IODP Expedition 368X: Return to Hole U1503A (South China Sea)

Site U1503 Summary

Background and Objectives

During Expedition 368X, we returned to Site U1503 to complete operations initiated during Expedition 368. Site U1503 (proposed Site SCSII-9B) is located at 3867.7 m below sea level near the top of the South China Sea structural high named Ridge C. Ridge C is the most seaward ridge of the three margin-parallel Ridges A, B, and C that characterize the lower continental slope underlain by thin (5–7 km) crust. Ridge C is believed to represent at least partial, if not full, igneous crust and hence the completion of continental breakup along this margin segment of the northern South China Sea.

A key operational objective of Site U1503 was to sample the lowermost ~300 m of sediments on top of basement to constrain the age and subsidence history of the crust at this location, the timing of normal faulting, and the environment of the early half-graben fill. The other critical goal was to sample the igneous stratigraphy to at least 100 m below the sediment/basement interface. Deep, representative sampling of the basaltic material at this site will provide an important reference frame for the modeling of South China Sea breakup. With an estimated sediment thickness of 1640 m overlying basement, obtaining basement samples and log data at this site represented a challenging operation.

Operations

We conducted operations in one hole at Site U1503. In Hole U1503A, we used the reentry system and 10¾ inch casing (to 995.1 m below seafloor [mbsf]) installed by Expedition 368 to reenter the existing hole. The existing reentry cone was slightly below the level of the seafloor and full of debris from the previous drilling at Hole U1503A. A free-fall funnel atop a 5 m extension was added to the reentry system. We cored the sediment sequence with the rotary core barrel (RCB) system from 995.1 to 1597.84 mbsf (602.74 m cored; 128.01 m recovered; 21% recovery) and then continuously cored 112.26 m into the underlying basalt from 1597.84 to 1710.1 mbsf (47.91 m recovered; 43% recovery). Following the final core, the bit was released on the seabed. Logging with the Vertical Seismic Imager (VSI) tool was conducted within the casing only.

Principal Results

Lithostratigraphy, igneous and metamorphic petrology, and structural geology

Site U1503 is divided into four lithostratigraphic units, three composed of sediments and one containing the igneous basement. The uppermost 995.1 m of sediment was drilled without coring during Expedition 368. Lithostratigraphic Unit I (995.10–1484.74 mbsf) is a 489.6 m thick sequence of well consolidated to lithified, brownish gray, moderately bioturbated claystone with greenish gray sandstone and siltstone interbeds. Some of the coarser intervals have high carbonate content and multiple sedimentary structures (mud clasts, fining upward sequences, parallel and convolute laminations) potentially related to deep-sea turbiditic flows. The relatively low recovery (21%) of Unit I is attributed to the presence of thick sandstone layers, inferred from the high amplitude reflectivity of the seismic section. Unit II (1484.74–1542.77 mbsf) was divided into Subunit IIA (1484.74–1533.60 mbsf) and Subunit IIB (1533.60–1542.77 mbsf) based on carbonate and nannofossil content. Subunit IIA has a recovery of 36% and consists of lithified, dark reddish brown, massive claystones with greenish gray intervals containing heavier bioturbation. Subunit IIB has an extremely low recovery (3%) and consists of lithified, reddish brown, clay-rich chalk. The boundary between Subunits IIA and IIB is also based on geochemical data. Subunit IIA has low carbonate content and high Sr, Fe, Ni, Zn, and Al content, whereas Subunit IIB is carbonate rich and low in Sr, Fe, Ni, Zn, and Al. Unit III (1542.77–1597.84 mbsf) contains heavily bioturbated, lithified, greenish gray nannofossil-rich claystone, greenish gray claystone, light greenish gray siltstone, and dark gray banded claystone. Recovery in Unit III is extremely low (5%). A 4 cm thick greenish black interval is present in Unit III, and likely composed of highly altered volcanoclastic material.

Unit IV (1597.84–1710.10 mbsf) is an igneous unit that represents the uppermost part of the South China Sea basement. The boundary between the sediment of Unit III and the underlying basalt of Unit IV was placed at 1597.84 mbsf, but is unfortunately disturbed by drilling and corresponds to the separation between claystone and basalt rubbles at the bottom of the core. Lithostratigraphic Unit IV continues through 112.26 m of basement from which 47.91 m was recovered. Unit IV is composed primarily of sparsely plagioclase to plagioclase phyric basalt with no vesicle to high vesicle content. Basalts have mostly an ophitic to subophitic texture with euhedral phenocrysts of plagioclase. This basalt unit contains chilled margins with preserved fresh glass and occasional hyaloclastites with brecciated glass fragments imbricated with clayey sediments or recrystallized carbonate. Veins occur throughout Unit IV and are predominantly filled with carbonate minerals, Fe oxides, chlorites, and zeolites. Alteration of these basalts remains slight overall, as evidenced by the minimal alteration of interstitial glass as well as the good preservation of plagioclase. The texture, contacts, and structures of Unit IV suggest an emplacement as pillow or lobate lava flows in a subaqueous environment.

Biostratigraphy

Between Cores 368X-U1503A-2R-1 and 48R-CC, a 5 cm whole-round sample was collected from each core catcher on the catwalk. The sample was vacuum sealed and stored for shipment to the Gulf Coast Repository (GCR) in College Station, TX, at the end of the expedition. Exceptions to this occurred in particularly low recovery cores. No samples were collected for biostratigraphy in lithified sediments and basement below 1441.70 mbsf.

Paleomagnetism

The intensity of the natural remanent magnetization in sediments at Site U1503 is higher in the reddish claystone (10^{-2} A/m) of Unit II than in the brownish, greenish, and gray sediments of both Unit I (10^{-3} A/m) and Unit III (10^{-4} A/m). In the basalts (Unit IV), average initial intensity is at least two to four orders of magnitude higher than in sediments (1 A/m).

Both sediments and basalts show two components of magnetization. The first component is isolated at lower fields and, at least in the sediments, shows steep positive inclination and can be correlated to a drilling overprint. The second component, which is interpreted as the characteristic remanent magnetization (ChRM), shows both reversed and normal polarities and can be isolated in different field ranges, depending on the coercivity of the magnetic carriers. In the sediments, the presence of both normal and reversed polarities and a mean ChRM inclination of 26.4° ± 8.0° (close to the 25° inclination expected at the coordinates of Hole U1503A) support a primary nature of the magnetization. However, the observed inclination pattern cannot be correlated with a reference geomagnetic polarity timescale due to the extremely low recovery.

The anisotropy of magnetic susceptibility shows strong oblate shape and horizontal planar fabric in sediments, consistent with deposition in a calm pelagic environment. An inclined planar fabric is present in Units II and III and shows a foliation inclined by ~30°. In basalts, a prolate shape of the ellipsoid and an intermediate fabric indicate the presence of flows whose direction is not possible to determine as cores are not oriented.

Geochemistry

Geochemical analyses were conducted for headspace gas safety monitoring in all sediment cores and in two basement cores. Methane values in the sediment sections are low (<30 ppmv) above 1394 mbsf. Below 1404 mbsf, methane values in sediments gradually increase (average 1249 ppmv) before reaching a maximum of 5066 ppmv very near the sediment/basement interface. Quantification of sediment $CaCO_3$, inorganic and organic carbon, nitrogen, and sulfur content was made for 43 samples. Samples with carbonate content >30 wt% found near the top of the cored sedimentary sequence correspond to sandstones in lithostratigraphic Unit I. With three exceptions, TOC/TN values range from <1 to 6.4 (average = 4.3), suggesting that the majority of the organic matter is likely from a marine source. Source rock analysis (SRA) was performed on three sediment samples. Samples collected for X-ray diffraction (XRD) analysis

were retained for shore-based analysis for concentrations of major elements and several trace elements using inductively coupled plasma–atomic emission spectroscopy (ICP-AES).

Physical properties

We measured physical properties on whole-round cores, section halves, and discrete samples. These measurements included gamma ray attenuation (GRA) bulk density, magnetic susceptibility (MS), natural gamma radiation (NGR), *P*-wave velocity, moisture and density (MAD) and porosity, and thermal conductivity. The variations in physical properties (PP) values led us to define PP Units 1 to 9, each with specific characteristics. Lithostratigraphic Unit I encompasses PP Units 1–5. Lithostratigraphic Subunit IIA includes PP Units 6 and 7. Lithostratigraphic Subunit IIB and Unit III correspond to PP Unit 8. Lithostratigraphic Unit IV corresponds to PP Unit 9. In Unit I, physical properties variations are mostly related to the nature of the sediment, with higher values of NGR, MS, and porosity, and lower values of density, *P*-wave velocity, and thermal conductivity in the claystones and siltstones compared to the sandstones. *P*-wave velocity also increases slightly with depth due to lithification. In PP Unit 7, MS values increase markedly in the red clays of lithostratigraphic Subunit IIA. The nannofossil-rich claystone of lithostratigraphic Unit III, which corresponds to PP Unit 8, displays a clear decrease with depth in bulk density, MS, and *P*-wave velocity. Such variations, opposite to what is expected due to lithification or compaction effects, are possibly caused by the abundance of nannofossils. MS values in the basalt are very high, but show some variations that might correspond to changes in the nature of the magnetic minerals or the grain size. Compared to the sedimentary rocks above the basement, the *P*-wave velocities of the basalts are quite high. NGR (<10 cps) and porosity values are quite low, whereas density values are much higher than in the sediment. The high MS values in Cores 368X-U1503A-87R and 88R correspond to basalts that display more massive textures than the ones from the other cores, and likely contain distinct magnetic minerals and a range of grain sizes.

Downhole measurements and seismic correlation

A VSI tool string was deployed in Hole U1503A to collect a vertical seismic profile. To avoid potentially deteriorated conditions in the open hole, the VSI tool string did not pass into the open hole and all check shots were conducted inside the casing. The VSI logging string was first lowered to near the end of the casing at ~995 mbsf. The logging string was then pulled up and stopped at 18 stations, at 50 m intervals between 974.9 and 124.9 mbsf. The VSI tool string was combined with telemetry and gamma ray tools. Following data collection, logging specialists at the Lamont-Doherty Earth Observatory provided corrected two-way traveltimes. The combined VSI and *P*-wave measurements were used to calculate the velocity-depth relationship for Hole U1503A, using the interval velocity from the VSI experiment for the top part, and the average *P*-wave velocity of sediment cores for the lower part. Seismic waveforms at Hole U1503A were then extracted from the seismic data and converted to depth using the composite depth-velocity relationship of Hole U1503A.