IODP Expedition 324: Shatsky Rise Formation

Site U1349 Summary

28 October 2009

Background

Site U1349 (Prospectus Site SRCH-5), located on the summit of Ori Massif (Central High), was the fourth site completed on Expedition 324. One hole, U1349A was cored at the site. According to the initial expedition plan, Site U1349 was to be the second deepest penetration site to be drilled, with a target of ~200 m into igneous basement. As with most Expedition 324 sites, the penetration rate of drilling was slower than expected and this goal was not reached. Approximately 85 m of basement rocks were recovered, but alteration was severe and did not appear to improve with depth. Thus, the science party decided to terminate drilling and to move on to Site U1350. Nevertheless, despite the alteration, the rocks recovered from Site U1349 tell a story of eruption of primitive lavas near or above sea level, erosion, and extensive and variable alteration with burial and submergence.

Ori Massif is the second largest volcanic construct within Shatsky Rise, having a volume of ~0.7 x 10^6 km^3 and has the appearance of a large central volcano with low flank slopes (Sager et al., 1999). Like TAMU Massif, it may have formed over a geologically short period of time (<1 m.y.) with a high effusion rate, but the actual age and duration are unknown. According to the geomagnetic polarity time scale (Ogg et al., 2008), the age of the lithosphere at Ori Massif is ~142-140 Ma and this may also be the age for Ori Massif if it formed nearly synchronously with the lithosphere, as implied by compensation (Sandwell and McKenzie, 1989). Because Ori Massif is separated from TAMU Massif by a narrow, rectangular, faulted basin, there has been speculation that Ori and TAMU massifs formed together and were later rifted apart (Nakanishi et al., 1999; Sager et al., 1999). In the context of the plume head hypothesis, Ori Massif appears to represent the eruptions during a transition in volume from plume head (TAMU Massif) to plume tail (Papanin Ridge).

Hole U1349A was drilled into a flat topped-ridge located near the middle of the Ori Massif summit. It was thought that since this ridge has a flat top and is at the tallest point on the volcano, it was probably eroded flat by wave action at sea level. Thus, an expected result from Site U1349 drilling was to find evidence for subaerial exposure.

Sampling the summit of Ori Massif was an important objective because this volcano is a major edifice within Shatsky Rise. Furthermore, Site U1349 is at the center of a transect of sites along the axis of Shatsky Rise planned to yield age and geochemical trends within the plateau. As with most Expedition 324 sites, the operational goal for the site was to drill through the sediment overburden, core the oldest sediment overlying igneous basement, and core as deeply into the igneous formation as possible with the time allowed. The primary objectives were to recover suitable fresh rock to determine the age of igneous basement and to carry out a suite of geochemical and isotopic studies. Such data are crucial for determining the source of magma, to infer its temperature and depth of melting and crystallization, to deduce the degree of partial melting, as well as tracking its evolution with time. Expedition 324 also sought to constrain the evolution of Shatsky Rise by collecting samples for a host of non-geochemical studies focusing on varied aspects of rise geology. Physical volcanologists, alteration specialists, structural geologists, and logging geophysicists will use cores and logs to infer the eruption style, igneous products, and physical structure of Shatsky Rise. Considering the altered nature of the rocks recovered from this site, alteration studies will play a critical role in better understanding and using other data sets. Paleomagnetic studies seek to determine the magnetic polarity of basement, for comparison with surrounding magnetic lineations and the geomagnetic polarity time scale, as well as the paleolatitude of the rise and its plate tectonic drift. Finally, studies of sediments overlying the igneous basement will determine the paleontological age of Shatsky Rise and its subsidence history. It was hoped that shallow water sediments would be cored at Site U1349, but the sediment recovery was poor. Nevertheless, sedimentologists will carefully examine the sparse sediments that were recovered.

Operations

The drill string was deployed and after the driller tagged seafloor at 3138.0 m DRF (3127.0 mbsl) or ~5 m shallower than the corrected PDR depth, Hole U1349A was spudded with the rotary system at 0600 hr on 8 October. The hole was drilled with a wash barrel to 116 m DSF where coring was initiated. The sediment portion of the hole was cored with the usual low average recovery (23%) because of the prevalence of chert within the soft pelagic ooze. At a depth of 165 m DSF, basement was encountered. Coring in the hole continued into basement without incident to a depth of 250.4 m DSF (85.4 m into basement) by 1430 hr on 11 October, when coring in the hole was terminated. Hole U1349A was cored with an overall average recovery of 49.0%. The basement portion of the hole was cored at an average rate of penetration of 1.8 m/hr and with an average recovery of 67.0%.

The hole was prepared for logging with a 50-barrel mud flush followed by a round trip of the drill string from 250 m DSF to 86 m DSF. After one more 50-barrel mud treatment, the bit was released at the bottom of the hole with the rotary shifting tool (RST) on the coring line. Prior to tripping the drill string to the logging depth of 119.3 m DSF, the hole was displaced with 56 barrels of 10.5 ppg heavy mud. The first log of Hole U1349A was made with the triple combo, which was deployed at 2140 hr on 11 October and retrieved at 0240 hr the next morning. The second log was conducted with the FMS-sonic tool string, which was deployed at 0355 hr and recovered at 0930 hr. The hole was found in good condition (except for one tight spot just below the end of the pipe) and both the triple combo and FMS-sonic runs retrieved excellent data.

After the logging equipment was secured, and the drill string and beacon were recovered, the vessel departed for the Site U1350 at 1930 hr on 12 October. The time expended on Site U1349A was 126.8 hours or 5.3 days.

Scientific Results

In total, 10.1 m of sediment was recovered from Cores 324-U1347A-1W to -7R over a stratigraphic interval of 49 m (~20% average recovery). Cores 324-U1349A-1W to -4R recovered predominately red chert with occasional ooze and porcellanite intervals (Unit I). Below this, a friable sand-silt-claystone sequence was found that also contains granules of highly weathered volcanic material (Unit II-III). This interval, however, is so disturbed by drilling that further interpretation of the rock is difficult. Most of Cores 324-U1349A-5R and -6R contain greenish-gray volcaniclastic sandstones and lapillistones, likely deposited by turbiditic flows. A thin, yellowish-red clay-rich horizon in Section 324-U1349A-6R-CC is interpreted as a paleosol within the deepest purely sedimentary section recovered. In the underlying basement, several other thin sedimentary beds are found between basaltic lava flows. The most significant of these is a piece of oolitic limestone in Section 324-U1349A-9R-1 at 173.7 m CSF-A, which logging data suggests may have up to 6 m stratigraphic thickness.

Calcareous microfossils occur in chalk that encrusts reddish cherts and in pinkish nannofossil ooze recovered in Cores 324-U1349A-1W to -4R, whereas they are barren in the underlying siliciclastic and volcaniclastic sediments of Cores 324-U1349A-4R to -7R. The nannofossils are rare to common in abundance, but poorly preserved throughout. Planktonic foraminifera are represented in exceptionally high abundance and diversity with good preservation in the nannofossil ooze recovered in Core 324-U1349A-2R. Zonal marker and other age-diagnostic species strongly indicate a narrowly constrained age at the middle/late Albian transition. Although available foraminiferal material are scarce, other examined levels above and below, are also marked by the occurrences of some age-diagnostic species, allowing the entire age range of Cores 324-U1349A-1W to -4R sediments to be estimated as Albian–Cenomanian. Core 324-U1349A-2R also yields a diverse benthic foraminiferal assemblage, and the estimated bathymetric range is middle bathyal.

Volcanic basement was encountered in Core 324-U1349-7R at 165.1 m CSF-A. The cored basaltic succession of Unit IV is ~55 m thick (Cores 324-U1349A-7R-2 to -13R-4) and consists of 25 lava units characterized by high (40-75%) vesicularity, the presence of magma mixing features and, in all but the interiors of the thickest inflation units, a pervasive reddish-brown, Fe-oxyhydroxide-hematite alteration. This succession also contains 10 recovered weathered flow tops readily identified by a reddening over ~5-10 cm intervals, tentatively interpreted as subaerial alteration occurring between the emplacements of successive eruptive units. In the top ~10 m of this lava succession, the flow inflation units are relatively thin (~0.3 to 1.1 m) and, while many have highly vesicular, reddened, flow tops, a number of examples preserve inter-flow carbonate sediment. The most significant of these is an oolitic limestone that is preserved at the top of a highly vesicular flow. Other instances of this interflow carbonate sedimentation are preserved only as carbonate infilling of vesicular voids within flow tops. In addition to the subaerial exposure inferred elsewhere in Unit IV, these filled-vesicle flow tops record contrasting periods of shallow marine inundation of the evolving lava field. The lowermost part of Unit IV contains a series of much thicker (1-6 m) massive flows. Preliminary comparisons to degassing models for basalt in Hawaii, and assuming 0.05-0.5 wt% H_2O concentrations in the source, imply pressures below 15-20 bars in order to produce the high 40-70 vol% vesicularity in the lavas of Unit IV, corresponding to less than 100 m water depth.

Beneath the lava succession of Unit IV there is a transition to flow breccia at 221.7 m CFS-A. This section consists of ~29 m of an alternating assemblage of massive lava pods and fragmental basalt. The lava pods are vesicular, though to a lesser degree than the flow tops in Unit IV, on average ~1 m thick, but ranging in thickness between 0.5 and 2 m. These cored assemblages are interpreted as a series of autobrecciated inflation units (Unit V).

Petrographic examination reveals that the basalts of both Unit IV and V are all Cr-spinel-bearing and olivine-phyric. Based on ICP-AES analyses these basalts have >8-12% MgO and thus may be termed picritic. Olivine phenocrysts are sparsely to moderately abundant (up to 4%), but are usually entirely altered to iddingsite, clays and Fe-oxyhydroxides. The groundmass of some rocks contains abundant "ophimottle" crystal aggregates up to ~5 mm in size and consisting of well-preserved clinopyroxene ophitically intergrown with plagioclase. Fe-oxyhydroxides and secondary hematite are present in the groundmass and responsible for the red-brownish color of the rocks in the lower part of Units IV.

Extensive water-rock interactions, under variable temperature conditions resulted in complete replacement of glassy mesostasis and olivine phenocrysts in both Unit IV and V rocks. Both plagioclase and clinopyroxene are generally well preserved in Unit IV, whereas below ~218 m CSF-A (bottom of Unit IV and Unit V, from Core 324-U1349A-13R-5 to -16R-7), alteration is more pronounced with near complete replacement of clinopyroxene and almost complete replacement of plagioclase microliths. The overall alteration of the basaltic rocks ranges from high to complete. Three types of alteration have been determined at Hole U1349A (from top to the bottom): (1) a red-brown alteration (upper and middle of Unit IV), (2) a transition alteration (bottom of Unit IV), and (3) a green alteration (Unit V). In addition, subaerially weathered flow tops have been identified within Unit IV. Clay minerals (saponite, nontronite and montmorillonite) are the predominant secondary minerals in Hole U1349A samples, replacing glassy mesostasis, primary phases (olivine, plagioclase and pyroxene), and filling vesicles and veins. Calcite and hematite are also abundant secondary minerals, especially in Unit IV. Secondary mineral assemblages change with depth from clay minerals + hematite + calcite in the red-brown alteration to clay minerals + chlorite + zeolite ± hematite in the transition zone to saponite ± serpentine in the green alteration. This suggests variations in alteration conditions starting with sub-aerial oxidative tropical weathering within Unit IV. Upon submergence of the lavas, relatively low-temperature oxidizing seawater alteration occurred at the top of the hole (in the red-brown alteration) and transitioned to more reducing and higher temperature alteration toward the bottom of the hole (in the green alteration).

The severe alteration has affected and modified the bulk-rock chemical compositions of the basement rocks significantly. In addition, chemical evidence is present for accumulation of olivine, and possibly clinopyroxene, crystals. The combined effects of crystal accumulation and alteration hinder interpretation of magmatic liquid compositions. However, shipboard measurements indicate that the Site U1349 samples are the least differentiated of any Shatsky Rise basement rocks analyzed thus far. Both the lava section of Unit IV and the autobreccia of Unit V appear to be low-TiO_2, low-Zr tholeiitic basalts with similarities to primitive ocean-ridge and Ontong Java Plateau basalts.

Aspects of the mineralogy, especially the compositions of clinopyroxenes and intergrown plagioclase in the ophimottled rock, and of Cr-spinel throughout, might further help in constraining the primary composition of the Hole U1349A lavas prior to alteration. Perhaps the most pressing question concerning the pervasive alteration of Units IV and V has to do with the inferred high temperature assumed for some of it. Oxyexsolution is observed in all titanomagnetite crystals and may indicate that alteration approached temperatures up to 600ºC.

Structural investigations are consistent with the interpretation that Hole U1349A penetrated several piled-up sheet flow units, which are sometimes intercalated by limestone. Evidence for apparently subaerial features (including pahoehoe structures) and submarine structures (including pillow lava and brecciated pillow lava) is obvious. The typical sheet flows at this site can be described in three parts: the upper lava crust with horizontal zones of hollow vesicles, the middle lava core with quite regular veins well-developed in fine-grained groundmass and low vesicularity, and the basal zone with less vesicles and few veins. In this hole, there are no joints observed, but veins are well developed. Vein dips become steeper downhole, shallower again, and then increase downhole again.

Physical property measurements of the recovered igneous and sedimentary material can be used to distinguish four of the five units (II-V) of Hole U1349A. No discrete samples were taken from the chert fragments of Unit I, nor was the material continuous enough for whole round track measurements. Volcaniclastic sandstones and claystones of Unit II and volcaniclastic sandstones and lapillistones of Unit IIIa yielded magnetic susceptibilities below 1000 x 10^{-5} SI, GRA densities below 2.0 g/cm^3 and NGR counts between 10 and 40 cps. Three discrete measurements of Units II and IIIa revealed high porosities (20% to 40%) accompanied by P-wave velocities below 4.0 km/s. Thermal conductivity measurements yielded low values between 1.01 and 1.57 W/m·K, typical of sedimentary material.

Beneath the sandstones of Unit II and IIIa, a volcaniclastic conglomerate (Unit IIIb) can be clearly distinguished by excursions to extremely elevated magnetic susceptibility. A distinct spike reaching almost 4000 x 10^{-5} SI, the highest value measured in Expedition 324, is derived from an individual volcanic clast in Section 324-U1349-7R-1 containing abundant groundmass magnetite. The upper oxidized portion of the vesicular basalts of Unit IV, lying below the conglomerate, have low magnetic susceptibility (<1000 x 10^{-5} SI) and low total NGR counts (<20 cps) similar to sedimentary Units II and IIIb, but are distinguishable by higher GRA density (>2.0 g/cm^3). Discrete sample measurements confirm higher bulk density (over 2.5 g/cm^3) and yield lower porosity (less than 10%) and higher P-wave velocities (4.0 km/s to 6.0 km/s) compared to the sedimentary units. Core 324-U1349-11R in Unit IV marks the end of the oxidized material and shows an increase in magnetic susceptibility, averaging around 1000 x 10^{-5} SI, with excursions to values over 2000 x 10^{-5} SI. The increase in magnetic susceptibility is not accompanied by any significant difference in GRA density, porosity, or P-wave velocity compared to the oxidized material above. Thermal conductivity measurements throughout Unit IV, irrespective of relative oxidation, yielded some of the highest values recorded on Expedition 324, and averaged 1.799 W/m·K ± 0.357 2σ (n=22).

The autobreciated basalt Unit V is clearly distinguishable from the vesicular basalts above by a decrease in magnetic susceptibility (values averaging 100 x 10^{-5} SI). Total counts from the NGR show a muted decrease to 5-10 cps whereas GRA density remains consistent compared with the basalts above. Discrete sampling reflects the heterogeneous distribution of clasts within Unit V, showing large variations in porosity, P-wave velocity and, to a lesser extent, bulk density. Thermal conductivity measurements reflect the higher porosities measured in the unit, yielding values lower than the basalts, with an average of 1.364 W/m·K ± 0.305 2σ (n=10).

A total of 32 basement samples were demagnetized for paleomagnetic studies (18 AF and 14 thermal). As expected, samples from volcaniclastic units show demagnetization results in which a characteristic remanent magnetization is difficult to isolate. These samples likely carry a depositional remanent magnetization, which makes the interpretation more complicated. Samples from olivine phyric amygoloidal basalt flows were characterized by a high coercivity, high unblocking temperature magnetization carrier. It is still unclear whether this magnetization is carried by (titano-)magnetite, which is a true thermoremanent magnetization, or by hematite, which is a chemical remanent magnetization. Both minerals have been identified in thin section observations. Additional rock magnetism measurements and interpretations are necessary to interpret these results. The averaged inclination in Hole U1349A is -4.3° ± 5.9° (1 s), suggesting that the lavas were formed near the magnetic equator.

Downhole logging data obtained from Hole U1349A included natural and spectral gamma ray, density, and electrical resistivity measurements from three depths of investigation. Interpretations of gamma ray and electrical resistivity downhole logs were used to identify a total of 15 logging units in Hole U1349A with one in the section covered by the BHA, five in the sedimentary sequences in the open hole interval, and thirteen in the basaltic basement section. Electrical resistivity measurements show distinctive higher resistivity zones that likely represent less altered intervals, interspersed with low resistivity zones that mark more altered sequences. Natural gamma-ray measurements show a large peak just below the sediment-basement interface that may indicate a zone of concentrated hydrothermal alteration. This interval also displays very high uranium values and a smaller peak in potassium values. Formation MicroScanner (FMS) images show zones with highly fractured intervals, potential veins, and vesicular or brecciated intervals.

References

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