IODP Expedition 330: Louisville Seamount Trail

Site U1377 Summary

Background and Objectives

Background

Site U1377 (Prospectus Primary Site LOUI-4B) on Hadar Guyot (168.6°W Guyot) was the sixth and last site completed during Integrated Ocean Drilling Program (IODP) Expedition 330. This is also the youngest seamount targeted during Expedition 330 with a measured $^{40}Ar/^{39}Ar$ age of 50.1 Ma similar to Koko Seamount in the Hawaiian-Emperor Seamount Trail. Hadar Guyot belongs to a cluster of three seamounts that is located in close proximity to the Wishbone Scarp fault zone. Hadar Guyot is the smallest seamount cored during Expedition 330, consisting of a single volcanic center with a base diameter of ~25 km, and like all Louisville seamounts drilled, it has a flat summit plane, defining it as a guyot that at some point must have emerged above sea level as a volcanic island. Site U1377 was placed near the middle of this small edifice, away from its shelf edges and away from any packages of dipping volcaniclastics on its flanks. Sidescan sonar reflectivity survey and 3.5 kHz sub-bottom profiling data indicate that Site U1377 is covered with less than 8 m of pelagic sediment, and seismic reflection profiles show that this site is characterized by a 52 m thick section of dipping volcaniclastics and 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 material and 350 m into igneous basement. A full downhole logging series was planned including the standard Triple Combo and FMS-Sonic tool strings, the Ultrasonic Borehole Imaging (UBI) tool, and the third-party Göttingen Borehole Magnetometer (GBM) tool. Similar to drilling at Site U1375 on Achernar Guyot, drilling at Site U1377 became difficult after instabilities were met in the uppermost part of the seamount formation, likely due to the presence of loose clast-rich volcanic breccias, which were only rarely recovered due to the low 16% and 39%

recovery in Holes U1377A and U1377B. Drilling reached 53.3 mbsf in Hole U1377A and 37 mbsf in Hole U1377B, but due to time constraints no logging was carried out.

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.

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). However, since Site U1377 is located in close proximity to the Wishbone Scarp, it was speculated whether the recovered rocks would have a slightly different geochemical composition as a result of a possible step in lithosphere thickness across this scarp (Beier et al., 2011). 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. In addition, incremental heating $^{40}Ar/^{39}Ar$ age dating will allow us to establish age histories within each drill core delineating any transitions from the shield-building phase to the post-shield capping and post-erosional stages.

Finally, basalts and sediments cored at Site U1377 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. We also planned to determine $^{3}He/^{4}He$ and $^{186}Os/^{187}Os$ signatures of the Louisville mantle plume to evaluate its potential deep mantle origin, to use oxygen and strontium isotope measurements on carbonates and zeolites to assess the magnitude of carbonate vein formation in aging seamounts and its role as a global CO_2 sink, to age date celadonite alteration minerals for estimating the total duration of low-temperature alteration following seamount emplacement, and to determine the hydrogeological and seismological character of the seamount basement.

Operations

The vessel arrived on Site U1377 (Prospectus Site LOUI-4B) at 0930 hr on 5 February. A 3-stand rotary core barrel (RCB) drilling assembly was made up and seafloor was tagged at a depth of 1262.0 mbrf (2050.8 mbsl). The vibration-isolated television (VIT) showed a seabed that appeared to be mostly covered by a fine layer of sediment with a few rocks scattered about and didn't generate any anxiety regarding the spudding of the hole. Hole U1377A was spudded at 1510 hr. Rotary coring advanced with increasingly difficult hole conditions and overall poor recovery. Finally after coring to a depth of 53.3 mbsf, the hole became too unstable and had to be abandoned. The bit cleared the seafloor at 1815 hr on 6 February and was picked up to 1103 mbrf. The average recovery for Hole U1377A was 16.4%. The time expended at Hole U1377A was 12.5 hours.

It was decided to offset the vessel 500 m south of Hole U1377A and attempt to spud another hole at this site. After a 30 minute vessel offset with the bit 159 m above the seafloor, the vessel was on position. The VIT was deployed and a seafloor covered with soft sediment was observed. The driller tagged seafloor at 1262.0 mbsl. Hole U1377B was spudded with the RCB at 2325 hr on 6 February. Rotary coring advanced the hole to a final depth of 37.0 mbsf with an average recovery of 14.5% when time on site expired. After the drill string was recovered, and the beacon retrieved, the vessel departed Site U1377 for Auckland at 0730 hr on 8 February. The time on Hole U1377B was 57.5 hours and the total time on site was 70.0 hours (2.9 days). Because of concerns of moderate headwinds and rough seas on the transit to Auckland, the vessel departed the location approximately 18 hours earlier than originally planned.

Scientific Results

Sedimentology

Although the characterization of the stratigraphy at Site U1377 has been limited by a very poor recovery, observations define a consistent sedimentary pattern on top of Hadar Guyot. Two units were recognized based on macroscopic and microscopic observations of the sediment. Unit I represents the uppermost sediment of Hadar Guyot and was recovered at Holes U1377A and U1377B. The sediment is composed of nannofossil foraminiferal ooze, which strongly resembles the soft sediment recovered in the uppermost part of Sites U1372 on Canopus Guyot, U1374 on Rigil Guyot, and U1375 on Achernar Guyot, and is considered to reflect recent pelagic sedimentation on top of the drilled seamount. Unit II corresponds to few cuttings recovered in Section U1377A-3R-CC, and ten small-sized (<20 cm-thick) pieces recovered by drilling of *in situ* sediment (Holes U1377A and U1377A B) and out of sequence material due to partial collapse of Hole U1377B during drilling of Core U1377-3R. Unit II includes (1) a middle-late Eocene foraminiferal limestone with abundant planktonic foraminifers, a few ferromanganese encrustations, and rare shallow-marine bioclasts (e.g., echinoderm fragments); and (2) a latest Paleocene-early Eocene (see below), heterolithic multicolor basalt conglomerate with a few ferromanganese encrustations. The matrix of the conglomerate is composed of foraminiferal limestone with abundant plantkonic

foraminifers and a few shallow marine fossils (e.g., echinoderm fragments, larger foraminifera, shell fragments, and gastropod). Faunal assemblages and sedimentary textures indicate that Unit II at Site U1377 represents a (or several) condensed section(s) likely to have deposited in a shallow marine to hemipelagic-pelagic environment on top of Hadar Guyot.

Biostratigraphy

The foraminiferal ooze of Unit I from Holes U1377A and U1377B contained mixed assemblages of calcareous microfossils that displayed a range from Pliocene to Holocene, though Pleistocene to Holocene species are the dominant component. Planktonic foraminifers observed in thin sections, prepared from the limestone of Unit II from Holes U1377A and U1377B, indicate a preliminary age of middle-late Eocene and late Paleocene-early Eocene, respectively. This discrepancy may indicate the presence of diachronous limestones in Holes U1377A and U1377B. On the basis of these preliminary age estimates, an unconformity representing approximately 30 million years exists between Units I and II.

Igneous Petrology

Hole U1377A penetrated a total of 38.2 m of igneous rocks after entering the igneous basement at 15.1 mbsf. Hole U1377B penetrated a total of 27.9 m of igneous rocks after entering the igneous basement at 9.1 mbsf. The igneous sequences have been divided into six lithologic units in Hole U1377A and 18 in Hole U1377B. The similarity of the rocks throughout both sequences led to the definition of one stratigraphic unit in each hole (Unit III in both cases). The lithology in the two holes is broadly similar, consisting largely of aphyric trachybasalt with occasional olivine-rich bands, and in Hole U1377B intervals containing plagioclase-augite glomerocrysts. Throughout Hole U1377A and in the upper part of Hole U1377B the trachybasalt units exhibit intervals of pronounced flow banding, suggesting that these parts of the successions formed as massive lava flows or smaller lobate flows. There is no evidence in these flows that allows us to determine whether they erupted in a submarine or subaerial environment. The lower part of the succession in Hole U1377B, however, consists of much smaller (7 cm to 2.08 m)

individual cooling units with well-preserved, curved glassy margins, diagnostic of small lobate flows or pillows, and emplacement in a submarine environment. A curious feature of these margins is that, in several instances, the volcanic glass between adjacent pillows is seen to connect with the more massive interior of the unit below. It appears that lava in the still molten interior of a pillow has broken out as a protrusion that filled the space between overlying pillows. Alternatively, magma may have been injected into a stack of pillows, but the similarity in appearance between injected and pillow trachybasalt suggests that, in either case, both were part of the same eruptive event. The presence of glassy pillow margins that are distinct from the glass in the protrusions shows that the pillows must already have had glassy crusts when lava from below protruded into the space between them. In one case, fragments of the pillows are incorporated into the protrusion.

Time constraints limited the shipboard petrographic and geochemical investigation of the lithologic units at Site U1377 and so we have to infer the rock composition from visual inspection of the core. However, it seems likely that the magma represented by the rocks recovered at this site was generally alkalic and intermediate in composition. If post-cruise petrographic and analytical studies confirm this, then the rocks recovered at Site U1377 will have the most evolved composition of all rocks drilled during Expedition 330.

Alteration Petrology

The rocks recovered from Holes U1377A and U1377B have undergone secondary alteration by low temperature water-rock interactions and/or weathering. The overall alteration of the volcanic rocks from Hole U1377A ranges from slight to high (between 10% to 75%), whereas the rocks from Hole U1377B vary from moderately to completely altered (between 30 % to 100%). Brown to reddish brown alteration indicates the prevalence of oxidizing conditions at both sites. Olivine is typically completely altered to white clay minerals in rocks in Hole U1377A, and iddingsite, and Fe-oxyhydroxides in Hole U1377B. Plagioclase generally is well preserved, as phenocrysts and in the groundmass, in several lithologic units in Hole U1377B. A few sparse bands of relatively fresh glass are also present in margins of pillows or lava lobes toward the bottom of Hole

U1377B. Alteration phases for both holes are primarily carbonates (Mg-calcite, siderite, ankerite), white clay minerals, and Fe-oxyhydroxide (e.g., goethite). Fe-oxyhydroxide is particularly abundant in veins in the rocks from both holes.

Structural Geology

Structural features at Site U1377 are dominated by veins, vein networks, and vesicle bands. The highest vein density in Hole U1377A is at 15.1-16.6 mbsf (Lithological Unit 1), with 34 veins/meter, while most of the recovered intervals have between 5-25 veins/meter. In Hole U1377B the maximum vein density is 26 veins/meter, which occurs from 20-21 mbsf (Lithological Unit 2), while other recovered intervals typically have between 10-24 veins/meter. The veins in both holes have moderate to steep dips. A single horizontal geopetal structure at 0.85 mbsf in U1377B is evidence that this part of Hadar Guyot has not been tilted since deposition of the geopetal infilling material. Vesicle bands and chilled contacts in Hole U1377B are moderate to steep, with dips ranging from 45 to 90º. Vesicle bands (but not chilled contacts) were recovered in Hole U1377A, with either moderate or sub-horizontal dips.

Geochemistry

Major and trace element concentrations were measured for one altered (3.0 wt% loss on ignition) igneous sample from Unit III of Hole U1377A. It is the most siliceous rock analyzed during Expedition 330, with 55.00 wt% SiO_2. It also has the highest Al_2O_3, lowest $Fe_2O_3^T$ (total iron as Fe_2O_3), and second-lowest MgO and CaO concentrations. In a total alkalis ($Na_2O + K_2O$) vs. SiO_2 diagram, data for the sample fall in the field of basaltic trachyandesite, very near the dividing line between alkalic and tholeiitic compositions. However, alteration may have modified the rock's K_2O, and perhaps Na_2O, concentration. Concentrations of incompatible elements less susceptible to alteration are near the high end of values measured for other Expedition 330 rocks, suggesting the sample represents a highly differentiated transitional to alkalic magma that could have evolved from a composition rather similar to those of many of the Expedition 330 basalts. However, other characteristics of the sample complicate any simple explanation of its origin. In particular, concentrations of the compatible trace elements

Cr, Ni, and Co are anomalously high (686, 421, 122 ppm, respectively). The unusual combination of characteristics suggests the sample may represent an evolved magma that was contaminated by a small amount of olivine-rich material from a mush zone or ultramafic wall rock during ascent.

Physical Properties

Characterization of physical properties was conducted for material recovered at Site U1377. The data sets are mutually consistent and fall within the ranges expected based on the identified lithologies. Several distinct intervals of high magnetic susceptibility in excess of 2.5×10^{-2} SI are observed within the aphyric trachybasalt. In addition, the level of natural gamma ray radiation is higher in both Holes U1377A and U1377B than has been observed at earlier sites on Expedition 330; this is likely due to a combination of the increased alteration and more evolved magma composition at this site. This increased alteration is also seen in the strongly red and yellow color reflectance spectrum seen in Hole U1377B. Density and p-wave velocity are consistently lower than has been observed in lavas at earlier sites, possibly reflecting the more evolved composition.

Paleomagnetism

The natural remanent magnetization intensity of archive half-core samples from Site U1377 is typically less than 1 A/m, notably lower than for other guyots sampled during Expedition 330. This lower value presumably reflects the higher degree of alteration observed. Holes U1377A and U1377B had only shallow penetration and, particularly for Hole U1377A, poor core recovery. Nonetheless, samples from both holes appear to have moderate to steep positive inclinations, indicating southern hemisphere reversed polarity. Shipboard sampling at these holes was limited because of the short time remaining for shipboard analysis during the expedition.

Microbiology

Two whole-round samples (8-11 cm long) were collected for microbiological analysis, a moderately olivine-phyric trachybasalt from Hole U1377A and an aphyric trachybasalt from Hole U1377B. Both samples were preserved for shore-based cell counting,

deoxyribonucleic acid (DNA) analyses and $\delta^{34}S$ and $\delta^{13}C$ analyses. The sample from Hole U1377A was used to inoculate culturing experiments with nine different types of cultivation media targeting sulfur and iron cycling microbes and general heterotrophic bacteria. Both samples were used to set up stable isotope addition bioassays to determine rates of carbon and nitrogen utilization by subsurface microbes at Hadar Guyot.

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