IODP Expedition 330: Louisville Seamount Trail

Site U1373 Summary

Background and Objectives

Background

Site U1373 (Prospectus Site LOUI-6A) on Rigil Guyot (working name) was the second site completed during Integrated Ocean Drilling Program (IODP) Expedition 330 and the first of two sites that were drilled on this seamount (Sites U1373 and U1374). Although originally considered as an alternate site, it was selected after operations at Site U1372 on Canopus Guyot were cut short due to hole instability. Rigil Guyot represents one of the older Louisville seamounts with an age of ~73 Ma, only a few million years younger than Canopus Guyot to the northwest. If the Louisville hotspot experienced a paleolatitude shift similar to the recorded ~15° southern motion of the Hawaiian hotspot between 80 to 50 Ma, this shift is expected to be the largest for the oldest seamounts in the Louisville seamount trail. Because the seamount is only slightly younger than Canopus Guyot, it is expected that the obtained paleomagnetic data from Site U1373 will match those from Site U1372 and will thus strengthen the determination of the hotspot's paleolatitude at the old end of the trail. Therefore, coring deep into Rigil Guyot was of great importance.

Site U1373 was determined to be a good target, as it shows no evidence of tilting or significant post-erosional volcanism. The site was placed on the summit plain and close to its northern shelf edge at ~1440 m water depth. Sidescan sonar reflectivity and 3.5 kHz sub-bottom profiling data indicate that Site U1373 is covered with less than 10 m of pelagic sediment, and seismic reflection profiles (Expedition 330 Prospectus, Koppers et al., 2010) show that this site is characterized by a 110 m thick section of volcaniclastics dipping toward the south 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. However, upon tagging the seafloor before starting Hole U1373A a vibration-isolated television (VIT) camera survey clearly showed cobble fields covered by a patchy sediment blanket. Using the VIT camera, a better spot with more sediment cover was selected, but upon spudding into the hole it was clear a hard bottom entry had to be made. As a result, almost no soft pelagic sediment was recovered and coring went straight into consolidated volcaniclastics and basaltic basement was encountered at a depth of 33.9 mbsf. Because re-entry using a free fall funnel failed, Hole U1373A had to be abandoned, reaching only 64.0 mbsf. No downhole logging could be 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 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 inclination can be determined. In combination 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. Any recorded paleolatitude shift (or lack thereof) can then be compared with similar old seamounts in the Hawaiian-Emperor seamount trail.

Expedition 330 also aimed to provide important insights into the magmatic evolution and melting processes that produced and constructed the 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 (e.g., 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. 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.

Another important objective at Site U1373 was to use the new paleolatitude estimates, $^{40}Ar/^{39}Ar$ ages and geochemical data to decide whether the oldest Louisville seamounts were formed close to the 18-28°S paleolatitude determined from ODP Leg 192 basalts for the Ontong Java Plateau (Riisager et al., 2003) and whether this Large Igneous Province (LIP) was genetically linked to the Louisville hotspot or not. These data will help to prove or disprove the hypothesis that the Ontong Java Plateau originated from the preceding plume head stage of the Louisville hotspot triggering massive LIP volcanism around 120 Ma (e.g. Richards and Griffiths, 1989; Mahoney and Spencer, 1991).

Finally, basalts and sediment cored at Site U1373 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 at Site U1373 on Rigil Seamount (Prospectus Site LOUI-6A) at 1730 hr on 31 December, after a 146 nautical miles long voyage from Site U1372 that was accomplished at an average speed of 10.1 knots. A new rotary core barrel bottom hole assembly (BHA) with a C-4 bit and mechanical bit release was made up and deployed. The corrected precision depth recorder (PDR) depth for this site was 1455 mbrf. The vibration-isolated television (VIT) camera was deployed with the drill string and by 0200 hr on 1 January 2011 a seafloor strewn with large boulders and outcrops of hard rock was displayed on the monitor. From 0230 hr to 0445 hr a VIT survey was made around the periphery of the site until a clear area was found that appeared to be able to support a free fall funnel (FFF) deployment. After the driller tagged the seafloor at 1458.0 mbrf, (1447.0 mbsl) the top drive was picked up and Hole U1373A was spudded at 0700 hr on 1 January.

The hole was advanced to a depth of 64.0 mbsf at which point the bit had accumulated 69.7 rotating hours and required bit replacement. Basaltic basement was encountered at a depth of 33.9 mbsf, and with an average basement penetration rate of 0.9 m/hr. The strategy of pulling half-cores helped to increase the average basement recovery to 91%. The average recovery for the entire hole was 72%.

A FFF was made up and deployed at 1845 hr on 4 January. The VIT was launched and the free fall funnel monitored as the bit was withdrawn from the hole. The bit cleared the lip of the funnel at 2005 hr and was on deck by 1210 hr on 5 January. The used bit was found to be in excellent condition exhibiting slight cone wear, no missing inserts, tight bearings, and less than 1/8” under-gage in spite of having accumulated 70 rotating hours. A new bit was made up to the BHA and deployed along with an additional stand of drill collars.

From 0630 hr to 0845 hr the driller attempted a reentry into the FFF, but the bit appeared to bind about a foot into the throat of the funnel and could not be advanced any further. The mud pump flow was increased on the chance that any obstruction would be hydraulically dislodged, but the end result was that the FFF tipped over on its side. We surmised that the 2.7 m FFF casing was not lodged firmly in the hole when the old bit was withdrawn. The only element that was holding the FFF vertical was the pile of cuttings.

Although the open hole was not visible on the camera, the driller attempted a blind stab into the hole by lowering the bit into the sediment cover around the periphery of the FFF. This course of action was terminated after 2.25 hours and the decision was made to offset to a recently approved alternate site (Site LOUI-6B) located on the other side of the seamount's summit. After the drill string was picked up to 1111 mbrf, the vessel was offset in dynamic positioning (DP) mode to Site U1374 in the afternoon hours of 5 January.

Scientific Results

Sedimentology

Sediment at Site U1373 on Rigil Guyot is exclusively composed of basalt breccias and conglomerates, with various amounts of bioclasts. Occurrence of distinct sedimentary facies, sediment compositions and cementation patterns were recognized based on macroscopic and microscopic observations, which allowed definition of three stratigraphic units. Units I and III consist of sedimentary deposits, whereas Unit II (interlayered between Units I and III) is predominantly composed of basalt lava flows with two minor intervals of sediment. Unit I extends from 0 to 9.60 mbsf and has been subdivided into three subunits. (1) Subunit IA is composed of a 15 cm-thick multicolor, polymict bioclast basalt conglomerate. Cement textures and composition of the bioclasts (planktonic foraminifera, calcispheres, sponge(?) spicule, echinoderms, annelids, alga, bryozoans and bivalves) indicate deposition in a shallow-marine environment. (2) Subunit IB is composed of a 2.51 m-thick matrix-supported, brown basalt breccia with few shallow-marine bioclasts. The conglomerate has a heterogeneous clast composition and includes a calcareous-clayey matrix. It was interpreted as a mudflow deposit emplaced in a marine, shallow-water environment. (3) Subunit IC is a 0.39 cm-thick multicolor bioclast basalt conglomerate similar in terms of composition and environment of deposition to Subunit IA above. Unit II (volcanic interval) is 6.10 m thick and includes two, thin (<50 cm-thick) inter-lava flow sedimentary deposits. The sedimentary deposits consist of fossil-free, heterolithic, multicolor basalt breccias, which were interpreted as proximal debris flows. Subunit III is another sedimentary interval that has been subdivided into four subunits. (1) Subunit IIIA is a 1.37 m-thick multicolor bioclast basalt conglomerate similar in terms of composition and environment of deposition to Subunits IA and IC above. (2) Subunit IIIB is composed of a 6.73 m-thick, well-sorted, multicolor bioclast basalt conglomerate, with distinctive cross-bedding and bedding structures, and a heterogenous assemblage of basalt clasts. Cement textures, fossil assemblages and sedimentary structures indicate that Subunit IIIB likely was deposited in a beach environment. (3) Subunit IIIC is composed of a 5.37 m-thick multicolor bioclast basalt conglomerate and a bluish gray basalt conglomerate. This subunit is believed to have deposited in a shallow-marine environment. (4) Subunit IIID includes a 4.73 m-thick, matrix-supported, dark multicolor basalt breccia devoid of bioclasts, which we interpreted as a matrix-supported debris flow deposit. Similar sediments were found as interbeds in the underlying volcanic basement sequence.

Seven different lithofacies were identified at Site U1373, which together define a shallow marine to beach environment of deposition, punctuated by "catastrophic" emplacement of two debris flow deposits and a volcanic interval. In contrast to Site U1372 on Canopus Guyot, no evidence for subsidence or any other significant eustatic changes were found at Site U1373.

Biostratigraphy

Sand and granule sized cuttings, including a small amount of fine fraction were recovered from Unit IA. The unconsolidated sediment includes the remnants of modern nannofossil and foraminiferal fauna, and therefore these microfossils were considered to represent samples from the modern seafloor. Thin section investigations of microfossils were conducted on consolidated samples from Unit I-III, but no age-diagnostic species could be identified. Therefore, the ages of Unit I, II, and III remain unidentified. Nonetheless, macrofossils of *Flamingostrea* sp. were found in Unit IIIB, leading to a preliminary age assignment for Unit IIIB to the late Cretaceous through Miocene.

Igneous Petrology

Hole U1373A penetrated a total of 38.4 m of igneous rocks comprising a 6.1 m thick sequence of volcanic breccia, which makes up Unit II within the sedimentary cover, and 32.3 m of igneous basement from the base of the sedimentary succession at 33.9 mbsf to the bottom of the hole at 66.2 mbsf. Sedimentary Units I and III are breccia and conglomerate composed largely of pebble- to boulder-sized basaltic clasts in a sandy matrix. Some basaltic clasts in Unit I have lobate margins with delicate protrusions, and therefore cannot have been transported far from their source. They may indicate syn-depositional interaction of lava and sediment (i.e., peperite) implying a late phase of volcanism contemporaneous with the formation of Unit I. Coarse-clastic sedimentation was interrupted by the emplacement of aphyric to olivine-phyric lava flows (Unit II). These are almost entirely brecciated but in places the fragments appear to fit together in a jigsaw-fit texture. This is a common feature of blocky peperites and is widely thought to reflect *in situ* quench fragmentation. The top basement unit (Unit IV) consists of subaerial lava flows of highly olivine-titanaugite-phyric basalt with very well preserved olivine phenocrysts. The next unit (Unit V) consists of aphyric basalt that was also erupted mostly in a subaerial environment but the base of the lowest flow shows peperitic mingling with sediment, as do the flows of Unit VI and the top of Unit VII. Drilling stopped within a >22 m thick inflated sheet flow (Unit VII) composed of aphyric basalt. The volcanological features of the igneous sequence drilled at Site U1373 suggest lava flowing into an area where water and water-saturated sediment were present, but which was not fully submarine. Emplacement of lava flows in an intertidal or fluvial environment provides a plausible scenario that is entirely consistent with the above sedimentological observations. The absence of thick volcaniclastic deposits at Site U1373 (in contrast to Sites U1372 and U1374) suggests that the sites of lava eruption were subaerial throughout the time interval represented by the Site U1373 cores. The presence of titanaugite and olivine-titanaugite phenocryst assemblages are characteristic of alkalic basalts.

Alteration Petrology

The entire section recovered from Hole U1373A has undergone secondary alteration by low temperature water-rock interactions and/or weathering. The alteration of the volcanic rocks, including basalts and hyaloclastite deposits, ranges from slightly to highly altered (between 10% and 95%). One massive basaltic lava flow (Unit VII) is relatively well preserved (10% of alteration).

Core descriptions and thin section observations allow the definition of two main intervals showing different dominant colors of alteration that can be directly related to the oxidation state during the alteration processes. From the top of Hole U1373A to ~45 mbsf the sequence has a dominantly reddish alteration color, pointing toward oxidizing environment under likely subaerial conditions. From 45 to 66 mbsf the nearly fresh basalts are faintly greenish, pointing to more reducing conditions related to the submarine environment of emplacement.

Primary magmatic plagioclase and augite are generally well-preserved, both as phenocrysts and in the groundmass throughout the entire igneous portion of the core. Plagioclase shows minor alteration to sericite/illite in some rocks, but is generally well preserved. Augite is almost always unaltered. Olivine is typically completely altered to iddingsite, hematite, and Fe-oxyhydroxide in the upper 35 meters of hole. From ~35 to 66 mbsf, the original olivine phenocrysts are largely replaced by green clay, Fe-oxyhydroxide and/or carbonates (calcite/magnesite). Fresh olivines were found in a type 7 clast in Unit I and moderately fresh olivines occur in Units IV through V. No fresh volcanic glass was encountered in Hole U1373A.

Overall, three main groups of alteration phases can be distinguished: carbonates (Mg-calcite and aragonite), clay minerals (saponite, nontronite, glauconite, montmorillonite, celadonite), and other secondary phases (such as zeolites, iddingsite, Fe oxyhydroxydes, goethite and pyrite/chalcopyrite).

Structural Geology

Structural features observed at Site U1373 are generally similar to Site U1372, with fractures, veins, magmatic foliations, and geopetals identified. Geopetal structures are horizontal, indicating this part of the seamount has not been tilted since its formation. Fractures and veins are common in the basaltic lava flows. Fractures are especially abundant in the lowermost Unit (VII), with up to 11 fractures per meter, over twice the density observed in other fractured rocks at Sites U1372 and U1373. Unit VII also has moderate to strong macroscopic and microscopic magmatic foliation, with directions ranging from sub-horizontal to sub-vertical, indicating that this thick flow (>22 meters) underwent several episodes of lava injection and flow inflation.

Geochemistry

Overall, the igneous samples from Site U1373 analyzed chemically are closely similar in both major and trace element composition to the basalts from Site U1372. With the exception of one highly altered Unit II lava, the Site U1373 samples are moderately altered, with weight loss on ignition (LOI) values less than 2.40 wt%. A total alkalis (Na_2O + K_2O) vs. SiO_2 diagram indicates that all the samples are alkalic basalts, except one sample that classifies as a transitional basalt. This sample is a clast from Unit I and is a high-MgO, highly olivine-augite-phyric basalt hosting excess olivine phenocrysts. Its liquid composition may have been slightly more alkalic than the composition of the bulk rock. Two other high-MgO, highly olivine-augite-phyric basalts were analyzed, both from Unit IV, and they too appear to contain excess olivine. Evidence that all three high-MgO samples contain excess augite is seen in the variation of Sc with MgO, and in their CaO contents and CaO/Al_2O_3 ratios, which are higher than those in their high-MgO Site U1372 counterparts. Despite the general compositional similarity of the Site U1373 and Site U1372 basalts, the two high-MgO samples from Unit IV at Site U1373 have relatively high Sr and Ba contents for their TiO_2 values. This characteristic does not appear to be caused by alteration. These two samples may represent a slightly different magma type than represented by the Site U1372 and the majority of Site U1373 basalts.

Physical Properties

The different physical property data sets from Site U1373 samples are mutually consistent and tend to correlate primarily with distinctions between conglomerate units, brecciated lava flows, peperitic basalts, and massive basalts. The brecciated lava flows of Unit II and peperitic basalts found in Units V, VI, and VII exhibit similar, more consistent physical properties values and trends, whereas the conglomeritic Units I and III exhibit varying properties depending on the proportions of matrix and clasts. The massive basalts of Units IV and VII have consistently high density, p-wave velocity, porosity, and natural gamma ray radiation, but show moderate internal variation in magnetic susceptibility and color reflectance. The variation in color reflectance agrees well with observed alteration colors across all units.

Paleomagnetism

The intensity of the natural remanent magnetization (NRM) of samples from Hole U1373A ranges from 0.08 A/m to 20.46 A/m (median 2.99 A/m) with the highest values exclusively associated with Stratigraphic Unit VII at the base of the hole. Relatively well-defined principal component directions with maximum angular deviations (MAD) ≤7° were obtained for 1436 intervals from archive half-core measurements (for pieces >9 cm in length). These directions are generally consistent with stepwise alternating-field (AF) and thermal demagnetization results from 34 discrete samples. The range of inclinations recorded in Hole U1373A is broader and generally shallower than that found in U1372A. The limitations associated with the small number of recovered lava flows (n = 10, with 9 sampled for shipboard magnetic study) is evident from the significant error bounds on the calculated mean inclination.

Microbiology

Five whole-round samples (5-10 cm long) from this site were collected for microbiological analysis: sedimentary conglomerate (one), volcanoclastic breccia (one), and aphyric basaltic lava flows (three). All samples were preserved for shore-based cell counting, and four were preserved for shore based deoxyribonucleic acid (DNA) analyses and $\delta^{34}S$ and $\delta^{13}C$ analyses. One sample was used to inoculate culturing experiments with six different types of cultivation media, one sample was collected for shipboard analysis of contamination via fluorescent microsphere analysis, and one sample was used to set up a stable isotope addition bioassay. Fluorescent microsphere counts were practically zero, indicating that the microspheres were not able to penetrate the core, and therefore the chance for microbial contamination is low.

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