IODP Expedition 324: Shatsky Rise Formation

Site U1350 Summary

30 October 2009

Background

Site U1350 (Prospectus Site SRCH-4) on Ori Massif was the fifth and last site occupied on Expedition 324. This site is located on the lower east flank of Ori Massif, where it was intended as a comparison site to contrast against Site U1349 (on the summit of Ori Massif) and Site U1347 (on the flank of TAMU Massif). It was hoped that rocks at Site U1350 would represent an earlier stage of volcanism compared to the rocks recovered from the summit site. Only one hole was cored, and it reached a total depth of 315.8 m CSF-A. According to the initial expedition plan, Site SRCH-4 was an alternate site and Site SRSH-8, located on the southern flank of TAMU Massif, was planned as the last place to drill on Expedition 324. Site SRCH-4 was substituted because the scientific party decided that it was more important to recover cores from the flank of Ori Massif than to drill another site on TAMU Massif close to Site 1213, where igneous rocks were cored during Leg 198 (Shipboard Scientific Party, 2002). Most of the Site 1213 igneous cores were available on board and have been described by the science party in great detail during the transit from Yokohama to the first drill site. Furthermore, it was felt that the lower flank location of SRCH-4 would be a good spot to core fresh igneous rocks (important to meet the primary objectives of the expedition) in contrast to the highly-altered rocks recovered at Site U1349 on the Ori Massif summit. Because it was the last site to be occupied on Expedition 324, Site U1350 was cored until time expired. Nevertheless, a better-than-average rate of penetration allowed the deepest penetration into igneous basement (172.7 m) of any Expedition 324 site.

Ori Massif is the second largest volcanic construct within Shatsky Rise, having a volume of ~0.7 x 10^6 km^3 (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. 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).

Magnetic lineations surrounding Ori Massif imply that it formed on lithosphere of earliest Cretaceous age. Anomaly M16 brackets the southeast flank whereas anomaly M14 crosses the northwest flank (Nakanishi et al., 1999). 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 isostatic compensation (Sandwell and McKenzie, 1989).

Like TAMU Massif, Ori Massif has the appearance of a large central volcano with low flank slopes (Sager et al., 1999). Too few bathymetry data exist to say which flanks of this edifice are smooth and which are faulted; although, the shape of the southern margin implies rifting, whereas the smooth nature of the eastern flank suggests a simple volcanic slope (Sager et al., 1999; Klaus and Sager, 2002). Site U1349, drilled on the summit of Ori Massif, returned igneous rocks that appear to have formed in a subaerial or shallow-water environment and perhaps represent a late stage of Ori Massif formation. In contrast, the smooth, gently sloping eastern flank acoustic basement, where Site U1350 is located, probably represents lava flows erupted during the main, shield-building phase of Ori Massif eruptions.

Sampling the flank of Ori Massif was considered an important objective because this volcano is a major edifice within Shatsky Rise. Furthermore, Site U1350 is near the center of a transect of sites along the axis of Shatsky Rise planned to yield age and geochemical trends within the plateau, so coring relatively fresh basalt from Ori Massif was a high priority. As with most Expedition 324 sites, the operational goal for the site was to drill through the sediment overburden, core the oldest ~50 m of sediment overlying igneous basement, and core as deeply into the igneous formation as possible with the time allowed. A critical objective at Site U1350, and indeed all Expedition 324 sites, was to core enough igneous rock of suitable freshness to determine the age of the igneous basement, so that the age progression and duration of volcanism at Shatsky Rise can be constrained. Igneous rocks will also be used for geochemical and isotopic studies whose goals are to establish the elemental compositions of the rocks, variations in compositions, and the isotopic characteristics. 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. In addition, a host of non-geochemical studies focusing on varied aspects of rise geology (including alteration, structure geology and physical property studies) will be applied to the samples. Another important aspect are paleomagnetic studies to determine the magnetic polarity of the 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. It was also planned to use samples from the sediments overlying the igneous basement for constraining the paleontological age of oldest Shatsky Rise sediments, however, few sediment samples were recovered from Site U1350.

Operations

The vessel positioned on Site U1350 at 0115 hr on 13 October after a 53 nmi voyage from Site U1349. The driller tagged the seafloor at 4067.0 m DRF (4555.9 mbsl) at 1030 hr. Hole U1350A was spudded with a wash barrel in place and drilled to a depth of 104.6 m DSF where rotary coring was initiated. The sediment portion (48.0 m) of the hole was cored with the usual poor recovery (1.6%) owing to soft ooze and chalk sediments mixed with chert layers. Igneous basement was reached with Core 324-U1350A-6R at 143.1 m DSF, which was slightly higher than expected (~157 mbsf calculated from the site survey seismic data).

Rotary coring deepened the hole to a final depth of 315.8 m DSF by 2015 hr on 18 October when operating time expired. The final depth corresponds to a total penetration of 172.7 m in basement, which was cored with an average recovery of 43.2% and an average ROP of 2.0 m/hr. The total interval of 315.8 m was cored with an average recovery of 35.6% at an average ROP of 3.5 m/hr. When coring was halted, the bit had accumulated 91.2 rotating hours and was still viable.

In preparation for logging, the hole was flushed with a 50-barrel mud sweep followed by a wiper trip up to 84 m and back to 316 m DSF. Following another 50-barrel sweep, the bit was released with the rotary shifting tool and the hole was displaced with 90 barrels of 10.5 ppg heavy mud. The pipe was then pulled back in the hole with the end of pipe placed at the logging depth of 117 m DSF.

The first of potentially two logging runs was attempted with the triple combo, which was deployed at 0640 hr on 19 October and lowered at a speed of 2200 m/h to a depth of 3600 m DRF. At this depth, the head tension decreased dramatically and the cable speed was reduced to approximately 90 to 120 m/hr to avoid potential damage to the wireline. The slow progress required pumping pressure down the drill pipe to aid the descent. After making very slow progress to a depth of 4000 m DRF it was decided to pull out of the hole to check the tool string and cable for damage. With the tool string on the rig floor it was decided to pump down high volumes of water through the pipe to remove any potential obstruction. The tool string was deployed a second time with similar results, reaching a depth of 4122 m DRF. As time was running out and the weather was progressively deteriorating (initial ship heave conditions of ~2 m changed to ~4 m with wind gusts of up to 56 knots) and without knowing the cause of the low-tension problem, it was decided to terminate the logging operations. The tool was recovered at 2330 hr and after the logging equipment was rigged down, the drill string was pulled out of the hole clearing the seafloor at 0125 hr on 20 October. Following the securing of the drilling equipment, hydrophones and recovery of the beacon, the vessel departed for its long voyage to Townsville at 1245 hr on 20 October. The total time on Site U1350 was 7.5 days.

Scientific Results

Because recovery of the soft sediments overlying the igneous basement was poor, only one purely sedimentary unit was defined at Site U1350 (Unit I), which spans Cores 324-U1350A-1W to -6R. Although it is likely Unit I was comprised of both chert and soft calcareous ooze or chalk, only chert (predominantly black and less commonly reddish) with minor amounts of occluded porcellanite, was recovered. Well-preserved radiolarians, concentrated around relict burrow features, are a common in the cherts of Unit I. Igneous basement was reached in Core 324-U1350A-6R at 143.1 m CSF-A, but additional sediments were encountered interbedded with the basaltic strata in Units II and IV. These sediments were predominantly fine-grained carbonates with a persistent radiolarian component and volcaniclastics. Varying quantities of assorted bivalve and brachiopod fossils were also present. Sedimentary interbeds were especially prevalent in Unit IV (Cores 324-U1350A-25R and -26R), where carbonate-rich oozes had apparently been intruded by small pillow basalts, prior to lithification.

Calcareous nannofossils sampled from chert-rich lithologies of (Units I and IIa; Cores 324-U1350A-1W to -9R) are frequent to high in abundance, and moderately to poorly preserved. The assemblage is indicative of Early Cretaceous age. However, both planktonic and benthic foraminifera are almost barren in these two units, with only a few silica-replaced specimens. The intercalated limestone sediments of Unit IV are severely recrystallized and do not yield any calcareous microfossils. A low-diversity, poorly preserved assemblage of radiolaria is present throughout the examined Site U1350 sediments. No contact between the overlying sediment of Unit I and the volcanic basement succession was recovered. The ~173 m of igneous basement are composed of massive basalt flows, which pass down, through a transitional zone, into a package of aphyric pillow lavas (Unit II). Below this a ~6 m thick layer of hyaloclastite and brecciated basalt (Unit III), followed by a lowermost succession of well-preserved, plagioclase-phyric pillow lavas set in a matrix of intercalating micritic limestone (Unit IV), as described above. Unit II may be divided into an upper ~77 m thick succession (Cores 324-U1350A-6R to -16R) predominantly consisting of a series of larger inflation units yielding recovered thicknesses of 1-2 m, with two larger 3-5 m thick flows and sparsely intercalated with thin layers of volcanogenic limestone (Unit IIa). Below this is a middle ~23 m thick transitional succession (Sections 324-U1350A-17R-1 to -19R-1) in which both larger inflation units of 1-2 m are intercalated with smaller pillow lava units (Unit IIb). The pillows display chilled margins, glassy contacts and vesicle distribution patterns similar to those of pillow units observed in Holes U1346A and U1347A. At its base, Unit II concludes with a ~50 m stack of 0.2-0.9 m thick pillow lava units (Sections 324-U1350A-19R-2 through -24R-2) with well-preserved glassy contacts and chilled margins (Unit IIc). Within Unit IIc the lowermost ~23 m consists of a well-preserved stack of units displaying pillow-pillow contacts, relatively thin glass rims and chilled margins, but lacking intercalated sediment layers. In this lowermost part the pillow units become sparsely plagioclase phyric (up to 2%), and magnetic susceptibility abruptly diminishes to lower values characteristic of Units III and IV below.

The pillows of Unit II lie atop ~6 m of hyaloclastite (Unit III) consisting of gravel- to sand-sized glassy material, larger hyaloclastite fragments and/or small pods (~5-15 cm) of aphyric basalt (Sections 324-U1350A-24R-3 through -25R-3). The rock in the aphyric basalt pods appears to be petrographically similar to those of Unit II above, but on the whole the material is a sufficiently different facies of hyaloclastite to merit is own division and represents a thin series of autobrecciated inflation units. The lowermost ~1 m of core material of Unit III in Section 324-U1350A-24R-4 consists of gravel and pebble-sized fragments only, preventing identification of the contact between Unit III and the underlying volcanic succession.

The lowermost ~19 m thick sequence (Unit IV) consists of Cores 324-U1350A-25R and -26R with extremely high recovery (>90%). These cores preserve a stack of ~0.1-0.5 m thick plagioclase (~6%) phyric pillow lavas, including the sedimentary material that occurs between individual pillow lavas. Glassy rinds and thick chilled margins can be readily examined, and pillow-pillow and pillow-sediment contacts are abundant throughout. Thermal alteration effects can be observed at most basalt/sediment contacts, but especially in examples where the pillow lava actively injected into soft sediment. The encasement of some pillow units within sediment indicates that the substrate onto, and into which, the pillow lavas were extruded was unconsolidated and/or fluidized by the entry of hot lava.

Thin section examination shows that crystallites in well-preserved glass rims are mainly plagioclase and clinopyroxene, but that spinel is not present in the basalts of Hole U1350A. Groundmass textures consist of networks of interlocking acicular plagioclase around which both clinopyroxene and titanomagnetite have crystallized to varying proportions, depending on grain size and rate of cooling. Only in the transition succession of Unit IIIb do some well-developed networks of interlocking clinopyroxene and plagioclase occur as clumps or aggregates at all grain sizes.

The entire basement section (massive lava flows, pillow lavas, and hyaloclastites) has been affected by slight to high degrees of low temperature water-rock interactions, resulting in a complete replacement of glassy mesostasis and olivine phenocrysts and a slight to almost complete replacement of groundmass minerals (plagioclase and clinopyroxene). In contrast, plagioclase phenocrysts are generally well preserved throughout the hole, except in Unit IV. Fresh glass is commonly preserved on the margins of flows and pillows in Units IIa and IIb, rarely preserved in Unit IIc and not preserved in Units III and IV. One type of gray alteration was identified, with significant variation in alteration degree, from slight to moderate in the upper flow succession and hyaloclastites (Units II and III) to moderate to high in the plagioclase-phyric pillow succession (Unit IV). Clay minerals, together with calcite, are the predominant secondary minerals at Hole U1350A, replacing primary phases, glassy mesostasis, and filling vesicles and veins. Other alteration minerals observed in the basaltic cores are pyrite and zeolites, present as filling vesicles and veins, and possible sanidine replacing plagioclase phenocrysts in Unit IV. Four main vein types have been identified in basaltic rocks of Units II to IV: (1) calcite veins (± pyrite), (2) saponite veins, (3) calcite and saponite veins (± pyrite) and (4) pyrite veins. A total of 461 veins and vein networks were recorded in the recovered 75 m, which corresponds to an average of 6.1 veins/m. Most of the veins in Hole U1350A are calcite veins, consisting of either crystalline blocky calcite or cross-fiber calcite. Alteration of Hole U1350A samples is comparable to alteration mineralogy encountered at Hole U1347A on TAMU Massif.

The chemical effects of the alteration are comparatively modest at Site U1350. The shipboard chemical data reveal that the basement section is composed of variably evolved tholeiitic basalts. Broad similarities with the Site U1347 and ODP Leg 198 Site 1213 basalts are present, but the Site U1350 lavas also differ in important respects. For example, they show systematic downhole variation in several key chemical parameters, exhibit a wider range of TiO_2, Zr, and Mg#, extend to higher Mg# values (as high as

68.5), and have higher Sr concentrations. They also show a wider spread of Zr/Ti ratios, implying that variations in amount of partial melting and/or source composition were important.

The overall structure of the basement can be divided by the hyaloclastite of Core 324-U1350A-24R (Unit III) into two kinds of extrusive structures: sheet flow lavas with intercalated pillows in the upper part and piled-up pillows in the lower part. Both parts are characterized by syn-magmatic structures, including inter- and intra-pillow structures. Inter-pillow structures are structures observed in the surrounding rocks. In the upper part of the hole, the surrounding rocks are characterized by hyaloclastite breccias or calcite fillings. In the lower part of the hole, inter-pillow structures are characterized by limestone, which shows only weak bedding. Intra-pillow structures are similar in texture through out the hole, but differ in size ranging from ~5 cm to ~30 cm depending on the size of the pillows. They are characterized by thin glassy margins, radially aligned vesicles, concentric vesicular zones and spheroidal shapes. In addition, structural features can be divided by syn- and post-magmatic structures. Syn-magmatic structural features are represented by amygdaloidal structure, irregular vein networks or curved veins, and breccias. Post-magmatic structures are conjugate veins and joints. Dip angles of both veins and joints recorded in the rocks from Hole U1350A vary irregularly with depth. A larger population of veins and/or joints is found in the lower part of the hole (Unit IV).

The physical properties data obtained from the basement units can be separated into three distinct units or divisions based on magnetic susceptibility: (1) Cores U1350A-7R to -11R from ~150-190 m CSF-A, (2) Cores U1350A-12R to -21R from ~190-270 m CSF-A and, (3) Cores U1350A-22R to -26R from ~270-316 m CSF-A) and three distinct units based on natural gamma radiation: (1) Cores U1350A-7R to -10R from ~150-175 m CSF-A, (2) Cores U1350A-11R to -24R from ~175-295 m CSF-A, and, (3) Cores U1350A-24R to -26R from ~295-316 m CSF-A). Interestingly, neither set of divisions corresponds with any of the lithologic units except for the lowermost natural gamma radiation division. Magnetic Susceptibility (MS) shows a decreasing downhole trend from values reaching over 2000 x 10^{-5} SI in the upper portion of Unit IIa, to values below

1000 x 10^{-5} SI in the lowermost Unit IV. There is a sharp decrease in MS found between Cores 324-U1350A-21R and -22R within the pillow basalts of Unit IIc. This decrease corresponds to the disappearance of sediment interbeds and the onset of a continuous stack of pillows.

Data from the Natural Gamma Ray logger yields generally low counts (<5 cps) with two notable exceptions. These exceptions occur in the upper portion of Unit IIa and in the lower Unit IV. Examination of spectra from both of these intervals shows that counts are dominated by products of the ^{40}K decay chain. This is in agreement with the increased K-rich alteration clays seen in the lowermost Unit IV. The Gamma Ray Attenuation bulk density is consistently around 2.5 g/cm^3 throughout Units II-IV. Measurements of discrete bulk density samples agree fairly well with the maximum values of the whole round data, having uniform values with an average of 2.61 ± 0.17 (2σ). Porosity measurements on discrete samples show a range from 3.43% to 28.45%, and display a good negative correlation with P-wave velocity, as expected. P-wave velocity shows no appreciable anisotropy and averages 4.793 ± 1.249 km/s, which is typical for basaltic material and of a similar range to measured velocities from recovered igneous material in all sites. Overall, discrete physical property measurements do not change significantly with different lithologic units.

A total of 42 samples were analyzed for paleomagnetism (18 alternating-field and 24 thermal demagnetizations). AF demagnetizations were characteristic of low-coercivity magnetic minerals, except for the samples from Sections U1350A-25R-2 to -26R-1. All the AF-demagnetized samples have a stable direction pointing towards the origin, but the inclinations derived from PCA analysis show a large spread, between -12° and 27°. From thermal demagnetizations, there seems to be a large distribution of Ti-content in the samples. PCA analysis carried out on the thermal demagnetization specimens defined stable magnetization components, but also lead to a scatter of inclination values. Overall, inclinations are shallow, both positive and negative, but with large variations even within the same lithologic unit.

Because the logging tools were unable to leave to drill pipe and enter open hole, only gamma ray measurements could be recorded (from inside the BHA). The gamma ray data in the shallow sediments show an anomaly from seafloor to approximately 25 m WMSF. The contributions to this anomaly are mainly an increase in thorium and a smaller contribution from uranium.

References

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