IODP Expeditions 367 and 368: South China Sea Rifted Margin

Site U1500 Summary

Background and Objectives

Site U1500 is located on a basement ridge ("Ridge B"), and it is the most seaward site that Expedition 367 drilled within the South China Sea continent-ocean transition (COT). Ridge B is located ~80 km seaward of a basement structure labeled the Outer Margin High, and ~20 km seaward of "Ridge A" where Site U1499 was drilled. The goal of drilling here was to sample and log the lowermost sediments and underlying basement rocks, and to determine basement age and lithology of the COT or embryonic oceanic crust (EO). This would provide a test of different possible models for the processes and rheology controlling the breakup of the continent. Ridge B was expected to have basement of upper continental crust, lower continental crust, mantle rocks, or oceanic crust. The coring and logging would also constrain the history of the region after rifting by determining the age, water depth, and subsidence rates of the overlying sedimentary packages.

Operations

We conducted operations in two holes at Site U1500 (proposed site SCSII-8B). Hole U1500A is located at 18°18.2762′N, 116°13.1916′E in a water depth of 3801.7 m. In Hole U1500A, we (a) drilled without coring from the seafloor to 378.2 m, (b) rotary core barrel (RCB) cored from 378.2 to 494.6 m and recovered 26.5 m (23%), (c) drilled without coring from 494.6 to 641.2 m, and finally (d) RCB cored from 641.2 to 854.6 m and recovered 67.2 m (31%). Hole U1500B is located at 18°18.2707′N, 116°13.1951′E in a water depth of 3801.7 m. After installing casing, we continuously RCB cored the sediment sequence from 846.0 to 1379.1 m (533.1 m cored, 164.7 m recovered, 31%), and then continuously RCB cored 149.9 m into the underlying basalt from 1379.1 to 1529.0 m (114.92 m recovered, 77%). This made Hole U1500B the eighth deepest the *JOIDES Resolution* has drilled. Three downhole logging strings were run in Hole U1500B from 842 to 1133 m.

Principal Results

Lithostratigraphy

The cored sediment at Site U1500 is divided into eight lithostratigraphic units. The uppermost 378.2 m of sediment was drilled without coring. Lithostratigraphic Unit I (378.2–410.0 m) is a 31.8 m thick upper Miocene sequence of greenish gray, heavily bioturbated clay with silt and sandy silt interbeds. Some of the clay intervals are nannofossil rich. Structure in the clay is mostly massive, but parallel laminations occur in the silt and sandy silt interbeds. Unit II (410.0–494.6 m) is an upper Miocene sequence of interbedded dark greenish gray clay and silt. Recovery was very low for this unit (~8%), which may indicate a change in lithology (e.g., increased abundance of nonlithified sands). This unit is underlain by another interval drilled without coring (494.6–641.2 m).

Unit III (641.2–892.4 m) is defined by upper Miocene interbedded claystone, siltstone, and sandstone. Many of the siltstone and sandstone intervals are organized into a variety of massive and stratified beds that include sedimentary structures such as parallel laminations, cross-stratification, and contorted strata. There are also several massive beds of sandstone that contain pebble-sized mud clasts. The well-organized coarser intervals fine upwards into more massive claystone intervals and are interpreted as turbidite sequences. Several of the stratified beds are composed of foraminiferal tests.

Unit IV (892.4–1233.3 m) also had very low recovery (15%). This unit is composed of upper Miocene very dark greenish gray to dark gray sandstone with dark brown to very dark gray claystone and siltstone intervals. Many of the intervals described in this unit contain interlaminations of silt or sand within a prevailing claystone lithology. Similar to Unit III, sedimentary structures in many of the sandstone and siltstone intervals are interpreted as turbidites. The claystone in some of the cores show a distinctive color banding, which was observed as a pattern of alternating reddish brown, dark greenish gray, and brownish gray. The color banding appears to be associated with fining-upward grain sizes and varying levels of bioturbation. Sandstone intervals within this unit contain high percentages of potassium feldspar, quartz, plagioclase, and mica minerals, which may have been sourced from granitic rocks exposed along the southern margin of China.

Unit V (middle-upper Miocene) was divided into Subunits VA (1233.30–1272.10 m) and VB (1272.10–1310.98 m) based on the abundance of calcareous material. Subunit VA consists of dark reddish brown, dark greenish gray, and dusky red homogeneous, massive claystone with few sandstone and siltstone interbeds (3–12 cm thick). Subunit VB consists of dark reddish brown, reddish brown, and greenish gray intervals of claystone, nannofossil-rich claystone, claystone with biogenic carbonate, and clay-rich chalk. Intervals of greenish gray color within Subunits VA and VB unit are interpreted as diagenetic alteration.

Unit VI (1310.98–1370.33 m) is composed of middle Miocene dark greenish gray massive silty claystone with biogenic carbonate and dark gray sandstone.

Unit VII (1370.33–1379.10 m) comprises a thin (30 cm thick) middle Miocene dusky red claystone. The lowermost 2 cm of this unit has a greenish gray color that marks a sharp horizontal contact with the igneous rocks below in Unit VIII. The pre-Middle Miocene basalt in Unit VIII (1379.10 m–1529.0 m) contains some fractures that are filled with well-lithified claystone. The claystone contains authigenic carbonate, siliciclastic components, and rare nannofossils. The basalt intervals are sparsely intercalated with dusky red claystone, with the basalt-sediment contacts often associated with chilled, glassy margins. Some claystone intervals within the basalt unit show evidence of dolomitization in thin section.

Igneous Petrology

In Hole U1500B, we cored 149.9 m of igneous rocks below the sedimentary section and recovered a total of 114.92 m of basalt. The aphanitic to porphyritic basalts are nonvesicular to moderately vesicular, glassy to hypocrystalline, with the latter ranging from cryptocrystalline to fine-grained in grain size, making up an aphyric to highly olivine-plagioclase phyric microstructure. These basalts contain 2–5 cm thick chilled margins, many with preserved fresh glass, as well as occasional hyaloclastites with brecciated glass fragments mixed with sediments. The basalts comprise Lithostratigraphic Unit VIII, but are subdivided into 18 igneous subunits (1a to 1r) according to flow boundaries to distinguish individual massive, sheet, pillow, and lobate lava flows. Pillow lobes are well preserved and are separated by chilled, glassy margins (distinguished into upper and lower chilled margins of individual pillows where possible) and occasional claystone. Plagioclase phenocrysts are found throughout these basalts with olivine being an occasional phenocryst. Modal abundances of olivine and plagioclase phenocrysts increase downhole, reaching a peak between 1420 and 1470 mbsf.

Veins occur throughout Unit VIII and are predominantly filled with carbonates and Fe-oxides/hydroxides, chlorites, zeolites, as well as sediments (Neptunian dikes). Veins usually show a sharp contact with the surrounding host basalt and are either polycrystalline or massive. Claystone is a ubiquitous phase in many carbonate-rich veins, especially in pillow lava flows, and is usually found as very fine aggregates within carbonate veins or as centimeter-thick veins with no preserved textures or structures. Red to green-red haloes are usually found surrounding the carbonate veins, which are related to the background alteration of interstitial glass, olivine, and occasionally plagioclase and clinopyroxene. Alteration of these basalts remains overall slight, evidenced by the minimal alteration of interstitial glass as well as the degree of preservation of igneous minerals, including olivine and plagioclase. Alteration intensity does increase downhole.

Structural Geology

Tilted sedimentary bedding and deformation structures were observed in all lithostratigraphic units. Faults, tilted beds, folds, and mud clasts observed in Units I, II, and III are likely related to gravity-controlled deposition (e.g., debris flows, slumps, slides, etc.). Unit IV has low recovery and exhibits only a few tilted beds and compaction faults. A total of 47 centimeter-scale faults were measured in the claystone of Units V, VI, and VII. Many of these faults have slickensides and are likely related to clay compaction during lithification. Open fractures and veins are identified in the sparsely to highly plagioclase phyric basalts of Unit VIII. There are no preferred orientations of these structures. Most of the veins are filled by carbonate minerals, Fe oxides, sediments, and secondary minerals. Veins are often haloed by Fe-oxide alteration. The vein connectivity is variable; single veins, branched veins, and vein networks are observed. There is no mineral preferred orientation. Although the seismic profile across Site U1500 shows dipping reflectors in the basalt, we do not observe any clear paleohorizontal or dipping features within these lavas.

Biostratigraphy

All core catcher samples were analyzed for calcareous nannofossil and foraminiferal content. Additional samples were taken from the split-core sections when necessary to refine the ages between core catcher samples. Preservation of microfossils varies from poor to good. Overgrown as well as abundant broken fragments are common in the sediment sequences. The total abundance varies from barren to abundant and most samples exhibit some degree of reworking.

Although the recovery is low and ~50% of samples are barren, twelve biostratigraphic datums are recognized, revealing that we recovered an apparently continuous succession of Late–Middle Miocene age. The Late/Middle Miocene boundary (11.6 Ma) can be placed between Samples U1500B-37R-1W, 40/41 cm and 44R-CC. Sedimentation rates varied from ~12 cm/ky in the upper Late Miocene, ~27 cm/ky in the lower Late Miocene, to ~5 cm/ky in the Middle Miocene. A total of 18 sediment samples from the veins and intrapillow fill of the basalts of Lithostratigraphic Unit VIII were analyzed for nannofossil content. Only two samples contain poorly preserved calcareous nannofossils and indicate an Oligocene age. However the ages of these samples relative to the basalts are not clear.

Geochemistry

At Site U1500, measurements of organic and inorganic carbon and nitrogen were conducted on one sample per sedimentary core that had relative high recovery, and headspace gas measurements were taken for all sediment cores. In addition, four basalt samples were analyzed for concentrations of major elements and several trace elements using inductively coupled plasma–atomic emission spectroscopy (ICP-AES). The headspace gas values do not exceed 15 ppmv and are mostly below the quantification limit. The carbonate contents are dominated by biogenic carbonate and vary between <1 to 40 wt%, with higher values corresponding to the calcareous-rich lithologic units. TOC and TOC/TN are low, averaging 0.14 wt% and 4.6, respectively. ICP-AES analyses of basalts from Site U1500 indicate subalkaline, MORB-like compositions.

Paleomagnetism

We conducted alternating field (AF) demagnetization of archive-half sections and AF and thermal demagnetization of representative discrete samples. For the sedimentary samples, AF demagnetization effectively removed the drilling-induced overprint and provided inclinations. Inclination data from the sedimentary long-core and discrete samples are in agreement, but due to discontinuous coring and poor recovery in many cored intervals we are not able to correlate these to the standard geomagnetic polarity timescale. The pass-through measurements of the basalts show an effective removal of a low coercivity component; however, it is not clear that we have revealed the characteristic remanent magnetization. The basalts sometimes show both positive and negative inclinations upon stepwise AF treatments within a single igneous subunit. The basalts show a more complex pattern when progressive thermal demagnetization measurements are made on discrete samples. The close association of negative inclinations, changes in magnetic susceptibility, and demagnetization behavior with fractures in the cores points to the possibility of a secondary chemical remanent magnetization (CRM) as the source of the reversed intervals in the basalt.

Petrophysics

We conducted measurements of bulk density (GRA), magnetic susceptibility (MS), and natural gamma radiation (NGR) on whole-round cores, and additional measurements on split cores and discrete samples, including thermal conductivity, caliper *P*-wave velocity (PWC), porosity, and bulk, dry, and grain density. In general, bulk density, *P*-wave velocity, and thermal conductivity increase with depth, whereas porosity decreases with depth as a result of compaction and lithification. However, some properties, such as NGR or MS, show local variations related to the specific lithology. A significant increase in carbonate content in Lithostratigraphic Unit VB (1272–1311 m) causes a general decrease in NGR counts, and only a slight decrease in the MS data. Physical properties change significantly in the basalts of Lithostratigraphic Unit VIII (1379–1529 m). MS values are two orders of magnitude higher than in the sediment above, and vary depending on the degree of alteration. *P*-wave velocity values are also much higher, ranging between 4430 and 5710 m/s, while porosity and NGR values are very low compared to the sediments above.

Correlation to Seismic Data

We used physical properties measurements on cores and samples to correlate Site U1500 data with the available seismic reflection profile. We also used the Site U1500 density and PWC velocity data to create synthetic seismograms that provided additional constraints on the correlation. The time-depth relation (TDR) obtained for Site U1500 show substantial agreement with those for Site U1499 as well as IODP Sites U1431 and U1433; in contrast, the ODP Site 1148 TDR exhibits higher velocities in the deeper layers. The comparison between the seismic reflectors and the variations in physical properties and lithology characteristics using the computed Site U1500 TDR shows a good correlation between the high-amplitude seismic reflector at ~6.4 sec two-way traveltime (TWT) and the top of basalts of Lithostratigraphic Unit VIII.

Downhole Measurements

Three downhole logging tool strings were run in Hole U1500B: a modified triple-combo (sonic velocity, NGR, bulk density, resistivity, caliper), the Formation MicroScanner (FMS resistivity images and caliper, NGR), and the Versatile Seismic Imager (VSI) (check shot, NGR). During the first run, the tool string encountered an obstruction at 4946 m WRF (~1133 m depth below seafloor) and we were unsuccessful in getting the tool string to pass below this depth. We collected FMS data from ~1044 m up to the bottom of the casing (842 m). Although the hole had many zones that were significantly enlarged, initial observations of the real-time FMS data indicate that some intervals exhibit relatively good caliper contact and should provide useful resistivity images. A seismic check shot survey with the VSI tool was able to collect data successfully at one depth in the open hole as well as at the base of the casing. Since this was the last operation conducted on Expedition 367 and we only had a 1 d transit to Hong Kong, data processing data and a full evaluation of the log data will be conducted after Expedition 367.