IODP Expedition 360: SW Indian Ridge Lower Crust and Moho

Week 4 Report (20–26 December 2015)

Operations

Week 4 of Expedition 360 (Southwest Indian Ridge Lower Crust and Moho) began while coring Core U1473A-2R at a depth of 9.5 mbsf. Coring continued through Core U1473A-9R (80.4 mbsf), when drill bit use reached 39.5 h at 1500 h on 21 December. The hole was cleaned and the drill pipe was pulled to the surface, equipped with a new C-7 RCB bit, and redeployed. Hole U1473A was reentered for the second time at 2335 h on 21 December. No fill was recorded at the bottom of the hole. RCB coring resumed at 1315 h on 22 December from 80.4 mbsf. At 0400 h on 24 December, when coring had reached 167.7 mbsf (Core U1473A-18R) and bit rotating hours was at 42.5 h, the drill string was again retrieved to install a new bit. We reentered Hole U1473A with the third RCB bit at 1137 h on 24 December. No fill was detected on bottom and coring resumed at 1415 h from 167.7 mbsf. While cutting Core 19R, the ship's heave continued to increase. The situation worsened while attempting to cut Core 20R. When it became impossible to keep the bit on bottom after a 2.7 m advance, we suspended coring. Core 19R was recovered and the drill string was tripped out of the hole and secured with the end of pipe in the water column at 624 mbsl while we waited on the swell to subside. Ship heave of over 6 m total amplitude was recorded while waiting on weather.

After a 1 h period with heave consistently <4 m, the ship was positioned to reenter Hole U1473A at 1122 h on 25 December. After reentering the hole and lowering the bit to the bottom, no fill was observed and RCB coring continued at 1400 h from 180.1 mbsf. By the end of the week, Cores 21R through 29R had penetrated to 264.7 mbsf, and RCB coring was continuing in Hole U1473A with 29.7 h on this third RCB bit.

During the past 8 d, we recovered a total of 28 cores from the interval 9.5–264.7 mbsf and recovered 128.6 m (49%), with individual core recoveries ranging from 16% to 80%.

Science Results

During Week 4, all laboratory teams described and measured Cores U1473A-2R through 27R (9.5–245.3 mbsf), including some of the initial thin sections and other discrete subsamples taken from these cores.

The section described so far consists of gabbroic rocks, mostly coarse-grained deformed granular olivine gabbro. The top 75 m of the section is the least deformed, and when not deformed, textures are subophitic. The gabbros include 65% olivine gabbro, 14.5% disseminated-oxide gabbro (containing 1% to 2% of oxides), 7.5% oxide gabbro (oxide >5%), and 3% gabbro. Locally, zones of felsic melt infiltrated into deformed granular gabbros. Some rare felsic and diorite veins were observed. A single small fragment of a sparsely plagioclase phyric diabase

dike was found, which attests to the presence of crosscutting dikes in the lower part of the section drilled to date. Layering was observed at 100–150 mbsf, with alternating coarse- and fine-grained layers of olivine gabbro. The original, undeformed relationship between those layers was observed in some rare samples, but in most instances we infer it has been overprinted by subsequent crystal-plastic deformation. Detailed observations of the corresponding thin sections have allowed us to document the evolution of this plutonic section, from the crystallization of relatively primitive subophitic (olivine) gabbros to the evolution of late-stage melts within the crystallizing mush. Orthopyroxene was observed in strongly deformed and recrystallized samples, attesting to the equilibration of those gabbros in the granulite facies (800°–1000°C).

The proportion of static alteration minerals varies throughout the section from <10 vol% to 60 vol%, increasing in extent in proximity to veins. Observations in thin sections from representative intervals reveal mineral parageneses and textures indicative of different temperatures and order of formation. Common relationships include the partial replacement of olivine by actinolite, talc, serpentine, and clay minerals; of primary clinopyroxene by secondary clinopyroxene and brown/green amphibole; and of primary plagioclase by secondary plagioclase and fracture-filling amphibole or chlorite. Veins of brown/green amphibole with a subordinate amount of plagioclase are cut by, or contain in their center, veins composed of zoisite, actinolite, and chlorite. Later veins filled with clay minerals and calcite + aragonite were also detected with XRD analysis. These observations together suggest a sequence in which static alteration persisted under conditions ranging from amphibolite to sub-greenschist facies. Neoblasts in mylonitic gabbros consist of plagioclase, clinopyroxene, and brown amphibole, locally associated with olivine or green amphibole, indicating dynamic recrystallization under granulite and amphibolite facies conditions. A small amount of native copper was found along a fracture within Core 15R, confirmed by XRD analysis.

The interval drilled this week (9.5–196 mbsf) is dominated by crystal-plastic deformation, which likely represents the influence of the Atlantis Bank detachment fault system. The uppermost 10 m of the section was conspicuously undeformed, but below this the core reveals a well-developed sequence of porphyroclastic shear zones and mylonites. Fabric dip varies systematically down the core with an abrupt change from moderately dipping to subvertical at 60–70 mbsf, followed by a gradual shallowing of dip to 20°–40° within a 50 m thick gneissic protomylonitic to mylonitic sequence. A crosscutting series of narrow shear bands is associated with the intrusion of felsic melts, forming vein networks and distorting the primary fabrics.

Grain-size layering is variably developed, with fine grained to coarse-grained layers present throughout much of the core. Less deformed intervals within which the grain-size variation is not overprinted by crystal-plastic deformation indicate that the layering is a primary igneous fabric. The originally finer-grained layers preferentially localized deformation compared to the coarser-grained zones. In general, the contacts between grain size layering are subparallel to the crystal-plastic fabrics.

Magmatic fabrics, defined by the shape preferred orientation of elongated pyroxene and plagioclase, typically have a moderate dip, parallel to that of the crystal-plastic fabrics. Several intervals lack a magmatic fabric. In other intervals it is apparent that the crystal-plastic fabric overprints the magmatic fabric.

Alteration veins are numerous and are filled with amphibole, clay, or carbonate. Amphibole veins are more abundant above 90 mbsf, but markedly less so below this depth, where clay and carbonate veins dominate. A bimodal distribution in amphibole vein dips may indicate that the amphibole veins form conjugate sets. All vein types crosscut deformation fabrics and magmatic layering. Amphibole veins can displace the foliation with both normal and reverse shear-sense and in some instances fold and offset the foliation.

Brittle deformation occurs as fracture networks, typically deforming plagioclase and sometimes pyroxene, and as discrete fractures. The fracture networks are commonly associated with alteration and overprinting of the crystal-plastic fabrics. Four cataclastic zones (one each at 15 and 130 mbsf and two at 197 mbsf) range from 1 to 5 mm thick, and two fault breccias were recovered at 97 and 179 mbsf. Several fractures display intermediate-plunging slickenlines with a steep rake suggesting oblique- to dip-slip. When identified, the sense of slip from steps in the slickensides is typically normal.

The microbiology team processed a total of 28 samples during this week. All samples were processed for post-cruise cell counts, DNA iTAG sequencing (microbial diversity), RNA-based iTAG sequencing (active fraction of diversity), shipboard adenosine triphosphate (ATP) analysis, and shore-based thin section and scanning electron microscopy analysis. When sufficient material was available for RNA-based iTAGs (~50% of samples), we also preserved samples for shore-based lipid, metagenome, and metatranscriptome analyses. For seven samples we performed extensive fungal and prokaryotic enrichment culturing. For an additional six samples we initiated fungal enrichments. All culturing results will be assessed postcruise. For nine samples we established time-course exo-enzyme assays for three different exo-enzymes. These assays will be completed postcruise.

So far, ATP was detected in three samples (Sections 2R-1, 3R-1, and 8R-3). We have since changed our protocol for sampling for ATP. Since microorganisms are unlikely to be uniformly distributed throughout rocks, but are instead more likely to be localized in sites where fluids can flow and where nutrients are available (e.g., sites of alteration/weathering or veins), we shifted to sampling just those areas for ATP measurements. We have not yet analysed ATP from vein material.

On three occasions the microbiology team has also collected drilling fluids and muds along with core exterior samples for contamination control. These samples will be analysed using DNA-based iTAGs postcruise. Samples from Cores 3R, 4R, 12R, and 30R were used for analysis of tracer contamination. During the drilling of those cores, the tracer perfluoromethyldecalin (PFMD) was run with the drilling fluids at a final concentration of ~1 mg/L. A gas

chromatograph was used to measure the concentration of tracer in rock material from the outside of the sample before cleaning with sterile water (four times washes) and then 95% ethanol. Results indicate that the tracer is undetectable and that the cleaning protocol we are using is effective at either completely eliminating the tracer, or at least reducing its concentration by half.

The paleomagnetics team completed measurement and processing of archive section halves from Hole 1105A, generating a quality-controlled set of downhole data that show a consistent reversed polarity magnetization with a mean inclination of 73° (calculated from piece averaged data). Measurements of archive section halves from Hole U1473A began, demonstrating that these rocks also carry a reversed polarity magnetization (down to at least 180 mbsf). The first discrete samples from this hole were prepared for demagnetization using a combination of alternating field, low temperature, and thermal techniques.

The petrophysics team performed measurements of magnetic susceptibility, density, and natural gamma radiation on whole-round sections from Hole U1473A. Filtered point magnetic susceptibility data from Cores 2R to 17R average ~800 Instrument Units. Bulk density measured on whole-round sections from Cores 2R to 17R averages 2.6 kg/m^3. Thermal conductivity measurements on 15 pieces from Cores 2R to 19R average 2.2 W/(m·K) and range from 1.8 to 2.4 W/(m·K). The team began measurements of compressional seismic velocity, density, and porosity on discrete samples.

Education and Outreach

Interactions

- Facilitated 17 personal broadcasts for science party members to friends and family over the holidays.
- Held a total of six broadcasts to schools: three to the USA, two to France, and one to Italy. The number of broadcasts was reduced because of the winter holiday season.
    - Total students reached: 165
    - Total scientists engaged: 6

Outreach Products

- The third podcast episode was published, currently at ~700 listeners.

Social Media

- *JOIDES Resolution* blog (http://joidesresolution.org/): seven posts, 1,721 reads.
- Facebook (https://www.facebook.com/joidesresolution): 15 posts, 9,242 people reached.
- Twitter (https://twitter.com/TheJR): 14 tweets, 12,400 impressions.
- Instagram (http://instagram.com/joides_resolution): 10 posts.

Media

- Article published in the Boston Globe, interview broadcast on ABC World News.
- Three news stories and 24 photos submitted to the Xinhua News Agency.

Technical Support and HSE Activities

Laboratories

- Core Laboratory
    - Routine processing of igneous rock cores.
    - Routine support for core description template configuration.
- Biology and Chemistry Laboratory
    - Processed samples for shipboard and shorebased analysis.

HSE Activities

- A Fire and Boat Drill was held on 22 December.