**IODP Expedition 324: Shatsky Rise Formation**
**Site U1346 Summary**

29 September 2009

## Background

Site U1346 (Prospectus Site SRNH-2) on Shirshov Massif was the first site to be drilled on Shatsky Rise Expedition 324. The site is located on the north rim of the summit of Shirshov Massif (or "Northern High"), the northernmost large edifice of Shatsky Rise. Magnetic lineations imply that Shatsky Rise formed from along the trace of a triple junction (Sager et al., 1999; Nakanishi et al., 1999) and volcanism appears to have followed the track of the triple junction (or vice versa), but the amount of volcanism appears to have diminished over time. Shirshov Massif appears to be one of two intermediate volcanic edifices between the initial eruptions of Tamu Massif, on the southwest end of the rise, and the waning volcanic trail of Papanin Ridge on the northeast end of the rise. Thus, Shirshov Massif is important in the study of Shatsky Rise because it represents the transitional, waning magmatic output of the rise volcanism. In the parlance of the plume head hypothesis, Shirshov Massif is in the transition between plume head and tail.

## Operations

After transit from Yokohama, Japan, the *JOIDES Resolution* set position on Site U1346 (Prospectus Site SRNH-2) at 0930 hr on 14 September and the rotary core barrel drilling assembly was prepared. Seafloor was tagged at 3630.0 m DRF and Hole U1346A was advanced without coring to a depth of 100.5 m CSF-A. Rotary coring was initiated at a depth of 100.5 m and deepened the hole to a total depth of 191.8 m by 0915 hr on 18 September. Basaltic basement was contacted at a depth of 140 m (total penetration into basement at this site was 51.8 m). The average penetration rate for basement coring was 1.3 m/hr with an average recovery of 38.7%. Because of the slow penetration rate combined with the successful recovery of material suitable to address most of the objectives for this site, it was decided to end coring at this depth and prepare the hole for logging operations. An additional factor in the decision to cease coring operations at this site was the approach of Typhoon Choi-Wan. The hole was logged with the triple combo on 18 September. The poor

hole conditions, however, did not warrant deployment of the FMS-sonic tool string. The vessel departed to Prospectus Site SRSH-3B at 1800 hr on 19 September. Because of the proximity of Sites SRCH-5 and SRSH-6 to the projected track of Typhoon Choi-Wan, it was decided to proceed directly to the more southerly and higher priority site.

**Scientific Results**

Since the primary goal of drilling Hole U1346A was to recover the igneous basement (estimated to reside below ~140 m CFS-A) sediment coring began only ~70 m above the suspected basement/sediment interface. Despite difficult drilling conditions, approximately 4 m of sediments were recovered in the first six cores prior to entering into basaltic basement. The recovered sedimentary material represents various lithologies and depositional environments, with an average recovery of 10.2% between 100.5 and 141.7 m CSF-A. The uppermost sedimentary interval, Unit I, (Cores U1346A-1W to -3R) yielded only small isolated pieces of dark-colored chert fragments. Recovery in Cores U1346A-4R to -6R improved, due to a reduction in the amount of chert in the formation. This short sequence of lithified sediments included an intriguing sequence of intermingled basalt and limestone in Section U1346A-4R-1, interpreted as a debris flow (Unit II). In this unit soft sediment deformation occurs around the larger volcanic clasts indicating that the clasts impacted the sediment, either rolling down slope from its eruption source or as a mass flow deposit generated through post-eruptive erosion of the volcanic edifice. Section U1346A-4R-2, yielded a series of laminated volcaniclastic sequences, with grading from very coarse sand to clay, which are interpreted as turbiditic in origin (Unit III). The remaining sediments (Unit IV), from the base of Section U1346A-4R-2 to the top of Section U1346A-6R-1, are composed of clay-bearing limestones and calcareous mudstones containing abundant shell fragments and other biogenic components, along with glauconite and altered volcaniclastics. Taken together these components are suggestive of a relatively shallow marine depositional environment in close proximity to a volcanic material source.

Calcareous nannofossils in the recovered sediments are rare to abundant, and moderately to poorly preserved. The age of four samples from Cores U1346A-4R and

-5R is assignable to the Berriasian to Hauterivian biostratigraphic stages. Within the foraminiferal assemblage obtained from Section U1346A-4R-CC, the planktonic group is completely absent. Benthic foraminifera are well-preserved and diverse, comprising the neritic–upper bathyal assemblage (estimated paleodepth ≤500 m). Various biogenic sedimentary components were observed in the samples examined for biostratigraphic analyses; these were dominantly radiolaria with lesser amounts of ostracoda, inoceramid prisms, echinoid plates, sponge spicules, bryozoan, and carbonaceous fragments.

Basement coring at Site U1346 on Shirshov Massif, established that a stack of highly vesicular basaltic pillow lavas or lava 'inflation units' (defined as stratigraphic Unit V) occurs beneath the succession of pelagic nannofossil-bearing chalks and cherts, volcanogenic silts and sands, and larger volcaniclastic debris materials. Within the lava stack, individual pillow (or inflation) units were readily identified by the presence of chilled glassy margins, upper and lower chill zones, characteristic pillow vesicle patterns, and crystal grain size variations. In total 40 individual 'lava cooling units' were recognized in the recovered cores of Unit V and interpreted to represent a single eruptive event.

The pillow basalts are generally vesicular in nature and have zones that are moderately vesicular (30%-50% vesicles). Although they appear macroscopically aphyric, a closer inspection reveals that micro-phenocrysts of olivine and pyroxene were originally present but are now totally replaced by calcite. All samples contain large proportions of less altered, very fine-grained plagioclase laths set in a variolitic matrix.

Extensive low temperature water-rock alteration has left a marked impression on all igneous rocks recovered at this site, resulting in near complete replacement of pyroxene, olivine and glassy pillow rinds and complete replacement of glassy mesostasis. In contrast, plagioclase shows only slight to moderate alteration. Based on rock color and mineralogy, three types of alteration have been determined at Hole U1346A: a green alteration, recovered only in volcaniclastic debris interspersed with sediment at the top of the hole (Unit II; interval U1346A-4R-1, 0 cm to U1346A-4R-1, 39 cm), a dark gray alteration and a brown alteration. In the basement pillow lavas, the dark gray alteration is most abundant and is interspersed with the brown alteration

throughout the hole. The most abundant secondary minerals observed in the basaltic rocks are clay minerals, and the nature of clay minerals changes with respect to alteration type, from predominantly green clays, including nontronite, in the green alteration, to green and brown clays in the gray alteration, including saponite, to mainly brown clays in the brown alteration. Calcite is also abundant in all alteration types, replacing pyroxene and olivine, rarely the groundmass, and filling vesicles and veins. Sulfide minerals are present only in Unit II and the upper portions of basement pillow lavas in Sections U1346A-7R-1 and U1346A-8R-1. These mineral assemblages suggest that the basaltic rocks from Hole U1346A have extensively interacted with seawater-derived and $CO_2$-rich fluids at low temperature, and more locally with S-rich hydrothermal fluids.

Despite the moderate to complete alteration, shipboard analysis of major and several trace elements by inductively coupled plasma – atomic emission spectroscopy (ICP-AES) of lava samples recovered from lithologic Unit V, reveals that the rocks are tholeiitic basalt. The concentrations of many elements, including K, Si, Ca, P, Sr, Ba, and Ni, were modified significantly by the alteration. However, several elements, including Ti, Zr, Y, Cr, V, and Sc, appear to have been affected relatively little. Relationships among these elements indicate a strong similarity with the approximately 5 m.y. older basalts recovered from ODP Site 1213, which lies approximately 870 km to the southwest of Site U1346.

There are two kinds of structures that can be distinguished within the igneous complex penetrated at Hole 1346A; i.e. syn- and post-magmatic structures. The main syn-magmatic structural features are represented by amygdaloid structures, pillow structures, irregular vein networks or curved veins, and breccias. Post-magmatic structures include conjugate veins and joints. Dip angles of the veins in the hole from top to bottom become gradually steeper; however, joint dips are generally low. The structures observed in the entire Unit V are consistent with the interpretation as a pile of stacked pillows, whose sizes differ from ~20-200 cm.

Gamma Ray Attenuation (GRA) measurements of the basement sections reveal that there is low variability in bulk density despite changes in the style and degree of alteration. Magnetic susceptibility (MS) appeared to be a more sensitive tracer of

alteration, and several regions were identified where MS co-varied with changes in alteration style. Thermal conductivity measurements averaged 1.52 W/(mK), with no significant relationship with depth.

P-wave velocity measurements of 24 discrete samples showed no appreciable anisotropy or depth relationship and averaged 4.5 km/s throughout the core with maximums of ~5.6 km/s and minimums of ~3.5 km/s. Moisture and density measurements of bulk, dry, and grain density of the discrete samples confirmed indications from the GRA density (measured on whole cores) that there was little systematic change in the density of the basaltic sequence with depth. Porosity was high and ranged from 8% to 33% with the highest values closer to the top of the hole. As expected, P-wave velocity followed expected relations with bulk density determined on discrete samples.

In total, 20 discrete samples obtained from Hole U1346A were measured to investigate paleomagnetic remanence of the upper part of the Shirshov Massif basement. Most of samples show a stable component between 300–475° C steps and have fairly low unblocking temperatures, around 400–450°C, which is characteristic of titanomagnetite (-maghemite). AF demagnetizations show that the magnetization is stable after 10-15 mT demagnetization. These samples from Hole 1346A are characterized by shallow negative inclinations (arithmetic mean = -20.3°±5.3º).

Downhole logging data obtained from Hole U1346A included natural and spectral gamma ray, density, 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 14 logging units in Hole U1346A with three in the section covered by the bottom hole assembly (BHA), four in the sedimentary sequences in the open hole interval, and seven in the basaltic basement. The sedimentary sequence shows several prominent gamma ray anomalies associated with uranium enrichment. The most prominent anomaly is found at the sediment/basement interface and may be indicative of focused hydrothermal fluid flow. Shallower anomalies recorded through the BHA may represent oceanic anoxic events previously interpreted in this area. Electrical resistivity measurements in the basaltic basement show four distinctive massive zones characterized by higher

resistivity values, which may represent individual thick lava flows. Relatively high potassium content in the basement section also indicates a high degree of hydrothermal alteration.

**References**

Sager, W. W., Kim, J., Klaus, K., Nakanishi, M., and Khankishieva, L. M., 1999. Bathymetry of Shatsky Rise, northwest Pacific Ocean: Implications for ocean plateau development at a triple junction. *J. Geophys. Res.,* 104:7557-7576.

Nakanishi, M., Sager, W. W., and Klaus, A., 1999. Magnetic lineations within Shatsky Rise, northwest Pacific Ocean: Implications for hot spot-triple junction interaction and oceanic plateau formation. *J. Geophys. Res.,* 104:7539-7556.