IODP Expedition 324: Shatsky Rise Formation

Site U1347 Summary

15 October 2009

Background

Site U1347 (Prospectus Site SRSH-3B) is situated on TAMU Massif (Southern High). TAMU Massif is the largest volcanic construct within Shatsky Rise, having a volume of ~1.8 x 10^6 km^3 (Sager, 2005). It may have formed over a geologically short period of time (<1 m.y.) with a high effusion rate, similar to those of flood basalt eruptions (Sager and Han, 1993; Mahoney et al., 2005). In the context of the plume head hypothesis, TAMU Massif appears to represent the initial plume head eruptions.

Site U1347 is situated on the east flank of the summit of TAMU Massif, where the seismic signature suggests that there are layers within the volcanic basement that can be sampled with reasonably shallow coring. Over much of TAMU Massif, igneous basement is characterized by a curious “layered” appearance and at Site 1213 (Leg 198), igneous material with this signature was cored and found to be sills or sheet flows interbedded with sediment (Shipboard Scientific Party, 2002a). Another reason for coring at Site U1347 is that the sediments are thin at this location, with a thickness of 154 m estimated before drilling.

At Site U1347, the original plan was to drill to ~300 m into igneous basement (i.e., ~454 mbsf). This was predicated on an estimate of igneous rock penetration at a rate of 2.5-3.0 m/hr, a value based on previous experience with drilling seamounts (Shipboard Scientific Party, 2002b and oceanic plateaus (Shipboard Scientific Party, 2001). Unfortunately, the formation turned out harder than expected and the overall penetration rate was about half of the planned value with the result that only a little more than half of the planned igneous basement penetration was achieved before time ran out on operations (see “Operations” below).

Sampling the summit of TAMU Massif was an important objective of this expedition because this volcano is the main edifice within Shatsky Rise and Site U1347 is closest to its center. 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.

Samples of igneous rock will be used 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 are also critical to 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, collected samples will be used for a number of non-geochemical studies focusing on varied aspects of rise geology and volcanology (e.g., paleolatitude, eruption style, igneous products, and physical structure of Shatsky Rise). Sediment types and paleontological environment data will indicate the paleodepths of sediment deposition, information that is important for understanding the eruption and subsidence history of the volcanic edifices.

Operations

The *JOIDES Resolution* came to position on Site U1347 on 21 September and seafloor was tagged at a depth of 3461.0 m DRF. Hole U1347A was drilled with a wash barrel in place to a depth of 71.0 m DSF where rotary coring was initiated. Basaltic basement was reached at a depth of ~158 m DSF. Coring into basement continued until 2145 hr on 25 September when operations were suspended in order to change to a fresh bit after the initial rotary bit had accumulated 60 rotating hours. A Free Fall Funnel (FFF) was deployed and the bit was pulled out of the FFF early morning on 26 September. A new C-4 bit was affixed to the rotary drilling assembly and run back in the water column.

Hole U1347A was successfully reentered at 2250 hr on 26 September. The drill string was advanced to the bottom of the hole where the driller found only one meter of soft fill.

At 0500 hr on 27 September coring resumed, but had soon to be suspended for 5.75 hours to replace the broken core winch motor. Once the new motor was mounted and tested, coring resumed. From 1530 hr on 27 September to 1230 hr on 30 September rotary coring deepened the hole from 242.7 m DSF to a final depth of 317.5 m DSF. Operations were concluded when the last core was only able to advance one meter in three hours possibly due either to a worn bit, an extremely hard formation, or a combination of both.

The total penetration into basement in Hole U1347A was 159.5 m cored at an average rate of penetration (ROP) of 1.5 m/hr. While coring basement, the ROP for individual cores ranged from a lethargic 0.7 m/hr to a more energetic 4.1 m/hr. The average recovery for basement coring was 62.3%.

The hole was prepared for logging, the bit was released at the bottom and the bore was displaced with 83.5 barrels of 10.5 ppg mud. The drill string was pulled back in the hole and placed at the logging depth of 131.5 m DSF. The first logging run was made with the triple combo and succeeded in reaching within two meters of the bottom of the hole. A preliminary analysis of the results of the first logging run indicated that the hole was in good condition and suitable for the additional measurement runs planned for this site. The second tool deployed was the FMS-sonic, which was also successfully run (two complete passes). The third logging tool suite included the Ultrasonic Borehole Imager and had to be cancelled because of hardware problems.

After the logging equipment was secured, the drill string and the beacon were retrieved in routine fashion. Once the drilling equipment was secured, the vessel departed for the next site (U1348) at 0400 hr on 2 October. The total time on site for Site U1347 was 10.4 days.

Scientific Results

Hole U1347A recovered a total of 17.7 m of sediment in Cores U1347A-1W to -11R over a stratigraphic interval of ~88 m, before entering basaltic basement. The recovered sediments at Site U1347 are dominated by radiolarian-rich, volcaniclastic siltstones, with varying proportions of glauconite. There are also minor intervals of chert and claystone. Bioturbation is often pervasive in the silty facies, with rip-up clasts and erosional contacts as common features, suggestive of turbulent and transient depositional events. Sediments were also present as relatively thin interbeds between the massive basaltic flows and pillow basalt units within the igneous complex. These sediments are similar in character and composition (e.g., predominantly radiolarian-bearing siltstones) to the sediments above basement, although some show features consistent with thermal alteration due to subsequent basalt emplacement.

In general, calcareous nannofossils and foraminifera from the sediments of Site U1347 are moderate to poor in preservation, and low in abundance and diversity; intercalated sediments in the underlying basement section are almost barren of both microfossil taxa. Fortunately, the age of four samples from Cores U1347A-2R and -10R is assignable to the Berriasian to Valanginian based on calcareous nannofossils. The foraminiferal assemblage is marked by the absence of planktonic forms. Benthic foraminifera, though the total number of specimens is limited, are characterized by a neritic assemblage in the lower part of the sediment section (Cores U1347A-6R to -8R) and bathyal faunal assemblages up-section (Cores U1347A-1R to -2R). Therefore, an overall deepening trend from <200 m to 200–2000 m is inferred. Samples processed for foraminiferal analyses are to a large extent dominated by volcanogenic lithic fragments and minerals; the major biogenic component is radiolaria with peaks in size, abundance and diversity in Cores U1347A-6R to -8R.

After penetrating the sediment section (Units I-III), a 158.5 m thick volcanic basement succession (Units IV-XVI) was encountered consisting of 'packages' of massive basalt flows and pillow inflation units, intercalated by five sedimentary successions of up to ~5 m thick. Based on the dominant type of eruptive unit, the volcanic basement can be described in three main packages or groups. From top to bottom, these are: Group (1), an upper "layered" series of four massive lava flows (~8 to 19 m thick) intercalated with two

~5 m thick sediment packages, and totaling ~60 m in thickness (Units IV, V, VII, IX); Group (2), a ~75 m lava stack consisting for the most part of pillow basalts (each ~0.2-1.0 m thick) and medium-sized inflation units (1-2 m thick), interspersed by relatively thin sedimentary intercalations and three larger (~3-6 m thick) basalt flows (Units X, XII and XIV); and Group (3), a lower set of two particularly massive basaltic lava flows consisting of a very thick upper (~23 m) homogenous lava flow which overlies a unit of similar character at the bottom of the hole (Units XV, XVI). In many instances, the high 62.3% average recovery for Hole U1347A yielded well-preserved lower- and upper-contact zones with chilled margins, baked sediment contacts, and folded pahoehoe-type upper crusts. The frequent recovery of thick (often fresh) glassy rinds within the pillow-unit stack indicates that alteration was essentially buffered in these rocks.

In Group (1) the three uppermost massive flows are aphyric (Units IV, V, VII) and petrographically different from the sparsely to moderately pyroxene-plagioclase phyric basalt in the fourth flow (Unit IX) and the lavas lower in the succession. Examination of unit thicknesses within Group (2) reveals a pattern of repetition, beginning with massive inflation units, passing upward into predominantly medium-sized units, and then finally into a sequence of closely-packed pillow lavas, before the cycle is repeated again. These repetitions may represent repeated eruptive pulses during which the lava effusion rate diminishes. Group (3) includes the lowest two lava flows recovered (Units XV, XVI) with well-developed chilled margin zones at their tops (glassy to microcrystalline in the topmost ~2 m) and thinner ones (~0.5 m) above their bases. Thick glassy rinds were not recovered in these flows and vesiculation is confined to the upper 2 to 3 m, below which the flows become very homogenous and massive and largely non-vesicular. It may be deduced from their large thickness that these are likely to be laterally extensive ‘tabular flow’ units, possibly similar in dimension to those described in flood basalt provinces.

The majority of the volcanic units are plagioclase-pyroxene phyric basalts. Toward the cores of the lava flows and pillows crystallinity increases to 50% and in some cases to 95%. Most notable are the abundance of plagioclase phenocrysts in the fourth massive flow in the upper volcanic series (Unit IX), the rarity or absence of clinopyroxene phenocrysts in the lower pillow stack (Units XII, XIV), and their absence in the lowermost massive flows (Units XV, XVI). In all cases the basalts were saturated in both clinopyroxene and plagioclase, whereby these minerals always seem to occur together as clusters, glomerocrysts and intergrown in the matrix between the larger micro- and phenocrysts. The rocks appear therefore to have been in a condition of low-pressure plagioclase-clinopyroxene cotectic crystallization during all stages of their cooling and differentiation. Olivine phenocrysts occur rarely as early co-precipitating liquidus minerals, and now are completely replaced by clays and calcite. Only in a few thin sections some (remainders of) fresh olivine with melt inclusions or spinel were discovered. Titanomagnetite is highly variable throughout the lava succession as also is reflected in highly variable magnetic susceptibility measurements. For instance, glass in the chilled margins has no discernable titanomagnetite, and consequently very low magnetic susceptibilities. However, spherulitic overgrowths on plagioclases and larger (sometimes elongate skeletal) titanomagnetite grains can be seen to increase significantly toward the cores of the (thicker) lava flows, and are well correlatable to increased magnetic susceptibility readings.

Overall, basalts of Hole U1347A appear to be more differentiated than basalts of either Hole 1213B or Hole U1346A on Shatsky Rise. This is evident from the predominance of plagioclase and clinopyroxene intergrowths at all stages of crystallization in these basalts, the scarcity of olivine, and the almost complete absence of Cr-spinel. This phenocryst assemblage and character of intergrowths compare well to those of rather evolved, low-temperature, gabbros that formed in ‘shallow’ crustal magma chambers beneath (super-) fast spreading ridges.

Alteration within the volcanic section varies from slight to moderate, (estimated to range from 5% to 50%). Generally, both the primary mineralogy (with the exception of extensive olivine replacement) and, close to the pillow margins, even the finer spherulitic textures in the interstices between phenocrysts and microcrysts are well preserved, sometimes even with fresh glass still present in the groundmass. In contrast, away from the pillow margins, the glassy mesostasis in the general groundmass is almost completely replaced. Plagioclase and clinopyroxene are generally well preserved throughout the hole, either in the groundmass or as phenocrysts. Clay minerals, together with calcite, are the most abundant secondary minerals at Hole U1347A, replacing primary phases and glassy mesostasis and filling vesicles and veins. Pyrite is widespread throughout the hole, being present in the groundmass, vesicles and veins. Three main types of veins were observed at Hole U1347A: calcite veins, being predominant, green clay veins, and composite veins of calcite + green clays ± pyrite. There is an average of ~ 3 veins/m in the basement lavas and average vein thickness is ~1 mm. No significant variation in alteration mineralogy was observed at Hole U1347A and alteration of the basaltic rocks is interpreted to result from interaction with seawater-derived fluids at relatively low temperature (< 100°C).

There are two kinds of structures to be distinguished within the igneous complex, i.e. pillow structure and sheet flow structure. The typical sheet flow structure is normally characterized by three parts: the upper lava crust, the middle lava core, and the basal zone. Dip angles of both veins and joints in the hole become gradually steeper downward. The entire structure of the Hole U1347A igneous complex is consistent with the interpretation as stacked layers of pillows and massive basalt sheet flows. Taking also the horizontal sedimentary bedding into account, structural observations indicate that the site has undergone no tilting or horizontal-axis block rotation.

Onboard measurements of major and several trace elements by inductively coupled plasma atomic emission spectroscopy reveal that the Site U1347 lavas are tholeiitic basalts. The chemical effects of post-eruptive alteration are much smaller than for samples of previous Site U1346 lavas. In general, both the major and trace element compositions of the Site U1347 basalts are consistent with them being variably more evolved relatives of the basalts at ODP Leg 198 Site 1213 on the southern flank of the TAMU Massif. Compared to normal ocean-ridge basalts, the Site U1347 lavas exhibit modest relative enrichment in the more highly incompatible elements, qualitatively similar to that seen in the Site 1213 basalts. This result suggests a mantle source slightly richer in the more incompatible elements than normal ocean-ridge source mantle and/or that the Site U1347 magmas formed by slightly smaller amounts of partial melting and possibly in the presence of residual garnet.

Both destructive and non-destructive physical property measurements are applied to the igneous and sedimentary samples from Site U1347. Magnetic susceptibility in igneous material is typically ~2000 x 10^{-5} SI, and GRA density is in the range 2.4 to 2.6 g/cm^3. The massive flow (unit XV) below ~290 m CSF-A notably reached magnetic susceptibilities up to 3800 x 10^{-5} SI and also has the highest measured densities. Total counts of natural radiation measured in igneous material was between 2-4 cps throughout the hole, which is an order of magnitude less than observed at Site U1346. Fifty-eight thermal conductivity measurements of igneous material were performed, yielding an average of 1.59 ± 0.200 2σ W/m·K. One sedimentary measurement of 1.007 ± 0.017 2σ W/m·K was also obtained. In general, the massive igneous units have slightly higher thermal conductivity than pillow units. This is seen particularly well in the final massive flow unit below ~290 m CSF-A, which has a thermal conductivity of 1.733 ± 0.092 2σ W/m·K (n=11).

P-wave velocity measured on discrete samples showed no appreciable anisotropy, but appeared to vary with lithologic units. The massive flow (Unit XV) and upper pillow basalts (Unit X) had high compressional wave velocities (up to 7.04 km/s). The high velocities were coincident with low porosity (<5%) and high bulk densities (>2.75 g/cm^3) measured by discrete sampling.

A total of 61 discrete samples were measured to investigate paleomagnetic remanence of the upper part of the TAMU Massif basement. Only about half the samples demagnetized by thermal (TH) demagnetization show a stable component while most of samples demagnetized by alternating field (AF) demagnetization show a fairly stable component between 15 and 80 mT. Most samples have low unblocking temperatures, around 300-400°C, which is characteristic of titanomagnetite(-maghemite). We suggest four magnetic zones downhole: (1) the top igneous core section (Section U1347A-12R-1) with shallow negative inclination (-6º ±7), (2) Sections U1347A-17R-2 to 26R-1 (Units IV to VII), with an average inclination of 28º ±13, (3) Sections U1347A-26R-2 to 29R-4 (Units IX to XIV) with an average inclination of 20º±14, and (4) Sections U1347A-26R-2 to 29R-4 (Unit XV) with an average inclination of 54º±27. While results in upper three zones appear reasonably reliable, detailed rock magnetic analyses is necessary to interpret the erratic magnetic behavior of the lowermost zone.

Downhole logging data obtained from Hole U1347A included natural and spectral gamma ray, density, neutron porosity, photoelectric factor, 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 U1347A with three in the sediment sequences, and twelve in the basaltic basement. These units correlate well with those defined by core material logging. Electrical resistivity measurements in the basaltic basement show distinctive high resistivity zones that likely represent massive flows can pillow flow units, interspersed with low resistivity zones that mark sediment interbeds. Natural gamma-ray measurements show five intervals of higher reading that indicate interbedded sediments within the basaltic basement. These sedimentary intervals also display higher potassium values. Formation MicroScanner (FMS) images show zones of distinctive pillow lavas, zones with high fracture density, and intervals that seem to represent massive lava flows.

References

Mahoney, J. J., Duncan, R. A., Tejada, M. L. G., Sager, W. W., and Bralower, T. J., 2005. Jurassic-Cretaceous boundary age and mid-ocean-ridge-type mantle source for Shatsky Rise. *Geology*, 33:185-188, doi:10.1130/G21378.1.

Sager, W. W., 2005. What built Shatsky Rise, a mantle plume or ridge tectonics? In Foulger, G. R., Natland, J. H., Presnall, D. C., and Anderson, D. L., (Eds.), *Plates, plumes, and paradigms*, GSA Spec. Paper 388: Boulder, CO (Geological Society of America), 721-733, doi:10.1130/2005.2388(41).

Sager, W. W., and Han, H.-C., 1993. Rapid formation of Shatsky Rise inferred from its magnetic anomaly. *Nature*, 364:610-613.

Shipboard Scientific Party, 2002a. Leg 198 Summary. *In* Bralower, T. J., Premoli Silva, I., and Malone, M. J., (Eds.), *Proc. ODP, Init. Repts.,* 198, 1-148 [CD-ROM]. Avaiable from: Ocean Drilling Program, Texas A&M University, College Station, TX 77845-9547, USA.

Shipboard Scientific Party, 2002b Leg 197 Summary. In Tarduno, J. A., Duncan, R. A., Scholl, D. W., (Eds.), *Proc. ODP, Init. Repts,* 197, 92 pp., 148 [CD-ROM]. Avaiable from: Ocean Drilling Program, Texas A&M University, College Station, TX 77845-9547, USA.

Shipboard Scientific Party, 2001. Leg 192 Summary. *In* Mahoney, J. J., Fitton, J. G., and Wallace, P. J. (Eds.), *Proc. ODP, Init. Repts.,* 192, 1-75 [CD-ROM]. Avaiable from: Ocean Drilling Program, Texas A&M University, College Station, TX 77845-9547, USA.