IODP Expedition 330: Louisville Seamount Trail

Site U1372 Summary

Background and Objectives

Background

Site U1372 (Prospectus Site LOUI-1C) on Canopus Guyot (working name) was the first site completed during Integrated Ocean Drilling Program (IODP) Expedition 330. This was the first out of four seamounts planned to be drilled in the Louisville seamount trail and represents the oldest seamount target at 75-77 Ma. If the Louisville hotspot experienced a paleolatitude shift similar to the recorded ~15° southern motion of the Hawaiian hotspot between 80 and 50 Ma, this shift is expected to be largest for the oldest seamounts in the Louisville seamount trail. Canopus Guyot was determined to be a good target, as it shows no evidence of tilting or significant post-erosional volcanism. This volcanic edifice consists of two coalesced volcanic centers that together are 55 km long and 15 km wide. Its overall normal magnetic polarity (Lonsdale, 1988) would be consistent with its formation during magnetic Chron C33n (73.6-79.1 Ma; Cande and Kent, 1995) which in turn fits $^{40}Ar/^{39}Ar$ ages on neighboring seamounts (Koppers et al., 2004). Site U1372 was placed on the summit plain of the northern volcanic center, close to its southern shelf edge at ~1950 m water depth. Sidescan sonar reflectivity and 3.5 kHz sub-bottom profiling data indicate that Site U1372 is covered with 5-15 m of soft pelagic sediment, and seismic reflection profiles (see Expedition 330 Prospectus, Koppers et al., 2010) show that this site is characterized by a 40 m thick section of volcaniclastics thickening toward the margins 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, the targeted penetration of 350 m into basement could not be reached, as the drill string got irretrievably stuck in a sequence of rubbly volcaniclastic breccias with cobble-sized fragments of well-preserved basaltic lava lobes. This required the hole to be abandoned at 232.9 mbsf without any downhole logging being attempted because of the unstable hole conditions.

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 led 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). Thus the most important objective of Expedition 330 in general and at Site U1372 specifically, was to core deep into the igneous basement to sample a large number of *in situ* lava flows. With a sufficiently large number of these independent cooling units high quality estimates of the seamount's paleolatitude can be determined. In combination with high quality age determinations any recorded paleolatitude shift (or lack thereof) can be compared with the 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 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 contrasts 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 at any of the drill sites 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.

Besides the above mentioned general Expedition 330 objectives, a particular objective at Site U1372 was to use the obtained 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. This would prove or disprove the hypothesis that the massive LIP volcanism of the Ontong Java Plateau at around 120 Ma formed by the preceding plume head of the Louisville mantle upwelling (e.g. Richards and Griffiths, 1989; Mahoney and Spencer, 1991).
Finally, basalts and sediments cored at Site U1372 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 824 nmi transit from Auckland to the first site of Expedition 330 was accomplished at an average speed of 10.3 knots and was without incident. The vessel was positioning on Site U1372 (Prospectus Site LOUI-1C) by 1700 hr on 21 December. The corrected precision depth recorder (PDR) water depth referenced to the dual elevator stool on the rig floor was 1960.3 mbrf.

The drill string was deployed in routine fashion to 1885 mbrf at which point the operations were suspended to perform a pressure test on the newly-build non-magnetic sinker bar for the third-party Göttingen Borehole Magnetometer (GBM). The GBM sinker bar was deployed in the drill string via the logging cable at 0300 hr on 22 December and recovered by 0550 hr. The unit did not leak.

After the driller tagged the seafloor at 1968.5 mbrf (1957.6 mbsl) with the bit, the top drive and knobbies were picked up and Hole U1372A spudded with the rotary core barrel (RCB) at 0850 hr on 22 December. Initially, the driller could not apply very much weight on bit because the bottom hole assembly (BHA) was not buried. As a consequence, the rate of penetration (ROP) was very slow for the first few cores. Eventually, the ROP began to pick up as the hole was deepened and more bit weight was applied. Basaltic basement (i.e. the first lava flow) was penetrated at 45.6 mbsf. The hole was deepened to 145.0 mbsf (99.4 m into basement) by the early morning of 26 December. At this juncture, the bit had accumulated 64.4 rotating hours and it was time for a fresh bit. The average ROP for the hole was 2.3 m/hr and 2.2 m/hr into basement. The average recovery was 68.9% for the entire hole and 64.8% while coring into basement.

Prior to the deployment of the free fall funnel (FFF), the vibration-isolated television (VIT) was launched to observe the hole and the nature of the seafloor. The hole could not be seen because a cloud of heavy mud was suspended over the site. Following the recovery of the VIT, a FFF was made up and deployed at 1010 hr on 26 December. The VIT was then launched again to monitor the position of the FFF, which was still mostly obscured by a cloud of heavy mud. However, it was obvious the funnel was upright with the three flotation balls clearly visible. While being observed via the VIT, the bit was withdrawn from the hole at 1140 hr on 26 December. The VIT was recovered concurrent with the retrieval of the drill string. The bit cleared the rotary table at 1700 hr and was found to be in very good condition and only under-gage by 1/16”. Once a new bit was made up, the BHA was deployed with an extra stand of drill collars. The FFF was reentered at 0100 hr on 27 December and by 0430 hr rotary coring was resumed at a depth of 145.0 mbsf.

Coring advanced to 175.4 mbsf at which depth approximately 3 hours were expended working the tight hole by pulling back from 174 to 163 mbsf with a maximum overpull of

40,000 pounds and circulating frequent mud flushes. Once the drill string was free, rotary coring then advanced from 175.4 to 228.9 mbsf. At this depth, the drill string again had to be worked free over a duration of 5.5 hours. Coring then resumed and advanced slowly and smoothly from 228.9 to 232.9 mbsf. At this juncture, the hole was flushed with a 20-barrel mud sweep in preparation for a wiper trip. When the drill string was pulled back from 232.9 to 204.5 mbsf it became irretrievably stuck. Unlike the previous stuck pipe episodes where both circulation and rotation were maintained, the top drive stalled out at 800 amperes, making extrication even more problematical even though circulation was still possible. From 2130 hr on 29 December until 0800 hr on 30 December all attempts to free the drill string and salvage the hole failed. The only remaining course of action was to sever the first 5½" joint of drill pipe directly above the tapered drill collar in the BHA at a depth of 83 mbsf. This was successfully accomplished at 1950 hr on 30 December. This operation only left a short interval of around 40 m of (possibly) open hole above the severed BHA available for downhole logging. After considering the probable condition of the hole following the use of explosives and the potential risk to the logging tools, downhole logging was not attempted in Hole U1372A.

In summary, coring in Hole U1372A penetrated 232.9 m with an average recovery of 60.0%. The total penetration into basement was 187.7 m with an average recovery of 55.8% and an average rate of penetration of 2.2 m/hr. There was one bit change during the 227 hours (9.5 days) on site. After the pipe was recovered and the beacon retrieved, the vessel departed for approved Alternate Site LOUI-6A at 0300 hr on 31 December.

Scientific Results

Sedimentology

Core, smear slide and thin section observations at Site U1372 allowed us to recognize two stratigraphic units predominantly composed of sedimentary deposits.

Unit I extends from 0 to 13.50 mbsf and represents the youngest record of pelagic sedimentation on top of the seamount. Its lower boundary is defined by the first occurrence downhole of consolidated basalt breccia in Unit II. Unit I is composed of unconsolidated sandy foraminiferal ooze with local occurrences of reworked glass and pumice fragments. Analysis of grain morphology and paleontological observations indicate influence of strong oceanic currents during deposition of the unit. Occurrences of pumice and fresh glass fragments suggest that the sandy foraminiferal ooze includes a minor tephra component, most likely derived from the nearby Tonga-Kermadec volcanic arc.

Unit II extends from 13.50 to 45.58 mbsf and represents an older sedimentary deposit, which we interpret to have formed under relatively shallow, neritic to hemipelagic water conditions. Its lower boundary is defined by the first occurrence downhole of lava flows in the volcanic basement. Unit II is predominantly composed of a basalt breccia and conglomerate, with a minor interval of foraminiferal limestone that includes minor Mn encrustments and inoceramid shell fragments. Petrographic description shows that the composition of the basalt clasts is similar to that of volcanic deposits in the underlying volcanic basement (see below). Five stratigraphic subunits were defined based on clast angularity and composition of the inter-cobble and boulder spaces (i.e., the “matrix” of coarser clastic sediments): (1) Subunit IIA, a multicolor basalt breccia; (2) Subunit IIB, a foraminiferal limestone with basalt clasts, manganese encrustments and abundant inoceramid shell fragments; (3) Subunit IIC, a multicolor basalt breccia; (4) Subunit IID, a multicolor basalt conglomerate; and (5) Subunit IIE, a coarser, bluish gray basalt conglomerate that deposited on top of the volcanic basement. Occurrences of inoceramid shell fragments and stratigraphic relationships defined a Cretaceous age for Subunits IIB to IIE. Bioclasts of shallow water origin (annelid and calcareous alga) and well-rounded basalt clasts occur throughout Unit II. These observations indicate that the drilled sequence reflects a nearby rocky shore environment in the Cretaceous. Based on the increasing clast roundness and amount of shallow water bioclasts, in combination with the decreasing amount of planktonic fossils (foraminifera and calcispheres) with depth, it is concluded that Unit II essentially includes a deepening upward sequence that developed during the subsidence of the drilled seamount.

Biostratigraphy

Unconsolidated pelagic sediment recovered from Unit I in the core catchers of Cores U1372A-1R, -2R, and -3R was analyzed for calcareous nannofossil and planktonic foraminiferal biostratigraphy. Additionally, one sample from each section was taken for nannofossil analyses. Preliminary age estimations of Cores U1372A-1R, -2R, and -3R are late Pleistocene to Holocene, mid-Pleistocene, and late Miocene-early Pleistocene, respectively. In addition to the analysis of the pelagic sediment, thin sections taken from consolidated micrites and/or limestones from Unit II were examined. Preliminary age estimations for Cores U1372A-4R and -5R are early Paleogene and late Cretaceous, respectively. Unit II is unconformably overlain by Unit I, and late Paleogene and early Neogene sediment is missing,

Igneous Petrology

Below the sedimentary succession of Unit I and II, a 187 m section of volcanic rocks was penetrated (from 45.6 mbsf to the bottom of the hole at 232.6 mbsf). The overlying sedimentary breccias and conglomerates were also dominantly of igneous origin, being mostly composed of aphyric and olivine-phyric basaltic cobbles and boulders. The igneous basement section of the hole can be divided broadly into an upper (83 m thick) part consisting of lava flows, and a lower (104 m thick) part mostly composed of volcaniclastic rocks. The lava flows range from aphyric to highly olivine-phyric. Flows in the topmost 27.2 m of the succession (to 63.7 mbsf) have peperitic tops implying interaction between lava and carbonate mud, while those in the next 28.7 m (down to 92.4 mbsf) have scoriaceous tops. The first appearance downhole of hyaloclastic material containing altered glass between two lava flows at 92.4 mbsf marks a change to submarine conditions, and volcaniclastic rocks dominate the succession from 128.9 to 228.4 mbsf. The volcaniclastic deposits can be divided into seven individual eruptive packages on the basis of the phenocryst content of the basaltic clasts. Three of these packages (Units XII, XIV and XV) were separated from their underlying packages by short (0.13, 0.16 and 3.3 m, respectively) intervals of vitric-lithic volcanic sandstone. In all cases the sandstone was inferred to form the basal part of the overlying package, either through similarity of phenocryst abundance (Units XIV and XV) or through a graded contact (Unit XII). Drilling terminated in a thick (4.3 m penetrated), massive and essentially unaltered olivine-augite-plagioclase-phyric basalt lava flow. In conclusion, the recovered sequence of volcanic rocks covers the later part of the constructional phase of the seamount at Site U1372, a brief subaerial phase, and its final subsidence below sea level. Evidence for continued subsidence in a submarine environment is provided by the overlying sedimentary rocks.

Alteration Petrology

The entire igneous section has undergone secondary alteration by low temperature water-rock interactions and/or weathering. The alteration of the volcanic rocks, including basalts and volcanoclastic deposits, ranges from slight to complete (between 5% and 100%). Basaltic lava flow units are fresh to moderately altered (between 5% and 80%) and thus relatively well preserved. In many cases fresh olivine phenocrysts are encountered, as well as zones with fresh volcanic glass, in particular in the hyaloclastites of Units VI and XII.

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 of the alteration processes. Down to 90 mbsf, the volcanic basement has a dominantly reddish alteration color pointing toward an oxidizing environment under likely subaerial conditions. From 90 to 232 mbsf the alteration becomes more greenish pointing to more reducing conditions related to submarine environments.

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 characteristically fresh. Augite is almost always unaltered. In general, olivine is completely altered to iddingsite and Fe-oxyhydroxide in the first 90 meters of the hole, except for a few intervals were fresh to moderately olivine was recovered. Olivine is absent in Units VII through XV from 90 to ~200 mbsf where mostly aphyric basalts were recovered. From ~200 to 232 mbsf, the original olivine phenocrysts largely have been replaced by green clay, serpentine, Fe-oxyhydroxide and/or carbonates (calcite/magnesite). Overall, three main groups of alteration phases can be distinguished: carbonates (Mg-calcite and siderite), clay minerals (saponite, nontronite, glauconite, montmorillonite, celadonite), and other secondary phases (such as zeolites, iddingsite, glauconite, Fe oxyhydroxydes, and pyrite). Also, numerous vesicles and veins were observed (average of ~ 2 veins per meter), which are mainly filled with carbonates, clay minerals and zeolites.

Structural Geology

Structural features at Site U1372 are veins, vein networks, joints, fractures, aligned vesicles, and geopetal structures. Fractures and veins are relatively common in the upper lava flow units, but are rare to absent in volcaniclastic units. This distribution is likely due to differences in rock rheology, with lavas being comparatively impermeable and strong, but brittle, thus concentrating strain (fracturing) and fluids (veining) along zones of weakness. In contrast, the porous volcaniclastic units are able to deform relatively uniformly via compaction, with their high porosity enabling easy fluid flow, without requiring concentration of flow into veins. Veins that are present within the volcaniclastic units are concentrated along unit boundaries. Several of the recovered lava flows (particularly in the subaerial portion of the lava pile above 92 mbsf) display moderate to strong macroscopic and microscopic recognizable magmatic flow alignment in an approximately horizontal direction, including elongation and alignment of titanomagnetite. Geopetal structures in the upper part of the sequence are horizontal, indicating that the drilled succession has not been tilted, either by partial flank collapse, or incipient subduction of Canopus Guyot into the Tonga-Kermadec Trench.

Geochemistry

Major and trace element analysis of the igneous rocks by ICP-AES indicates that alteration has not obscured magmatic signatures significantly, with the exception of K_2O in some samples and CaO in two samples. The data indicate that most of the samples are alkalic basalt, although several are transitional basalt. Their compositions overlap with those measured for dredge samples from other sites along the Louisville Seamount Trail but cover a smaller range of variation. Nevertheless, a sizeable range of compositions is present, with Mg numbers ranging from 34.9 to 73.5. Two samples appear to contain excess olivine phenocrysts. Much of the chemical variation in the other samples appears to be explainable as a product of variable amounts of crystal fractionation involving olivine and lesser amounts of clinopyroxene and plagioclase. If so, the data imply a rather large total range in the amount of crystal fractionation. In general, the Site U1372 basalts are similar to oceanic island lavas elsewhere. On the basis of the ICP results for this site, no distinction between shield and post-shield stages of volcanism can be made.

Physical Properties

The individual physical property datasets are mutually consistent with each other and correlate well with the primary distinctions between the sedimentary sequence, units dominated by lava flows, and volcaniclastic intervals dominated by hyaloclastites. Distinctions that correspond with particular petrologically-determined stratigraphic units are also observed in porosity, density, p-wave velocity, natural gamma ray (NGR), color reflectance, and magnetic susceptibility. Volcaniclastic Units XII and XV, in particular, show markedly lower density, p-wave velocity and magnetic susceptibility, and higher porosity than the surrounding units. Unit XV also is distinctive with larger a* and b* color reflectance values and an increasing upward trend in NGR counts that contrasts with very low values in Unit XVI below.

Paleomagnetism

The intensity of the natural remanent magnetization of samples from Hole U1372A spans a very broad range, from 3×10^{-5} A/m to 39 A/m (median 1.7 A/m) with the lowest values associated with volcaniclastic units. Relatively well-defined principal component directions with maximum angular deviations (MAD) <7° were obtained for 3392 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 100 discrete samples. Both datasets indicate dominant normal polarity. These data should provide reliable inclinations for approximately 20 *in situ* cooling units. Directions within the volcaniclastic units are more scattered, reflecting the fact that some of the basalt pieces recovered from these intervals are clasts.

Nonetheless, some of these basalt intervals may represent *in situ* lavas that would further increase the number of flow units for determining the paleolatitude of Canopus Guyot around 71 to 77 Ma.

Microbiology

Fifteen whole-round samples (5-10 cm long) were collected for microbiological analysis. All samples were preserved for shore-based deoxyribonucleic acid (DNA) analysis, cell counting analysis and $\delta^{34}S$ and $\delta^{13}C$ isotope analysis (isotope analysis on only hard rock samples). Four samples were used to inoculate culturing experiments with up to ten different types of cultivation media, and one sample was collected for shipboard analysis of its possible contamination via fluorescent microsphere analysis. Samples were taken from unconsolidated sediment (two), volcanoclastic breccia (three) and basaltic lava flows (ten). The collected volcanic rocks cover nearly all lithologic units recovered from Hole U1372A. In particular, more altered rocks and rocks with indications of high porosity were selected for microbiological analysis.

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