All sample frequencies and sizes must be justified on a scientific basis and will depend on core recovery, the full spectrum of other requests, and the expedition objectives. Some redundancy of measurement is unavoidable, but minimizing the duplication of measurements among the shipboard party and identified shore-based collaborators will be a factor in evaluating sample requests.

If critical intervals are recovered, there may be considerable demand for samples from a limited amount of cored material. These intervals may require special handling, a higher sampling density, or reduced sample size. A sampling plan coordinated by the SAC may be required before critical intervals are sampled.

The SAC strongly encourages, and may require, collaboration and/or sharing among shipboard and shore-based scientists so that the best use is made of the recovered core. Coordination of postexpedition analytical programs is anticipated to ensure that the full range of geochemical, isotopic, microbiological, and physical properties studies are undertaken on a representative sample suite. The majority of sampling will take place at the Onshore Science Party in Bremen, and the SAC encourages scientists to start developing collaborations before and during the expedition.

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Table T1. Examples of potential energy sources for chemolithoautotrophic metabolism in mafic/ultramafic systems (modified after McCollom, 2007).

Aerobic reactions	
Sulfide oxidation	$H_2S + 2O_2 \rightarrow SO_4^{2-} + 2H^+$
Methanotrophy (CH_4 oxidation)	$CH_4 + 2O_2 \rightarrow HCO_3^- + H^+ + H_2O$
Iron(II) oxidation	$4Fe^{2+} + O_2 + 4H^+ \rightarrow 4Fe^{3+} + H_2O$
Hydrogen oxidation	$H_2 + ½O_2 \rightarrow H_2O$
Anaerobic reactions	
Methanogenesis with ΣCO_2	$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$
Sulfate reduction	$4H_2 + 2H^+ + SO_4^{2-} \rightarrow H_2S + 4H_2O$
Nitrate reduction	$4H_2 + 2H^+ + NO_3^- \rightarrow NH_4^+ + 3H_2O$
Acetoclastic methanogenesis	$CH_3COO^- + H_2O \rightarrow HCO_3^- + CH_4$
Methanogenesis with formate	$4HCOO^- + H_3O^+ \rightarrow 3HCO_3^- + CH_4$
Anaerobic methane oxidation	$CH_4 + 2H^+ + SO_4^{2-} \rightarrow H_2S + CO_2 + 2H_2O$
Anaerobic iron oxidation	$8Fe^{2+} + 10H^+ + NO_3^- \rightarrow 8Fe^{3+} + NH_4^+ + 3H_2O$

Table T2. Proposed site locations, preliminarily ordered by site visit order, Expedition 357. One hole will be cored at each site, with the exception of the two highest priority sites (AM-01 and AM-06), where there is potential to core two holes. The latest site strategy will be published on the ESO Expedition 357 website (**http://www.eso.ecord.org/expeditions/357/357.php**).

Site	Location (latitude, longitude)	Seafloor depth (m)	Operations	Proposed drill	Transit (km)	Hole operations (days)
Port of departure to be confirmed, expected to be in the UK			Start of expedition, Science Party boards platform			
			Transit to first site (8 days)		~4070	
AM-04A	30°07.70′N 42°09.20′W	1350	Coring, logging, hole plugging	MeBo		2.5
					2.8	
AM-05A	30°07.88′N 42°10.96′W	870	Coring, logging, hole plugging	RD2		2.5
					6.2	
AM-01A	30°07.80′N 42°07.33′W	720	Coring, logging, hole plugging	MeBo		5
					5.1	
AM-03A	30°07.67′N 42°03.91′W	1590	Coring, logging, hole plugging	RD2		2.5
					5.3	
AM-06A	30°07.95′N 42°07.20′W	870	Coring, logging, hole plugging	MeBo		5
					3.2	
AM-08A	30°09.50′N 42°08.05′W	1490	Coring, logging, hole plugging	RD2		2.5
					5.2	
AM-02A	30°07.50′N 42°05.75′W	1140	Coring, logging, hole plugging	MeBo		2.5
					5.0	
AM-09A	30°09.85′N 42°07.32′W	1560	Coring, logging, hole plugging	RD2		2.5
					2.8	
AM-07A	30°08.55′N 42°08.18′W	1150	Coring, logging, hole plugging	MeBo		2.5
					5.6	
AM-10A	30°11.43′N 42°07.04′W	1770	Coring, logging, hole plugging	RD2		2.5
AM-11A (alternate)	30°07.63′N 42°07.10′W	750	Coring, logging, hole plugging	Alternate		
			Transit to port of arrival (8 days)		~4070	
Southampton, UK			End of expedition, Science Party departs platform			

Table T3. Summary of science party and operator personnel (ESO staff), Expedition 357.

	Science Party	
ESO (22)	Offshore science team (9)	Expedition Scientists
ESO Operations Manager ESO Expedition Project Manager ESO Curator × 2 ESO Geochemist ESO Petrophysics Staff Scientist ESO Data Manager RD2 Engineer × 6 MeBo Engineer × 9	Co-Chief Scientist 1 (Petrologist/Geochemist) Co-Chief Scientist 2 (Microbiologist) Petrophysicist/Geophysicist Organic Geochemist Fluid and Gas Geochemist Microbiologist × 4	Comprises the offshore science team, additional invited scientists, Expedition Project Manager, and Petrophysics Staff Scientist. The exact expertise of the Science Party will be chosen by ESO and the Co-Chief Scientists. A maximum of 32 invited scientists will join the Science Party.
Offshore team total (31)		

Figure F1. Site locations, Expedition 357.

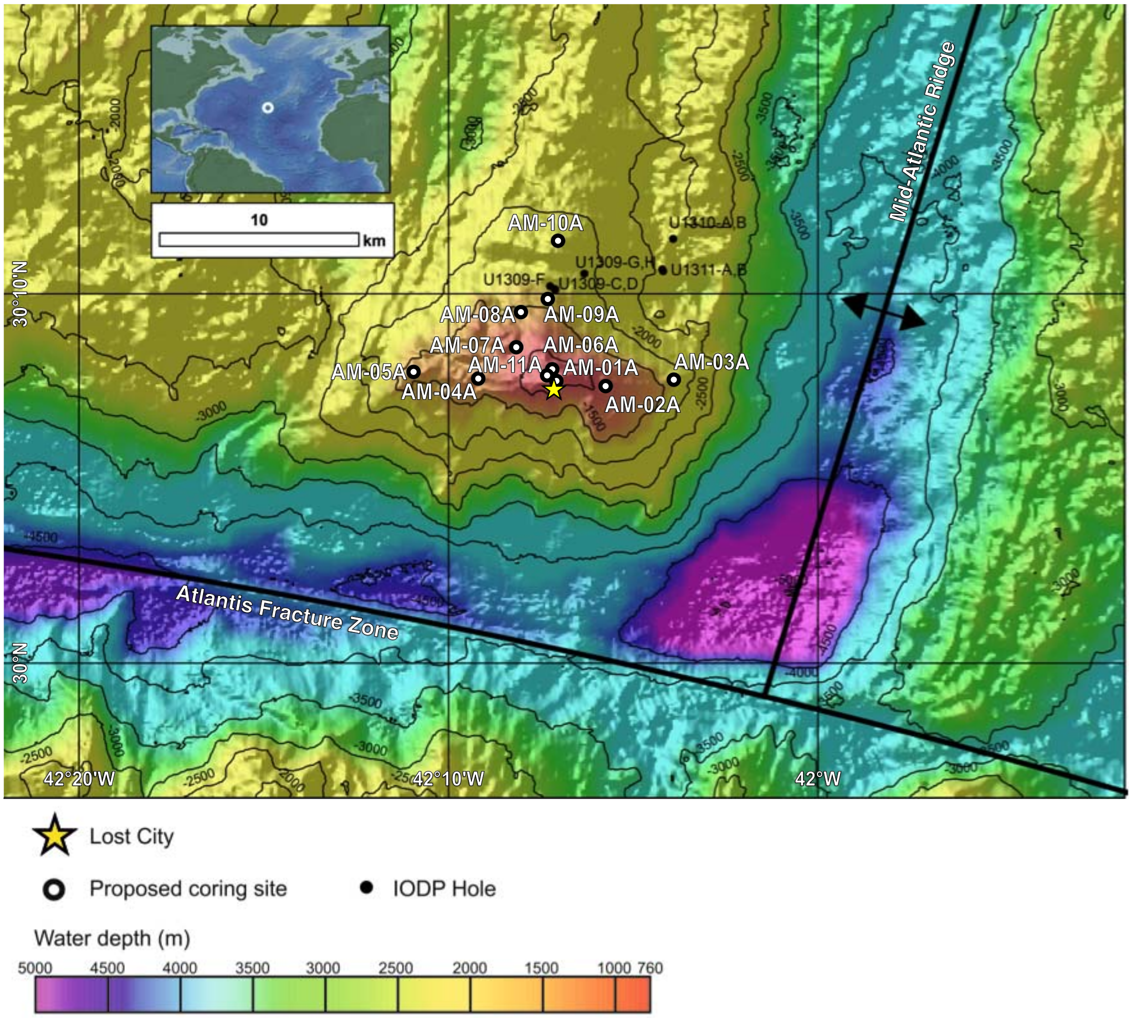


Figure F2. A. Conceptual sketch of lithospheric accretion and the tectono-magmatic evolution of a heterogeneous lithosphere and denudation of mantle rocks as detachment faulting progresses and oceanic core complexes are formed at slow-spreading ridges (from 2010 Chapman Conference Report "Detachments in Oceanic Lithosphere: Deformation, Magmatism, Fluid Flow, and Ecosystems": **http://2010chapman.blogspot.fr**). B. Example from Atlantis Massif: the southern wall is dominated by variably altered peridotites with gabbroic lenses (modified after Boschi et al., 2006) in contrast to C. C. Major gabbroic intrusions in the central dome (Grimes et al., 2008; copyright 2008 by the American Geophysical Union).

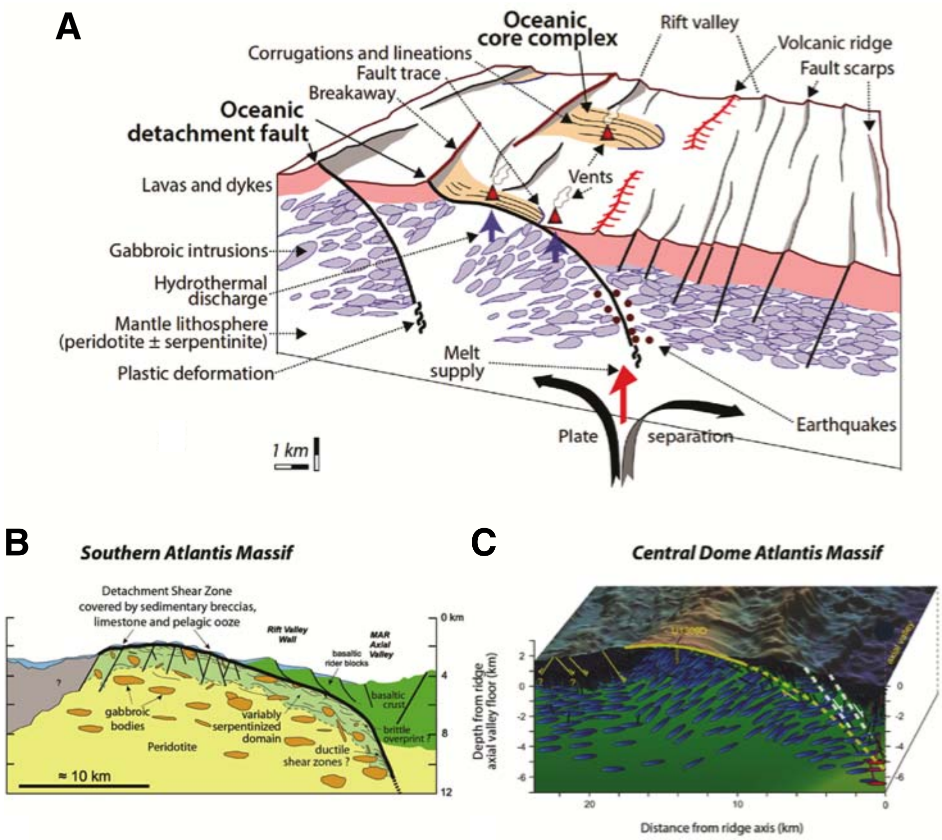


Figure F3. Field relations in the target area along the Atlantis Massif southern wall. A. Sedimentary cap sequences overlie the detachment fault zone (consisting of variably thick zones of talc-amphibole schists within mylonitic and serpentinized peridotites) (Boschi et al., 2006; Karson et al., 2006). B. These sequences underlie hydrothermal deposits in the vicinity of the LCHF (Karson et al., 2006; copyright 2006 by the American Geophysical Union). C. Above the LCHF, the cap sediments are cut by hydrothermal carbonates. D. These carbonates are locally venting diffuse fluids and have microbial filaments.

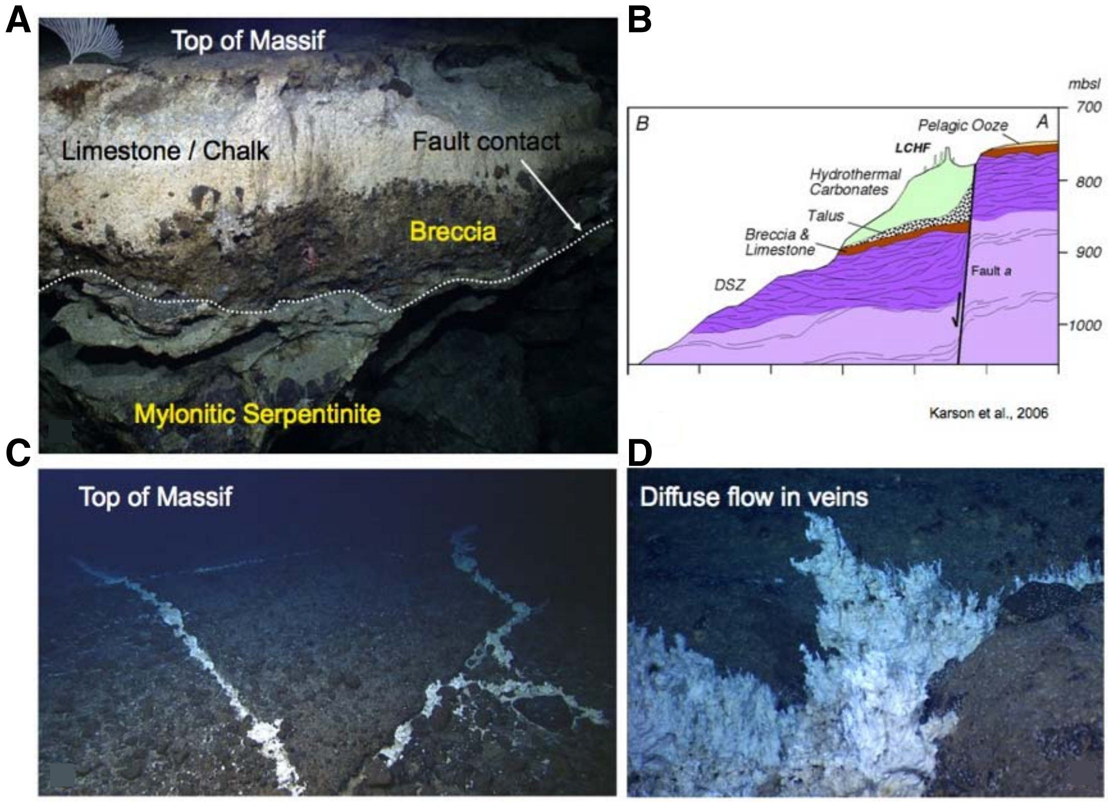
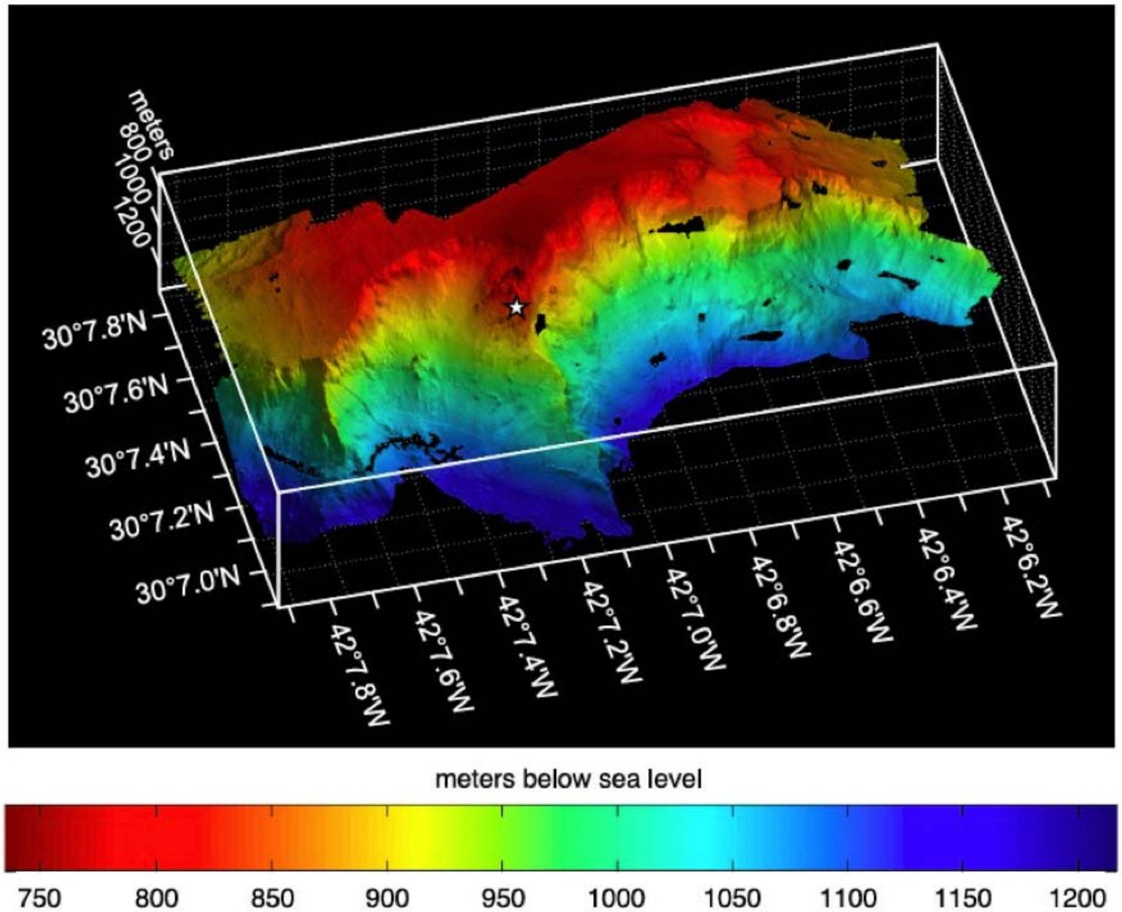


Figure F4. High-resolution bathymetry and 3-D image of the top of the Atlantis Massif southern wall viewed to the northeast, based on ABE SM 2000 data. Black areas = data gaps. This area is characterized by a flat top and arcuate scarps formed by mass movements. Star = location of LCHF. From Karson et al. (2006; copyright 2006 by the American Geophysical Union).



Site summaries

Proposed Site AM-01A

Priority:	Primary
Position:	30°07.80′N, 42°07.33′W
Water depth (m):	720
Target drilling depth (mbsf):	50–80
Approved maximum penetration (mbsf):	100
Seismic coverage:	Primary line: multichannel seismic Line MEG-4 crosses Site AM-01A; Line MEG-9 is just north of Site AM-01A (Cruise EW01-12: Canales et al., 2004, 2008; Henig et al., 2009).
Swath bathymetry:	• 100% coverage, Cruise CD100 Simrad. • DSL-120 bathymetry along tracks, in part of poor quality and with artifacts.
Side-scan sonar (bottom):	• TOBI from Cruise CD100 (Cann et al., 1997; Blackman et al., 1998). • DSL-120 (figure 8 in Blackman et al., 2002), in part of poor quality and with artifacts. • SM2000 with ABE (2 m resolution; figure 3 in proposal; Kelley et al., 2005; Karson et al., 2006).
Imagery:	• *ArgoII* and *Alvin* Dives 3645, 3645, 3651, and 3652 during Cruise AT3-60. • 19 *Alvin* dives during Cruise AT7-34 in 2003 (Blackman et al., 2002; Karson et al., 2006; Kelley et al., 2005). • *Argus/Hercules* Cruise NOAA-OE 2005 high-definition imaging (Kelley et al., 2007).
Sampling:	• *Alvin* Dives 3645, 3645, 3651, and 3652 during Cruise AT3-60. • 19 *Alvin* dives during Cruise AT7-34 in 2003. • 8 dives with ROV *Hercules* (NOAA-OE 2005).
Objectives (see text for details):	• Sample the upflow region of hydrothermal flow directly north of the Lost City field. • Recover continuous core of sediments, hydrothermal deposits, detachment fault zone consisting of talc-amphibole-chlorite schists, and serpentinites for petrological, geochemical, and microbiological studies. • Log, depending on the final seabed rock drill capabilities. • Determine constraints on the alteration end-member component of present-day serpentinization. • Evaluate microbial activity in the upflow and discharge region, prioritizing Sites AM-01A and/or AM-11A and AM-06A. • Install borehole plugs, prioritizing Sites AM-01A and AM-06A. • Plug additional holes where possible, allowing for borehole conditions, time, and cost efficiencies.
Drilling program:	1 hole using HQ-based diamond rotary hard rock coring techniques operated from a seafloor drill to target depth.
Downhole logging program:	The final downhole logging program will be constructed by the EPC working in conjunction with the Expedition Project Manager, Co-Chief Scientists, and operational team. This program can be adjusted on a site-by-site basis offshore, coordinated by the Petrophysics Staff Scientist, to respond to hole conditions, other operational constraints, and scientific considerations. Measurements will be selected from spectral gamma ray, induction resistivity, magnetic susceptibility, and image logs (optical/acoustic: RD2 only).
Anticipated lithology (seismic interpretation):	• 0 to ~3 mbsf: lithified pelagic carbonates and basaltic breccias (in carbonate matrix). • ~3–100 mbsf: Variably serpentinized peridotite with zones of talc-amphibole-chlorite schists and metagabbros (detachment fault zone assumed velocity = 7–7.5 km/s).

Proposed Site AM-02A

Priority:	Primary
Position:	30°07.50′N, 42°05.75′W
Water depth (m):	1140
Target drilling depth (mbsf):	50–80
Approved maximum penetration (mbsf):	100
Seismic coverage:	Primary line: MEG-9 ~0.5 km north of Site AM-02A (grid of five multichannel seismic lines, Cruise EW01-12: Canales et al., 2004, 2008; Henig et al., 2009).
Swath bathymetry:	• 100% coverage, Cruise CD100 Simrad. • DSL-120 bathymetry along tracks, in part of poor quality and with artifacts.
Side-scan sonar (bottom):	• TOBI from Cruise CD100 (Cann et al., 1997; Blackman et al., 1998). • DSL-120 (figure 12 in Blackman et al., 2002) ~0.5 km east of coverage with SM2000 with ABE (2 m resolution; Kelley et al., 2005; Karson et al., 2006).
Imagery:	*ArgoII* Dive 47 and *Alvin* Dive 3876 ~1 km west of Site AM-02A (Blackman et al., 2002; Karson et al., 2006; Kelley et al., 2005).
Sampling:	*Alvin* Dive 3876.
Objectives (see text for details):	• Drill an age transect to younger exposure on seafloor. • Recover continuous core of sediments and detachment fault zone consisting of talc-amphibole-chlorite schists and serpentinites for petrological, geochemical, and microbiological studies. • Log, depending on the final seabed rock drill capabilities. • Install borehole plugs, prioritizing Sites AM-01A and AM-06A. • Plug additional holes where possible, allowing for borehole conditions, time, and cost efficiencies.
Drilling program:	1 hole using HQ-based diamond rotary hard rock coring techniques operated from a seafloor drill to target depth.
Downhole logging program:	The final downhole logging program will be constructed by the EPC working in conjunction with the Expedition Project Manager, Co-Chief Scientists, and operational team. This program can be adjusted on a site-by-site basis offshore, coordinated by the Petrophysics Staff Scientist, to respond to hole conditions, other operational constraints, and scientific considerations. Measurements will be selected from spectral gamma ray, induction resistivity, magnetic susceptibility, and image logs (optical/acoustic: RD2 only).
Anticipated lithology (seismic interpretation):	• 0 to ~3 mbsf: lithified pelagic carbonates and basaltic breccias (in carbonate matrix). • ~3–100 mbsf: Variably serpentinized peridotite with zones of talc-amphibole-chlorite schists and metagabbros (detachment fault zone assumed velocity = 7–7.5 km/s).

Proposed Site AM-03A

Priority:	Primary
Position:	30°07.67′N, 42°03.91′W
Water depth (m):	1590
Target drilling depth (mbsf):	50–80
Approved maximum penetration (mbsf):	100
Seismic coverage:	Primary line: multichannel seismic Line MEG-9 crosses Site AM-03A; MEG-05 is ~1 km west of Site AM-03A (Cruise EW01-12: Canales et al., 2004, 2008; Henig et al., 2009).
Swath bathymetry:	• 100% coverage, Cruise CD100 Simrad. • DSL-120 bathymetry along tracks, in part of poor quality and with artifacts.
Side-scan sonar (bottom):	• TOBI from Cruise CD100 (Cann et al., 1997; Blackman et al., 1998). • DSL-120 (figure 13 in Blackman et al., 2002).
Imagery:	*Alvin* Dive 3647 and Dredge 3 during Cruise AT3-60 (Blackman et al., 2002; Karson et al., 2006; Boschi et al., 2006).
Sampling:	*Alvin* Dive 3647 and Dredge 3 during Cruise AT3-60 (Blackman et al., 2002; Karson et al., 2006; Boschi et al., 2006).
Objectives (see text for details):	• Drill an age transect to younger exposure on seafloor (youngest site). • Recover continuous core of sediments, detachment fault surface, and talc-amphibole-chlorite schists and serpentinites for petrological, geochemical, and microbiological studies. • Log, depending on the final seabed rock drill capabilities. • Install borehole plugs, prioritizing Sites AM-01A and AM-06A. • Plug additional holes where possible, allowing for borehole conditions, time, and cost efficiencies.
Drilling program:	1 hole using HQ-based diamond rotary hard rock coring techniques operated from a seafloor drill to target depth.
Downhole logging program:	The final downhole logging program will be constructed by the EPC working in conjunction with the Expedition Project Manager, Co-Chief Scientists, and operational team. This program can be adjusted on a site-by-site basis offshore, coordinated by the Petrophysics Staff Scientist, to respond to hole conditions, other operational constraints, and scientific considerations. Measurements will be selected from spectral gamma ray, induction resistivity, magnetic susceptibility, and image logs (optical/acoustic: RD2 only).
Anticipated lithology (seismic interpretation):	• 0 to ~2 mbsf: lithified pelagic carbonates and basaltic breccias (in carbonate matrix). • ~2–100 mbsf: Variably serpentinized peridotite with zones of talc-amphibole-chlorite schists and metagabbros (detachment fault zone assumed velocity = 7–7.5 km/s).

Proposed Site AM-04A

Priority:	Primary
Position:	30°07.70′N, 42°09.20′W
Water depth (m):	1350
Target drilling depth (mbsf):	50–80
Approved maximum penetration (mbsf):	100
Seismic coverage:	Primary line: multichannel seismic Line MEG 9 north of Site AM-04A; Line MEG 6 within 1 km east of Site AM-04A (Cruise EW01-12: Canales et al., 2004, 2008; Henig et al., 2009).
Swath bathymetry:	• 100% coverage, Cruise CD100 Simrad. • DSL-120 bathymetry along tracks, in part of poor quality and with artifacts.
Side-scan sonar (bottom):	• TOBI from Cruise CD100 (Cann et al., 1997; Blackman et al., 1998). • DSL-120 (figure 13 in Blackman et al., 2002). • SM2000 with ABE (2 m resolution; Kelley et al., 2005; Karson et al., 2006).
Imagery:	*ArgoII* dive west of Site AM-04A (Blackman et al., 2002; Karson et al., 2006).
Sampling:	None available.
Objectives (see text for details):	• Drill an age transect to older exposure on seafloor. • Recover continuous core of sediments, detachment fault surface, and talc-amphibole-chlorite schists and serpentinites for petrological, geochemical, microbiological studies. • Log, depending on the final seabed rock drill capabilities. • Install borehole plugs, prioritizing Sites AM-01A and AM-06A. • Plug additional holes where possible, allowing for borehole conditions, time, and cost efficiencies.
Drilling program:	1 hole using HQ-based diamond rotary hard rock coring techniques operated from a seafloor drill to target depth.
Downhole logging program:	The final downhole logging program will be constructed by the EPC working in conjunction with the Expedition Project Manager, Co-Chief Scientists, and operational team. This program can be adjusted on a site-by-site basis offshore, coordinated by the Petrophysics Staff Scientist, to respond to hole conditions, other operational constraints, and scientific considerations. Measurements will be selected from spectral gamma ray, induction resistivity, magnetic susceptibility, and image logs (optical/acoustic: RD2 only).
Anticipated lithology (seismic interpretation):	0 to ~3 mbsf: lithified pelagic carbonates and basaltic breccias (in carbonate matrix). ~3–100 mbsf: variably serpentinized peridotite with zones of talc-amphibole-chlorite schists and metagabbros (detachment fault zone assumed velocity = 7–7.5 km/s).

Proposed Site AM-05A

Priority:	Primary
Position:	30°07.88′N, 42°10.96′W
Water depth (m):	870
Target drilling depth (mbsf):	50–80
Approved maximum penetration (mbsf):	100
Seismic coverage:	Primary line: multichannel seismic Line MEG-9 north of Site AM-05A (Canales et al., 2004, 2008; Henig et al., 2009).
Swath bathymetry:	• 100% coverage, Cruise CD100 Simrad. • DSL-120 bathymetry along tracks, in part of poor quality and with artifacts.
Side-scan sonar (bottom):	• TOBI from Cruise CD100 (Cann et al., 1997; Blackman et al., 1998). • DSL-120 (figure 13 in Blackman et al., 2002). • SM2000 with ABE (2 m resolution; Kelley et al., 2005; Karson et al., 2006).
Imagery:	*ArgoII* dive east of Site AM-05A (Blackman et al., 2002; Karson et al., 2006).
Sampling:	None available.
Objectives (see text for details):	• Drill an age transect to older exposure on seafloor (oldest site). • Recover continuous core of sediments, detachment fault surface, and talc-amphibole-chlorite schists and serpentinites for petrological, geochemical, and microbiological studies. • Log, depending on the final seabed rock drill capabilities. • Install borehole plugs, prioritizing Sites AM-01A and AM-06A. • Plug additional holes where possible, allowing for borehole conditions, time, and cost efficiencies.
Drilling program:	1 hole using HQ-based diamond rotary hard rock coring techniques operated from a seafloor drill to target depth.
Downhole logging program:	The final downhole logging program will be constructed by the EPC working in conjunction with the Expedition Project Manager, Co-Chief Scientists, and operational team. This program can be adjusted on a site-by-site basis offshore, coordinated by the Petrophysics Staff Scientist, to respond to hole conditions, other operational constraints, and scientific considerations. Measurements will be selected from spectral gamma ray, induction resistivity, magnetic susceptibility, and image logs (optical/acoustic: RD2 only).
Anticipated lithology (seismic interpretation):	• 0 to ~3 mbsf: lithified pelagic carbonates and basaltic breccias (in carbonate matrix). • ~3–100 mbsf: variably serpentinized peridotite with zones of talc-amphibole-chlorite schists and metagabbros (detachment fault zone assumed velocity = 7–7.5 km/s).

Proposed Site AM-06A

Priority:	Primary
Position:	30°07.95′N, 42°07.20′W
Water depth (m):	870
Target drilling depth (mbsf):	50–80
Approved maximum penetration (mbsf):	100
Seismic coverage:	Primary line: multichannel seismic Lines MEG-4 and MEG-9 cross Site AM-06A (Cruise EW01-12: Canales et al., 2004, 2008; Henig et al., 2009).
Swath bathymetry:	• 100% coverage, Cruise CD100 Simrad. • DSL-120 bathymetry along tracks, in part of poor quality and with artifacts.
Side-scan sonar (bottom):	• TOBI from Cruise CD100 (Cann et al., 1997; Blackman et al., 1998). • DSL-120 (Blackman et al., 2002).
Imagery:	~1 km south: • *ArgoII* and *Alvin* Dive 3652 during Cruise AT3-60. • 19 *Alvin* dives during Cruise AT7-34 in 2003 (Blackman et al., 2002; Karson et al., 2006; Kelley et al., 2005). • *Argus/Hercules* NOAA-OE 2005 high-definition imaging (Kelley et al., 2007).
Sampling:	Sampling: • *Alvin* Dive 3652 during Cruise AT3-60 • *Alvin* Dives 3863, 3867, 3873, 3876 during Cruise AT7-34 in 2003.
Objectives (see text for details):	• Sample the upflow region of hydrothermal flow directly north of the Lost City field. • Recover continuous core of sediments, hydrothermal deposits, detachment fault surface, and talc-amphibole-chlorite schists and serpentinites for petrological, geochemical, microbiological studies. • Log and sample fluids, depending on the final seabed rock drill capabilities. • Determine constraints on the alteration end-member component of present-day serpentinization, prioritzing Sites AM-01A and/or AM-11A and AM-06A to evaluate microbial activity in the upflow and discharge region. • Install borehole plugs, prioritizing Sites AM-01A and AM-06A. • Plug additional holes where possible, allowing for borehole conditions, time, and cost efficiencies.
Drilling program:	1 hole using HQ-based diamond rotary hard rock coring techniques operated from a seafloor drill to target depth.
Downhole logging program:	The final downhole logging program will be constructed by the EPC working in conjunction with the Expedition Project Manager, Co-Chief Scientists, and operational team. This program can be adjusted on a site-by-site basis offshore, coordinated by the Petrophysics Staff Scientist, to respond to hole conditions, other operational constraints, and scientific considerations. Measurements will be selected from spectral gamma ray, induction resistivity, magnetic susceptibility, and image logs (optical/acoustic: RD2 only).
Anticipated lithology (seismic interpretation):	• 0 to ~3 mbsf: lithified pelagic carbonates and basaltic breccias (in carbonate matrix). • ~3–100 mbsf: variably serpentinized peridotite with zones of talc-amphibole-chlorite schists and metagabbros (detachment fault zone assumed velocity = 7–7.5 km/s).

Proposed Site AM-07A

Priority:	Primary
Position:	30°08.55′N, 42°08.18′W
Water depth (m):	1150
Target drilling depth (mbsf):	50–80
Approved maximum penetration (mbsf):	100
Seismic coverage:	Primary line: multichannel seismic Line MEG-6 crosses Site AM-07A, MEG-9 within 500 m south of Site AM-07A (Cruise EW01-12: Canales et al., 2004, 2008; Henig et al., 2009).
Swath bathymetry:	• 100% coverage, Cruise CD100 Simrad. • DSL-120 bathymetry along tracks, in part of poor quality and with artifacts.
Side-scan sonar (bottom):	TOBI from Cruise CD100 (Cann et al., 1997; Blackman et al., 1998).
Imagery:	No photography or video available.
Sampling:	None available.
Objectives (see text for details):	• Study axis-parallel variations in lithologies, alteration, and microbial activity away from the focus of present-day fluid discharge. • Recover continuous core of sediments, detachment fault surface, and talc-amphibole-chlorite schists, serpentinites, and gabbroic rocks for petrological, geochemical, and microbiological studies. • Log, depending on the final seabed rock drill capabilities. • Install borehole plugs, prioritizing Sites AM-01A and AM-06A. • Plug additional holes where possible, allowing for borehole conditions, time, and cost efficiencies.
Drilling program:	1 hole using HQ-based diamond rotary hard rock coring techniques operated from a seafloor drill to target depth.
Downhole logging program:	The final downhole logging program will be constructed by the EPC working in conjunction with the Expedition Project Manager, Co-Chief Scientists, and operational team. This program can be adjusted on a site-by-site basis offshore, coordinated by the Petrophysics Staff Scientist, to respond to hole conditions, other operational constraints, and scientific considerations. Measurements will be selected from spectral gamma ray, induction resistivity, magnetic susceptibility, and image logs (optical/acoustic: RD2 only).
Anticipated lithology (seismic interpretation):	• 0 to ~3 mbsf: lithified pelagic carbonates and basaltic breccias (in carbonate matrix). • ~3–100 mbsf: variably serpentinized peridotite with zones of talc-amphibole-chlorite schists and metagabbros (detachment fault zone assumed velocity = 7–7.5 km/s). • Depth and/or thickness of detachment fault zone unknown; transition from serpentinite to gabbroic basement.

Proposed Site AM-08A

Priority:	Primary
Position:	30°09.50′N, 42°08.05′W
Water depth (m):	1490
Target drilling depth (mbsf):	50–80
Approved maximum penetration (mbsf):	100
Seismic coverage:	Primary line: multichannel seismic Line MEG-6 crosses Site AM-08A (Cruise EW01-12: Canales et al., 2004, 2008).
Swath bathymetry:	• 100% coverage, Cruise CD100 Simrad. • DSL-120 bathymetry along tracks, in part of poor quality and with artifacts.
Side-scan sonar (bottom):	• TOBI from Cruise CD100 (Cann et al., 1997; Blackman et al., 1998). • DSL-120 (figure 6A in Blackman et al., 2002).
Imagery:	*ArgoII* dive to the west, *Alvin* Dive 3653 to the north (Blackman et al., 2002; Karson et al., 2006).
Sampling:	None available.
Objectives (see text for details):	• Study axis-parallel variations in lithologies, alteration, and microbial activity away from the focus of present-day fluid discharge. • Recover continuous core of sediments, detachment fault surface, and talc-amphibole-chlorite schists, serpentinites, and gabbroic rocks for petrological, geochemical, and microbiological studies. • Log, depending on the final seabed rock drill capabilities. • Install borehole plugs, prioritizing Sites AM-01A and AM-06A. • Plug additional holes where possible, allowing for borehole conditions, time, and cost efficiencies.
Drilling program:	1 hole using HQ-based diamond rotary hard rock coring techniques operated from a seafloor drill to target depth.
Downhole logging program:	The final downhole logging program will be constructed by the EPC working in conjunction with the Expedition Project Manager, Co-Chief Scientists, and operational team. This program can be adjusted on a site-by-site basis offshore, coordinated by the Petrophysics Staff Scientist, to respond to hole conditions, other operational constraints, and scientific considerations. Measurements will be selected from spectral gamma ray, induction resistivity, magnetic susceptibility, and image logs (optical/acoustic: RD2 only).
Anticipated lithology (seismic interpretation):	• 0 to ~3 mbsf: (semi)lithified pelagic carbonates and basaltic breccias (in carbonate matrix). • ~3–100 mbsf: variably serpentinized peridotite with zones of talc-amphibole-chlorite schists and metagabbros in fault zone; gabbros in basement (detachment fault zone assumed velocity = 7–7.5 km/s). • Depth and/or thickness of detachment fault zone unknown; gabbroic basement expected.

Proposed Site AM-09A

Priority:	Primary
Position:	30°09.85′N, 42°07.32′W
Water depth (m):	1560
Target drilling depth (mbsf):	30–50
Approved maximum penetration (mbsf):	100
Seismic coverage:	Primary line: multichannel seismic Line MEG 4 passes within 500 m of Site AM-09A (Cruise EW01-12: Canales et al., 2004, 2008; Henig et al., 2009).
Swath bathymetry:	• 100% coverage, Cruise CD100 Simrad. • DSL-120 bathymetry along tracks, in part of poor quality and with artifacts.
Side-scan sonar (bottom):	• TOBI from Cruise CD100 (Cann et al., 1997; Blackman et al., 1998). • DSL-120 (figure 6A in Blackman et al., 2002).
Imagery:	*ArgoII*, *Alvin* Dive 3653 (Blackman et al., 2002; Karson et al., 2006; Boschi et al., 2006).
Sampling:	• *Alvin* Dives 3641, 3642, 3653 during Cruise AT3-60 (Blackman et al., 2002; Karson et al., 2006; Boschi et al., 2006). • IODP drill cores from Site U1309. IODP Expedition 304/305 drilled at 3 sites. Full suite of standard IODP downhole logging tools were deployed in Holes U1309B and U1309D.
Objectives (see text for details):	• Study axis-parallel variations in lithologies, alteration, and microbial activity away from the focus of present-day fluid discharge. • Recover continuous core of sediments, detachment fault surface, and talc-amphibole-chlorite schists, serpentinites, and gabbroic rocks for petrological, geochemical, and microbiological studies. • Log, depending on the final seabed rock drill capabilities. • Install borehole plugs, prioritizing Sites AM-01A and AM-06A. • Plug additional holes where possible, allowing for borehole conditions, time, and cost efficiencies.
Drilling program:	1 hole using HQ-based diamond rotary hard rock coring techniques operated from a seafloor drill to target depth.
Downhole logging program:	The final downhole logging program will be constructed by the EPC working in conjunction with the Expedition Project Manager, Co-Chief Scientists, and operational team. This program can be adjusted on a site-by-site basis offshore, coordinated by the Petrophysics Staff Scientist, to respond to hole conditions, other operational constraints, and scientific considerations. Measurements will be selected from spectral gamma ray, induction resistivity, magnetic susceptibility, and image logs (optical/acoustic: RD2 only).
Anticipated lithology (seismic interpretation):	• 0 to ~3 mbsf: (semi)lithified pelagic carbonates and basaltic breccias (in carbonate matrix). • ~3–100 mbsf: variably serpentinized peridotite with zones of talc-amphibole-chlorite schists and metagabbros in fault zone; gabbros in basement (detachment fault zone assumed velocity = 7–7.5 km/s). • Depth and/or thickness of detachment fault zone unknown; gabbroic basement expected.

Proposed Site AM-10A

Priority:	Primary
Position:	30°11.43′N, 42°07.04′W
Water depth (m):	1770
Target drilling depth (mbsf):	50–80
Approved maximum penetration (mbsf):	100
Seismic coverage:	Primary line: multichannel seismic Line MEG 10 is just south of Site AM-10A; Line MEG4 passes within 500 m of Site AM-10A (Cruise EW01-12: Canales et al., 2004, 2008; Henig et al., 2009).
Swath bathymetry:	• 100% coverage, Cruise CD100 Simrad • DSL-120 bathymetry along tracks, in part of poor quality and with artifacts.
Side-scan sonar (bottom):	• TOBI from Cruise CD100 (Cann et al., 1997; Blackman et al., 1998). • DSL-120 (figure 6A in Blackman et al., 2002).
Imagery:	*ArgoII*, *Alvin* Dive 3653 (Blackman et al., 2002; Karson et al., 2006; Boschi et al., 2006).
Sampling:	IODP drill cores from Site 1309.
Objectives (see text for details):	• Study axis-parallel variations in lithologies, alteration, and microbial activity away from the focus of present-day fluid discharge. • Recover continuous core of sediments, detachment fault surface, and talc-amphibole-chlorite schists, serpentinites, and gabbroic rocks for petrological, geochemical, and microbiological studies. • Log, depending on the final seabed rock drill capabilities. • Install borehole plugs, prioritizing Sites AM-01A and AM-06A. • Plug additional holes where possible, allowing for borehole conditions, time, and cost efficiencies.
Drilling program:	1 hole using HQ-based diamond rotary hard rock coring techniques operated from a seafloor drill to target depth.
Downhole logging program:	The final downhole logging program will be constructed by the EPC working in conjunction with the Expedition Project Manager, Co-Chief Scientists, and operational team. This program can be adjusted on a site-by-site basis offshore, coordinated by the Petrophysics Staff Scientist, to respond to hole conditions, other operational constraints, and scientific considerations. Measurements will be selected from spectral gamma ray, induction resistivity, magnetic susceptibility, and image logs (optical/acoustic: RD2 only).
Anticipated lithology (seismic interpretation):	• 0 to ~3 mbsf: (semi)lithified pelagic carbonates and basaltic breccias (in carbonate matrix). • ~3–100 mbsf: variably serpentinized peridotite with zones of talc-amphibole-chlorite schists and metagabbros in fault zone; gabbros in basement (detachment fault zone assumed velocity = 7–7.5 km/s). • Depth and/or thickness of detachment fault zone unknown; gabbroic basement expected.

Proposed Site AM-11A

Priority:	Alternate (for Site AM-01)
Position:	30°07.63′N, 42°07.10′W
Water depth (m):	750
Target drilling depth (mbsf):	50–80
Approved maximum penetration (mbsf):	100
Seismic coverage:	Primary line: multichannel seismic Line MEG-04 crosses Site AM-11A; Line MEG-09 is just north of Site AM-11A (Cruise EW01-12: Canales et al., 2004, 2008; Henig et al., 2009).
Swath bathymetry:	• 100% coverage, Cruise CD100 Simrad. • DSL-120 bathymetry along tracks, in part of poor quality and with artifacts.
Side-scan sonar (bottom):	• TOBI from Cruise CD100 (Cann et al., 1997; Blackman et al., 1998). • DSL-120 (figure 8 in Blackman et al., 2002). • SM2000 with ABE (2 m resolution, figure 3 in proposal; Kelley et al., 2005; Karson et al., 2006).
Imagery:	• *ArgoII* and *Alvin* Dives 3645, 3645, 3651, 3652 during Cruise AT3-60, 19 *Alvin* dives during Cruise AT7-34 in 2003 (Blackman et al., 2002; Karson et al., 2006; Kelley et al., 2005). • *Argus*/*Hercules* NOAA-OE 2005 high-definition imaging (Kelley et al., 2007).
Sampling:	• *Alvin* Dives 3645, 3645, 3651, 3652 during Cruise AT3-60. • 19 *Alvin* dives during Cruise AT7-34 in 2003. • 8 dives with ROV *Hercules* (NOAA-OE 2005).
Objectives (see text for details):	• Alternate Site to AM-01A as highest priority site to evaluate microbial activity in the upflow and discharge region. • Sample the upflow region of hydrothermal flow directly north of the Lost City field. • Recover continuous core of sediments, hydrothermal deposits, detachment fault surface, and talc-amphibole-chlorite schists and serpentinites for petrological, geochemical, and microbiological studies. • Log and sample fluids, depending on the final seabed rock drill capabilities. • Determine constraints on the alteration end-member component of present-day serpentinization. • Install borehole plugs, prioritizing Sites AM-01A and AM-06A. • Plug additional holes where possible, allowing for borehole conditions, time, and cost efficiencies.
Drilling program:	1 hole using HQ-based diamond rotary hard rock coring techniques operated from a seafloor drill to target depth.
Downhole logging program:	The final downhole logging program will be constructed by the EPC working in conjunction with the Expedition Project Manager, Co-Chief Scientists, and operational team. This program can be adjusted on a site-by-site basis offshore, coordinated by the Petrophysics Staff Scientist, to respond to hole conditions, other operational constraints, and scientific considerations. Measurements will be selected from spectral gamma ray, induction resistivity, magnetic susceptibility, and image logs (optical/acoustic: RD2 only).
Anticipated lithology (seismic interpretation):	0 to ~3 mbsf: lithified pelagic carbonates and basaltic breccias (in carbonate matrix). ~3–100 mbsf: variably serpentinized peridotite with zones of talc-amphibole-chlorite schists and metagabbros (detachment fault zone assumed velocity = 7–7.5 km/s).

Expedition scientists and scientific participants

An up-to-date list of expedition scientists will be posted on the IODP Expedition 357 webpage at **http://www.eso.ecord.org/expeditions/357/357.php**.