

## **IODP Expedition 360: SW Indian Ridge Lower Crust and Moho**

### **Week 5 Report (27 December 2015–2 January 2016)**

#### **Operations**

Week 5 of Expedition 360 (Southwest Indian Ridge Lower Crust and Moho) began while coring Core U1473A-30R at 267.7 mbsf. Coring continued through Core 34R to 313.2 mbsf, when rotation time on the third RCB coring bit reached 41.9 h. The hole was cleaned and the drill string retrieved, with the bit clearing the rotary table at 1755 h on 27 December. The fourth C-7 RCB bit was made up to the bottom-hole assembly (BHA), the drill string was redeployed, and we reentered Hole U1473A at 0008 h on 28 December. When the drill string was lowered to the bottom of the hole, 1.5 m of soft fill was encountered, which was washed out and followed by another mud sweep to remove the cuttings from the hole.

RCB coring resumed at 313.2 mbsf and continued to Core 44R at 410.2 mbsf. At the end of cutting Core 44R a mud sweep was pumped, which was followed by an increase in drill string torque to ~700 A. The drill string was worked for ~3 h with a combination of excessive pull (50 klb), rotation (800 A), and circulation. The drill string became free at 0100 h on 30 December. Core 44R was retrieved and another core barrel was dropped. While attempting to get back on bottom to continue coring, the driller experienced erratic torque, up to 450 A. After a few minutes of attempting to core, the decision was made to pull the drill string even though we had only 34.6 rotating hours on the bit. Upon clearing the rotary table at 0740 h, the bit was found to be missing three out of four roller cones.

A new BHA was assembled with a 9 inch Bowen fishing magnet to attempt to retrieve the cones left in the bottom of the hole. Hole U1473A was reentered at 1244 h on 30 December and the fishing magnet was lowered to the bottom of the hole with circulation and slight rotation, in accordance with the Bowen procedures. The drill string was tripped back to the surface and the fishing magnet cleared the rotary table at 0740 h. The magnet had picked up some magnetic debris (core catcher parts); however, none of the three roller cones was retrieved.

During the trip out of the hole we were informed by the ship's physician of a medical emergency necessitating transfer of the patient to a medical facility for examination and treatment. At 2324 h on 30 December, the ship started the transit towards Mauritius. A helicopter was scheduled and the vessel sailed to a rendezvous point south of Mauritius. A recently formed tropical depression was present between the vessel and the meeting point, necessitating a course deviation to the west to avoid the worst of the bad weather. The vessel arrived at the agreed rendezvous point at 1634 h on 2 January and switched to dynamic positioning mode. The helicopter from the Mauritius Police Department touched down at 1717 h and departed at 1725 h with the patient on board. The ship started the transit back to Site U1473 at 1742 h. At the end of Week 5, the vessel was underway to Site U1473 with a distance of 600 nmi remaining.

## Science Results

During Week 4, all laboratory teams described and measured Cores U1473A-27R through 44R (235.6–410.2 mbsf), including thin sections and other discrete subsamples taken from these cores. In addition, we prepared for sampling the working section halves of all cores recovered so far (2R–44R) for postcruise research.

Cores 27R to 44R consist of gabbroic rocks. Detailed observations of the cores plus their corresponding thin sections have allowed us to document the magmatic evolution of the plutonic section, from the crystallization of relatively primitive subophitic gabbros to the evolution of late-stage melts within the crystallizing mush. The degree of deformation of the gabbroic rocks is variable. Those intervals unaffected or least affected by crystal-plastic deformation consist of coarse-grained subophitic olivine gabbro. This texture becomes more granular when deformation is more pronounced. Rare horizons enriched in oxides are present and are in many cases also deformed. Zones of pervasive felsic melt infiltration are locally observed in deformed granular gabbros, and several felsic veins crosscut the section.

Rare dikes intrude the gabbros. They display a pervasive granoblastic texture associated with an amphibolite-facies mineral assemblage rather than the intergranular textures and/or chilled margins expected of classic diabase. Their emplacement is associated with felsic melt circulation at the dike margins; in one instance narrow felsic veinlets also intrude the dike itself. These observations indicate that the dikes intruded into a hot host, and that their structural position was deep, potentially close to their rooting zone.

Detailed observations of oxide gabbros show that, in comparison to other gabbros, formation of these lithologies is associated with enrichment in oxide minerals for a given proportion of clinopyroxene and a strong depletion in plagioclase. The resulting oxide gabbros are thus poor in plagioclase. The Igneous Petrology group has used image analysis tools to evaluate visual estimates of modal composition, and compared magnetic susceptibility data with oxide modal composition and whole-rock major element composition to develop correlations that may be used to obtain accurate estimates of those parameters from routine magnetic susceptibility measurements.

Background static alteration of the cores is variable, ranging from slight to extensive. Intense alteration occurs in intervals with heavy veining. Most samples examined contain a variety of alteration minerals of secondary clinopyroxene, amphibole, chlorite, talc, clay minerals, and secondary plagioclase, which formed under a wide range of temperature conditions. Generally, olivine is more intensely altered than pyroxene and plagioclase. A broad difference in alteration assemblage is observed between the upper and lower parts of the section: high-temperature, granulite to amphibolite-facies recrystallization associated with plastic deformation and amphibole veins become less abundant downhole, whereas low-temperature clay and carbonate veins with clay-rich halos become more dominant. Felsic veins with modal compositions of leucodiorite also occur and are altered more intensely than host gabbros. X-ray diffraction

(XRD) analysis shows the occurrence of different clay minerals as secondary products in veins and primary minerals, quartz, and plagioclase in some of the felsic veins, and clinozoisite in some felsic and amphibole veins.

The Structural Geology team focused on identifying and measuring igneous contacts, magmatic fabrics, crystal-plastic fabrics, alteration veins, brittle deformation, and crosscutting relationships. The overall pattern of deformation is highly variable, with hints of a decrease in the crystal-plastic fabric intensity downhole. However, although it is possible to speculate from this observation that we are approaching the base of the broader Atlantis Bank detachment shear zone, relationships are not yet clear-cut and the kinematics of deformation cannot be constrained from shipboard data alone.

Leucocratic felsic veins are more numerous than in the upper part of Hole U1473, with 163 veins recorded in 18 cores. Many veins are altered; original compositions range from trondhjemite to quartz diorite. Two different styles of magmatic veins are observed. The first are felsic vein networks, which disrupt and infiltrate the host rock and in some cases form magmatic breccias (e.g., Section 32R-6). These networks commonly have diffuse and complex margins, and in some cases are intimately related to late ductile shear bands. Consequently, they likely intruded the gabbro sequence at high temperatures and hence at a relatively early stage. The second style of veins has sharp, planar margins, and was likely intruded later at lower temperatures. Some planar veins localize crystal-plastic deformation, confirming that deformation was still occurring after some of the veins had been intruded and solidified.

Igneous contacts between gabbros vary over the interval and may be intrusive and/or defined by mineral modes or grain size. The contacts typically dip at low angles. Magmatic fabrics are rare and, if present, are defined by the shape-preferred orientation of plagioclase and pyroxene. The transition from igneous textures to crystal-plastic textures is observed in thin sections by an increase in deformation of the primary minerals. Plagioclase typically shows increased undulose extinction, tapered twins, subgrain development, and local recrystallization and production of neoblasts. Olivine and clinopyroxene recrystallize and form irregular aggregates at porphyroblast grain boundaries, or elongated aggregates between neoblasts of plagioclase parallel to foliation.

Crystal-plastic fabrics are characterized by localized decimeter-thick shear zone sequences bounding several meter-thick zones of gabbro with reduced plastic deformation, indicating that deformation was preferentially partitioned into discrete high deformation zones. Most samples that appear undeformed in hand specimen at the core sample scale are nevertheless observed in thin section to have a distinct crystal-plastic overprint within plagioclase-rich areas.

Ductile, centimeter-scale shear bands are common throughout the cored interval. Crosscutting relationships between shear bands of different orientations are complex and non-systematic. For example, in Section 40R-1, a subhorizontal mylonite is cut at high angle by centimeter-wide shear bands. In other examples, subhorizontal shear bands crosscut subvertical shear zones.

These relationships record multiple generations of high-temperature deformation in different orientations.

Brittle deformation is exhibited by microfractures in plagioclase and pyroxene and decreases downhole. Three fault breccias were identified in Sections 31R-1, 35R-2, and 37R-3, all with variable proportions of angular clasts and matrix material. Several fractures have slickenlines with moderate to steep rakes suggesting oblique to dip-slip movement. Brittle deformation features were confirmed by microstructural observations. In some samples, for example Section 10R-1, the contemporaneous recrystallization and intense fracturing of plagioclase, clinopyroxene, and olivine document deformation spanning the ductile-brittle transition.

Alteration veins are dominantly filled with carbonate and, to some extent, clay and potentially quartz. Veins tend to form parallel sets and are often inclined. In some cases, for example Section 44R-2, faceted calcite crystals have grown within open voids.

The Paleomagnetic team completed measurement and alternating field demagnetization of archive halves down to Core U1473A-44R. After processing and quality filtering down to Core 40R (364 mbsf), these data show a reversed polarity magnetization with a mean inclination of  $71.5^\circ$  (calculated using data from 1860 measuring points with statistically acceptable principal components). This is comparable to the mean inclination of  $73^\circ$  derived from our earlier measurements from Hole 1105A, and indicates significant tectonic rotation of the Atlantis Bank footwall. The team completed demagnetization of the first batch of discrete samples from Hole U1473A. Results demonstrate that an initial low-temperature demagnetization step, prior to standard thermal demagnetization, is effective at removing low stability magnetic overprints. Anisotropy of low field magnetic susceptibility measurements on discrete samples from the interval down to 250 mbsf show a dominance of oblate magnetic fabrics. Magnetic foliations generally have dips of  $10^\circ$ – $40^\circ$ , consistent with the range of dips of crystal-plastic foliations determined in archive halves by the Structural Geology team.

The Petrophysics team continued their measurements of magnetic susceptibility, density, and natural gamma radiation on core sections from Hole U1473A. Cores 32R to 44R have an average magnetic susceptibility of  $\sim 400$ – $500$  Instrument Units, indicating an overall relatively low Fe-Ti oxide content. Natural gamma radiation from the gabbro cores remains very low ( $\leq 1$  counts/s), except for a few higher peaks up to  $\sim 10$  counts/s, which correspond to felsic veins.

Compressional wave velocity ( $V_p$ ) was measured on 71 gabbroic samples from Hole U1473 at room pressure and temperature along three perpendicular directions.  $V_p$  ranges from 5930 to 7140 m/s, with an average of 6775 m/s and an average standard deviation of 25 m/s. The apparent anisotropy of  $V_p$  is 2.6% on average. Density and porosity was measured on 66 samples; grain density ranges from 2.88 to 3.13 g/cm<sup>3</sup> and averages 2.97 g/cm<sup>3</sup>. Porosity ranges from 0.10% to 2.90% and averages 0.78%. Thermal conductivity was measured on 35 archive section half pieces and ranges from 1.77 to 2.38 W/(m·K), averaging 2.20 W/(m·K). The standard deviation of the measurements is  $<2\%$  (0.6% average).

The Microbiology team processed 18 samples for different types of analyses over the past week. Twenty-six samples were collected for ATP analysis; six of these showed detectable ATP and the rest were below detection limit. Of the six positive samples, five were prepared from vein material only; two were felsic veins and three were carbonate veins. We ran a new PFMD tracer contamination test by analyzing three replicate samples each of seawater with tracer collected prior to injection, small rubble from the core catcher to represent exterior contamination, rock chips from our core sample exterior following our cleaning procedure, and rock chips from our core sample interior. All core interior samples had no detectable tracer. One cleaned core exterior replicate produced a faint peak that was at the detection limit, and the other two replicates did not produce detectable tracer. The core catcher rubble (not subjected to cleaning) produced detectable tracer in the 60–88 ppb range. The drilling fluid produced detectable tracer in the 5160–6677 ppb range. We will repeat tracer tests with PFMD when we resume coring.

## **Education and Outreach**

### *Live Broadcasts*

- Held a total of 16 personal broadcasts to friends and family of the science party.
- Did not hold any school broadcasts due to the holiday season.

### *Outreach Products*

- Hosted an “Ask Me Anything” (AMA) session on Reddit, answering 64 questions over the course of 2 h.

### *Social Media*

- *JOIDES Resolution* blog (<http://joidesresolution.org/>): seven posts, 1,793 reads.
- Facebook (<https://www.facebook.com/joidesresolution>): 14 posts, 19,708 people reached.
- Twitter (<https://twitter.com/TheJR>): 20 tweets, 46,400 impressions.
- Instagram ([http://instagram.com/joides\\_resolution](http://instagram.com/joides_resolution)): four posts.

### *Media*

- Two news stories and 13 photos submitted to the Xinhua News Agency.
- One broadcast to the Sasha TV station in Hainan Province, China.

## **Technical Support and HSE Activities**

### *Laboratories*

- Core Laboratory

- Continued to support processing of cores.
- All 183 working section halves taken to date were laid out for scientists' postcruise research sampling.
- Section Half Imaging Logger (SHIL) 1 is being used to take whole round surface images rather than the dedicated SHIL2 delivered for Expedition 360. The lights on the SHIL2 were not sufficient, compromising image quality on that system.
- Chemistry and X-ray Diffraction Laboratories
  - Processed ICP and XRD samples. Sea state, however, was too rough during the transit for running ICP samples.
  - PFMB tracer for microbiology was run on the GC.
- Thin Section Laboratory
  - Processing 12 thin sections per day.
- Microbiology Laboratory
  - PFMB tracer was used while coring Core 43R.
- Developer Report
  - Continued development of new Web services.
  - Debugged root cause of problems with DESClogik in downloading all template data for all tabs for the entire hole.
  - Provided data repairs not supported by LIME: MAD masses applied against the wrong sample; velocity caliper observations recorded against the incorrect axis.
  - Revised and tested changes to the depth data management in LIMS, and dismantled the old depth computation scheme. This will enable the retirement of several database components.
  - Added a custom thin section report to LIMS Reports.
- Information Technology
  - Working with Novell support to resolve issues with AFP service crashing randomly on file servers. We have installed a patch provided by Novell and are now observing service behavior.
  - Working with Oracle support to resolve issues with server patches.
  - Working with our CommVault account manager to adjust our product license structure to accommodate recent and future changes to our shipboard IT environment in regards to file/server backup and recovery.

### *HSE Activities*

- A Fire and Boat Drill was held on 30 December.
- A medical evacuation to Mauritius was conducted starting from 30 December 2015 and continuing through 5 January 2016.