IODP Expedition 330: Louisville Seamount Trail

Site U1376 Summary

Background and Objectives

Background

Site U1376 (Prospectus Alternative Site LOUI-7A) on Burton Guyot was the fifth site drilled during Integrated Ocean Drilling Program (IODP) Expedition 330. This site and seamount have an estimated age of ~63-65 Ma, slightly older than Site U1375 on Achernar Guyot. Similar to Site U1375, new age data from Burton Guyot will fill in an important gap in the age *vs.* distance relationship of the Louisville Seamount Trail, providing key information in the reconstruction of past plate motions and the motion of the Louisville hotspot. This seamount is one of the smallest volcanoes in the Louisville Seamount Trail, with both Burton Guyot and Achernar Guyot having a base diameter smaller than 30 km. Site U1376 was targeted in the middle of this small edifice, away from its shelf edges and away from any packages of dipping volcaniclastics on its flanks, the latter sequences which were targeted at Sites U1372, U1373 and U1374. Sidescan sonar reflectivity survey and 3.5 kHz sub-bottom profiling data indicated that Site U1375 is covered with less than 10 m of pelagic sediment and seismic reflection profiles indicate that this central part of Burton Guyot is typified by a less than 110 m thick sequence of volcaniclastics overlaying igneous basement.

The original drilling plan was to recover the soft sediment using a gravity-push approach with little or no rotation using a Rotary Core Barrel (RCB), followed by standard coring into the volcaniclastic materials and down to 350 m into igneous basement. A short downhole logging series was planned including the standard Triple Combo and FMS-Sonic tool strings, and the third-party Göttingen Borehole Magnetometer (GBM) tool. Drilling and logging were successfully accomplished after drilling to 183 mbsf and carrying out the planned logging program. Coring was particularly successful with an average recovery of 75.6% in igneous basement.

Objectives

Drilling during ODP Leg 197 provided the first compelling evidence for the motion of mantle plumes by documenting a large ~15° shift in paleolatitude for the Hawaiian hotspot (Tarduno et al., 2003; Duncan et al., 2006). This lead to two geodynamical end-member models that are being tested during Expedition 330, namely that the Louisville and Hawaiian hotspots moved coherently over geological time (Wessel and Kroenke 1997; Courtillot et al. 2003) or, quite the opposite, that these hotspots show considerable inter-hotspot motions, as predicted by mantle flow models (Steinberger, 2002; Steinberger et al., 2004; Koppers et al., 2004; Steinberger and Antretter, 2006; Steinberger and Calderwood, 2006). The most important objective of Expedition 330 therefore was to core deep into the igneous basement of four Louisville seamounts in order to sample a large number of *in situ* lava flows ranging in age between 80 and 50 Ma. With a sufficiently large number of these independent cooling units high-quality estimates of their paleolatitude can be determined, and any recorded paleolatitude shift (or lack thereof) can be compared with seamounts in the Hawaiian-Emperor seamount trail. For this reason Expedition 330 mimicked the drilling strategy of ODP Leg 197 by drilling Louisville guyots equivalent in age to Detroit (76-81 Ma), Suiko (61 Ma), Nintoku (56 Ma) and Koko (49 Ma) in the Emperor seamounts, with Achernar Guyot being equivalent to Suiko Seamount. Accurate paleomagnetic inclination data are required for the drilled seamounts in order to establish a record of the past motion of the Louisville hotspot, and together with high-resolution $^{40}Ar/^{39}Ar$ age dating of the cored lava flows, these data will help us to constrain the paleolatitudes of the Louisville hotspot between 80 and 50 Ma.

Expedition 330 also aimed to provide important insights into the magmatic evolution and melting processes that produced and constructed Louisville volcanoes while progressing from their shield to post-shield, and maybe post-erosional, volcanic stages. Existing data from dredged lavas suggest that the mantle source of the Louisville hotspot has been remarkably homogeneous for as much as 80 m.y. (Cheng et al., 1987; Hawkins et al., 1987; Vanderkluysen et al., 2011). In addition, all dredged basalts are predominantly alkalic and possibly represent a mostly alkalic shield-building stage, which is in contrast to the tholeiitic shield-building stage of volcanoes in the Hawaiian-Emperor seamount trail (Hawkins et al., 1987; Vanderkluysen et al., 2011). Therefore, the successions of lava flows cored during Expedition 330 will help us to characterize the Louisville seamount trail as the product of a *primary* hotspot and to test the long-lived homogeneous geochemical character of its mantle source. Analyses of melt inclusions, volcanic glass samples, primitive basalts, high-Mg olivines and clinopyroxene phenocrysts will provide further constraints on the asserted homogeneity of the Louisville plume source, its compositional evolution between 80 and 50 Ma, potential mantle plume temperatures, and its magma genesis, volatile outgassing and differentiation. Finally, basalts and sediments cored at Site U1376 were planned to be used for a range of secondary objectives such as searching for active microbial life in the old seamount basements and to find fossil traces of these microbes left behind in volcanic glasses and biofilms on the rocks.

Operations

The vessel arrived at Site U1376 (Prospectus Alternate Site LOUI-7A) on Burton Guyot at 2300 hr on 26 January. Prior to spudding, the vibration-isolated television (VIT) was launched to observe the character of the seafloor and the tagging of the bit on the bottom. A rocky seabed devoid of any appreciable sediment was observed. After a 2.3 hour survey, a spot with a very small sediment pond was found, but it was clear that this would be essentially a hard rock entry, which would not support a potential free fall funnel (FFF) installation.

The driller tagged the seafloor at 1514.3 mbrf (1503.3 mbsl) and spudded Hole U1376A with the rotary core barrel (RCB) assembly at 0705 hr on 27 January. Coring was suspended on 30 January at a depth of 86.8 mbsf to change the bit, which had accumulated 72.4 rotating hours. Because of the absence of sediment cover needed to support an FFF installation, a marker comprised of a single glass float was remotely released from the VIT frame via an acoustic release. The bit cleared the seafloor at 1800 hr on 30 January. A new RCB bit was made up to the bottom hole assembly (BHA) and deployed. The open hole was successfully reentered at 0435 hr on 31 January. Coring continued without incident until the allocated coring time for this site expired at 1630 hr on 2 February leaving the hole at a final depth of 182.8 mbsf. The total average recovery for the hole was 74.5% with an excellent average recovery in basement of 75.6%. The average rate of penetration in basement was 1.8 m/hour.

Following a wiper trip, which included displacing the borehole with 42 barrels of heavy (10.5 ppg) mud, the bit was released at the bottom of the hole. The end of pipe was positioned at the logging depth of 80.4 mbsf by 2115 hr on 2 February. The Triple Combo (TC) tool string was deployed first. The tool was run into the hole at 2140 hr and reached a target depth of 1696.6 m wireline below rig floor (WRF) at 0139 hr (3 February). The TC made two full passes of the hole, and the tool string run was completed at 0511 hr (3 February). The second tool string deployed was the Göttingen Borehole Magnetometer (GBM). The GBM begins its log during the orientation (sighting) process on the rig floor and continuously collects data until its return to the rig floor following a down- and up-log portion. The GBM run began at 0531 hr, however, following a report that the pipe was stuck in the hole, the logging run was aborted and the tool returned to the surface (0643 hr). The tool was not totally rigged down and owing to its short length, was placed in one of the core barrel shucks on the rig floor. Once the pipe was worked free, the GBM tool was deployed again at 0726 hr. The tool ran perfectly with no communication or signal errors. It reached its target depths at 183 mbsf at 0956 hr. The tool returned to the surface at 1145 hr, was successfully sighted and rigged down by 1218 hr. The final tool deployed was the FMS-Sonic. The tool string was run into the hole at 1338 hr and successfully reached a depth of 182 mbsf. Two full passes were measured with the FMS-Sonic. The tool was rigged down by 1755 hr, and at this time logging operations concluded. All tool strings were able to reach their target depth in Hole U1376A and none of the tools encountered tight spots.

Once the logging was concluded, the drill string was recovered with the end of the pipe clearing the sea floor at 1850 hr on 3 February. Once the drill collars were set back in the derrick, the beacon recovered, and the drilling equipment secured, the vessel departed at

2200 hr for the 391 nmi voyage to the final site U1377 (LOUI-4B). The total time on Hole U1376A was 191 hours or 8.0 days.

Scientific Results

Sedimentology

Sediment at Site U1376 on Burton Guyot was restricted to the sedimentary cover only. Two stratigraphic units were defined on the basis of compositional and textural characteristics of the sediment at macroscopic and microscopic scales. Stratigraphic Unit I represents a younger sedimentary cover that extends between the seafloor and 23.45 mbsf. This cover is mostly composed of monolithic, juvenile volcaniclastic deposits, which extend between 4.50 and 21.48 mbsf. These deposits are interpreted as a possible record of a rejuvenated volcanic stage of Burton Guyot in a hemipelagic or pelagic environment. Other deposits of Subunit IA include layered volcanic breccias and sandstones, which are interpreted as turbidites and possible hyperconcentrated flow deposits. Four thin (<3 cm-thick) ferromanganese crusts occur in the uppermost part of the drilled sequence, which also yielded a minor amount of nannofossil and foraminifer-bearing chalk. Stratigraphic Unit II represents an older sedimentary cover of Burton Guyot that extends between 23.45 and 41.93 mbsf. A 15.15 m-thick interval of limestone (classified as boundstone-rudstone) occurs in the upper part of Unit II, which is composed of abundant red algae and minor amounts of other shallow marine fossils. This interval is interpreted to represent an algal reef that developed in very shallow marine conditions during subsidence of the drilled seamount. The base of Unit II between 38.60 and 41.93 mbsf is composed of a basalt conglomerate with few shallow marine bioclasts. The conglomerate emplaced on top of an erosional surface that marks the boundary between the sedimentary cover and underlying volcanic basement of Burton Guyot.

Biostratigraphy

Nannofossils found in the upper part of stratigraphic Subunit IA indicate a preliminary age of middle to late Miocene. No age diagnostic microfossils were identified in Subunit IB through Unit IV, but molluscan fossils may indicate a late Cretaceous age for Subunit IIB.

Igneous Petrology

The 140.9 m basement section cored at Site U1376 on Burton Guyot comprises a succession of basaltic breccia, pillow lava and massive lava flows. Two Units were defined on the basis of phenocryst minerals: Unit IV with mostly olivine phenocrysts, overlain by Unit III with olivine and augite phenocrysts. The bottom 13.1 m of the succession comprises mostly olivine-phyric basalt breccia, but an interval of highly vesicular aphyric basalt (166.5-167.2 mbsf) on top of this breccia heralds the arrival of a second, aphyric magma type. The next 31.7 m of the succession comprise heterolithic breccia with olivine-phyric and aphyric basalt clasts and thin flows of aphyric basalt. This interval records a period when two types of magma were being erupted in the area at the same time. The upper part of this interval (Lithologic Unit 26) consists of a number of highly vesicular and oxidized fragments of aphyric and olivine-phyric basalt, and may provide evidence for a period of shallow water or subaerial volcanism. Two thin flows of aphyric basalt separated by a 24 cm thick interval of olivine-phyric basalt breccia (Lithologic Units 22-24) mark the highest occurrence of aphyric basalt in the recovered eruptive succession (127.57 mbsf). The upper 17.35 m interval of Unit IV is composed of olivine-phyric hyaloclastite breccia containing a high proportion of fresh glass. Unit IV ends at an erosion surface that marks the beginning of Unit III and a change from magma crystallizing olivine alone to a slightly more evolved one that crystallized olivine and augite. Unit III includes a 33.11 m thick massive lava flow (Lithologic Unit 15). The presence of pillow lava high in the Unit III succession suggests that most, if not all, of the basement section was erupted in a marine environment.

Intrusive sheets (dikes) cutting Unit IV represent the last magmatic event recorded in the basement section of Burton Guyot. They were not seen in Unit III but may have extended through it. There are no aphyric basalt units in Unit III, immediately above the upper limit of the dikes, and therefore these dikes cannot be linked directly to any of the recovered volcanic units. It is possible that the dikes penetrated Unit III and fed lava flows that have since been removed by erosion. Alternatively, they may have fed aphyric lava flows similar to those in Unit IV and have been truncated at an erosion surface at the top of this unit. The presence of what looks like a fragment of a dike at the postulated erosion surface between Units IV and III supports this hypothesis.

A record of a post-erosional or rejuvenation phase of magmatism at Site U1376 is provided by the volcanic sands and breccias of sedimentary Unit I. Clasts in these sediments imply at least two magma types. Firstly, some of the sand layers contain fragments of hornblende and biotite, implying the eruption of magma more evolved than those represented by the basement succession. Secondly, Unit IC contains olivine-pyroxene aggregates that may be mantle xenoliths. This is supported by the occurrence of partly resorbed orthopyroxene xenocrysts in basalt clasts in Unit IC.

The presence of olivine and augite phenocrysts in the basaltic basement section at Site U1376, and the complete absence of plagioclase phenocrysts, suggests that the magmas were alkaline and more basic than those represented by most of the volcanic rocks drilled at Sites U1372, U1373 and U1374. Reaction coronae around orthopyroxene xenocrysts in basaltic clasts in sedimentary Unit I suggest that the rejuvenated stage magmas were strongly alkaline.

Alteration Petrology

The majority of the succession recovered from Hole U1376A has undergone some degree of secondary alteration by low temperature water-rock interactions and/or weathering, but large intervals are only slightly altered. The alteration of the volcanic rocks, consisting of basaltic flows, basaltic breccias, and hyaloclastite deposits, ranges from slightly to highly altered (between 2% and 95%). Several basaltic lava flows are relatively well preserved (10% or less alteration).

Core descriptions and thin section observations show that rocks in Hole U1376A are defined by a single overall alteration type typical for submarine environments. From the top of Hole U1376A to the bottom, the sequence displays a range in alteration, from slightly to highly altered, showing greenish colors indicating reducing conditions related to a submarine emplacement environment. Only minor and sporadic intervals in the upper 60 meters of the core show some reddish/brown alteration.

Augite is generally well-preserved, as phenocrysts and in the groundmass throughout the entire igneous portion of the core. Some olivine is completely altered to iddingsite, hematite, and Fe-oxyhydroxide near the top of the core, but large portions of the core contain fresh to slightly altered olivine. Some olivine in the greenish altered rocks is replaced by green clay and carbonates (calcite/magnesite).

Overall, three main groups of alteration phases could be distinguished. These are dominated by carbonates (Mg-calcite, aragonite, siderite) and clay minerals (saponite, nontronite). Other secondary phases (iddingsite, Fe oxyhydroxydes, hematite, goethite) are present and zeolites constitute only a minor amount of the alteration assemblage. Additionally numerous vesicles and veins were observed that are mainly filled with carbonates and clay minerals.

Structural Geology

Structural features at Site U1376 are dominated by veins (n=1190, with 1489 individual features) and vein networks (n=280, with 1995 individual veinlets). This site has the highest vein density of all Louisville seamounts drilled, with a maximum density of 39 veins/meter. Veins are also commonly wider than previously observed, with numerous veins between 5-10 mm wide, up to a maximum of 30 mm, indicating higher fluid flow than in previous sites. In further contrast to previous Louisville sites, veins and vein networks are abundant in breccias and hyaloclastites in addition to rheologically hard lava units, with the highest vein density actually occurring in hyaloclastite units at ~62 and 170 mbsf. The veins are dominantly shallowly dipping and often have sub-vertical fibrous mineral infills, both of which may indicate sub-vertical tension within this part of the seamount. The few fractures that are unfilled by veins (n = 55), are present mostly in the rheologically hard lava flows and intrusive sheets. Geopetal structures (n = 26) are horizontal, indicating that this part of the seamount has not been tilted since deposition of the geopetal infill material. Structural measurements were also undertaken for intervals with sedimentary bedding (n=153) and 7 igneous contacts.

Geochemistry

Major and trace element compositions of thirteen igneous samples from Site U1376 on Burton Guyot show general similarities to those from Site U1372 on Canopus Guyot and, to a lesser extent, Sites U1373 and U1374 on Rigil Guyot. However, as a group, the Site U1376 rocks are less alkalic. Alteration is generally moderate, and on a total alkalis ($Na_2O + K_2O$) vs. SiO_2 diagram most of the Site U1376 samples are classified as alkalic basalts, whereas four are transitional basalts. Olivine appears to have been the principal control on magmatic evolution. Seven highly olivine-phyric samples have high MgO (between 11.85 wt% and 16.79 wt%) and Ni contents and are likely to contain excess olivine crystals. These high-MgO basalts are distinct from other high-MgO rocks recovered during Expedition 330 in having somewhat lower Al_2O_3 concentrations. Downhole chemical variations indicate that three different magma types are represented among the lava samples from Site U1376. These types are generally consistent with the stratigraphic units defined petrographically. However, the composition of the topmost lava sample from Unit IV more closely resembles those of Unit III. One of the two aphyric dikes encountered in Unit IV is chemically similar to samples of low-MgO olivine-phyric lavas from Unit IV, but the other dike has a significantly higher Ba/Y ratio then other Site U1376 basalts.

Physical Properties

Physical property characterization was performed for material recovered from Site U1376. The different data sets are mutually consistent and show clear contrasts between lithified volcanic sandstone and conglomerate, carbonates, lava flows, and the pervasive volcanic hyaloclastites and breccias. In particular, the boundstone of Subunit IIA is characterized by very low magnetic susceptibility and natural gamma ray radiation. These carbonate samples have higher p-wave velocity and lower porosity than would be predicted based on their density, reflecting their different chemical composition when compared to the other basaltic lithologies. The 33 m thick lava flow in Unit III is characterized by an increase in magnetic susceptibility, p-wave velocity, and density.

Paleomagnetism

The natural remanent magnetization intensity of archive half-core samples from Hole U1376A ranges from 10^{-4} A/m to ~10 A/m (geometric mean = 0.4 A/m). The lowest values are associated with the sediments in Subunit IIA and the hyaloclastite in Unit IV, and the highest values are from the lava flows, intrusive sheets and basalt clasts in the volcanic breccia of Units III and IV. Relatively well-defined principal component directions were obtained for 1580 intervals from archive half-core measurements (for pieces >9 cm in length). These directions are generally consistent with stepwise alternating-field and thermal demagnetization results from 99 discrete samples. Both data sets reveal consistent reversed polarity magnetization throughout the hole.

Downhole Logging

Downhole logging of Hole U1376A took place between 2 February (2125 hrs NZDT) and 3 February (1755 hrs NZDT). We deployed three tool strings in Hole U1376A at Burton Guyot. Two tool strings took measurements of natural gamma ray radioactivity, density, neutron porosity, elastic wave velocity and collected borehole resistivity images. The third tool string, containing the third-party Göttingen Borehole Magnetometer (GBM), measured the three-component magnetic field in the drilled seamount formation. Measurement depths were adjusted to match across different logging runs, obtaining a wireline matched below seafloor (WMSF) depth scale. The logged depth interval for Hole U1376A was 80.4 – 182.3 m WMSF.

Resistivity, density, compressional velocity and neutron porosity derived from downhole logging measurements were used to identify a total of thirteen Log Units in Hole U1376A with three in the section covered by the bottom hole assembly (BHA) and ten in the volcanic sequences in the open hole interval. These defined Log Units correlated to changes from massive basalt flows (Stratigraphic Unit III) to more brecciated units, and interlayered aphyric and olivine-phyric flow units (Stratigraphic Unit IV).

The GBM was run once in Hole U1376A and collected good quality magnetic data, which will be reoriented postexpedition. The GBM data shows that the massive lava flow in Stratigraphic Unit III is not as homogeneous as it appears in the palaeomagnetic data obtained from the recovered cores from Hole U1376A. Additionally, in the unrecovered section of the hole, between ~130 and 140 mbsf, the GBM data shows strong variations. Post-expedition work, which will split the horizonal component into north and east components, should provide further insight into these observed variations.

Lithological and structural features are well imaged with the Formation MicroScanner (FMS), in particular fractures, clast size, shape and distribution and areas of solid, massive basalt versus brecciated material. Of particular importance is FMS coverage over the unrecovered section between ~130 and 140 mbsf because it will provide valuable information to reconstruct the lithology for this interval of the hole.

Microbiology

Eleven whole-round samples (5-13 cm long) were collected for microbiological analysis. Lithologies of the samples collected were volcanic sandstone (two), boundstone (two), volcanoclastic breccia (three) and basaltic lava flows (four). All samples were preserved for shore-based cell counting, deoxyribonucleic acid (DNA) analyses and $\delta^{34}S$ and $\delta^{13}C$ analyses. Five samples were used to inoculate culturing experiments with up to ten different types of cultivation media. Media targeting sulfur oxidizing bacteria and general heterotrophic bacteria were the most successful, and growth was detected in samples as deep as 174 mbsf. Two samples were used to set up stable isotope addition bioassays to determine rates of carbon and nitrogen utilization by subsurface microbes at Burton Guyot. One core was seeded with fluorescent microspheres, from which samples were collected for shipboard analysis of contamination via fluorescent microsphere counts. No microspheres were detected on the outside or inside of the whole round sample, indicating the likelihood for microbial contamination is low.

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