IODP Expedition 385: Guaymas Basin Tectonics and Biosphere

Site U1545 Summary

Background and Objectives

Site U1545 (proposed Site GUAYM-01B) is located ~52 km northwest of the axial graben of the northern Guaymas Basin spreading segment. The primary objective for this site is shared with Site U1546 (proposed Site GUAYM-02B), located just 1.1 km away. The objective is to compare the sediments at two sites that are very close to each other but which seismic data suggest have had very different degrees of alteration from intruding sills. Preexpedition seismic survey data indicated an undisturbed sedimentary succession at Site U1545 from the seafloor to ~2.8 s two-way traveltime (~540 m below seafloor [mbsf]), where an interpreted sill was observed. In contrast, seismic data showed the same stratigraphic sequence at Site U1546 to be substantially disturbed between an apparent unconformity at ~2.3 s and a bright reflector at ~2.6 s (~350 mbsf) two-way traveltime, which has been interpreted as a sill intrusion. Sills deeper than 2.6 s were also interpreted at Site U1546. Thus, the main objective of Site U1545 is to provide a reference sedimentary succession for comparison with Site U1546, enabling the quantification of thermal and hydrothermal alteration driven by sill intrusion at Site U1546.

Operations

We cored three holes at Site U1545 (proposed Site GUAYM-01B). Hole U1545A is located at 27°38.2325′N, 111°53.3406′W in a water depth of 1593.5 m. In Hole U1545A, we used the advanced piston corer (APC), half-length APC (HLAPC), and extended core barrel (XCB) coring systems to advance from the seafloor to a final depth of 505.3 mbsf with a recovery of 389.0 m (77%). We made formation temperature measurements at several depths using the advanced piston corer temperature tool (APCT-3) and the Sediment Temperature 2 (SET2) tool. We terminated coring based on the safety monitoring protocol for hydrocarbon gases after measuring a low methane/ethane (C_1/C_2) value. We then conducted downhole measurements in Hole U1545A, consisting of (1) recovery of borehole fluid with the Kuster Flow Through Sampler (FTS) tool and (2) downhole logging with the triple combination (“triple combo”) and the Formation MicroScanner (FMS)-sonic logging tool strings. In Hole U1545B, located at 27°38.2301′N, 111°53.3295′W in a water depth of 1594.2 m, we deployed the APC, HLAPC, and XCB coring tools. Cores penetrated from the seafloor to a final depth of 387.3 mbsf and recovered 340.1 m (88%). Formation temperature measurements were carried out at several depths with the APCT-3 and SET2 tools. In Hole U1545C, located at 27°38.2420′N, 111°53.3290′W in a water depth of 1595.0 m, we deployed the APC, HLAPC, and XCB coring tools to advance from the seafloor to a final depth of 329.0 mbsf with a recovery of 324.6 m (99%). Holes U1545B and U1545C were dedicated to extensive microbial and biogeochemical sampling that required the deployment of perfluorocarbon tracers (PFTs) downhole on all cores to monitor drilling fluid (seawater) contamination. During the first two days of coring in Hole U1545B, the pacing of coring was adjusted to accommodate the complex microbial sampling program conducted on the core receiving platform. A total of 232.1 h, or 9.7 d, were spent at Site U1545.

Principal Results

Lithostratigraphy

Three holes were drilled at Site U1545: the deepest record of sediments and igneous rocks was recovered in Hole U1545A from a curated depth of 507.3 mbsf, whereas the recovery reached 387.2 and 328.9 mbsf in Holes U1545B and U1545C, respectively. Site U1545 is composed of Holocene to Middle Pleistocene sediments that are primarily a mixture of laminated diatom oozes and clay minerals. Minor components include nannofossils and silt-sized siliciclastic particles and authigenic minerals. The latter include pyrite and clay- to silt-sized carbonate (micrite) particles (mainly dolomite) that occur both scattered within the sediment as well as concentrated in discrete nodules/concretions with different degrees of lithification. Downhole changes in lithology are not significant enough to require a subdivision of the site into more than one lithostratigraphic unit (Unit I). However, the presence of minor yet significant downhole lithologic changes, and/or changes in sediment induration and physical properties, prompted the subdivision of Unit I into four subunits (IA, IB, IC and ID). These differences arise mainly from different degrees and types of diagenetic processes and overprinting that have resulted in the formation of authigenic minerals (e.g., micrite in Subunit IB) and/or the selective dissolution of sedimentary particles (e.g., dissolution of diatoms during opal-A to opal-CT phase transformation in Subunits IC and ID). The transitions between the subunits are gradual, occur over more than one core, and they may be locally obscured in low-recovery zones. The mixed biogenic and siliciclastic nature of the sediments and the abundance of fine lamination in the sedimentary record suggests that the depositional environment at Site U1545 has remained essentially hemipelagic and suboxic to anoxic throughout the Middle to Late Pleistocene. Igneous rocks of subvolcanic texture and basaltic composition were encountered as an intrusive sheet within the sedimentary section near the bottom of Hole U1545A.

Igneous Petrology and Alteration

In Hole U1545A, we cored a basalt layer below the siliceous claystone with a total recovered core length of 81 cm from a depth of 482.17 mbsf. The basaltic sill intrusion is identified as part of lithostratigraphic Subunit ID. It is dominantly composed of aphyric basalt. A baked layer of carbonate metasedimentary rock, ~3 cm thick, lies above the top margin of the sill, defining the sediment/sill contact. The dark gray aphyric basalt shows an aphanitic texture with a micro- to cryptocrystalline inequigranular igneous mineral assemblage consisting of plagioclase, pyroxene, and accessory Fe-Ti oxides. Moderate to sparse vesicularity is overall decreasing with depth. Plagioclase phenocrysts are rarely present (<1 vol%). The entire length of the cored basalt is texturally and mineralogically homogeneous except for a 1 cm thick carbonate-rich vesicular basalt in the middle of the section. The vesicular basalt has an overall coarser grain size with no microphenocrysts. The entire recovered section shows moderate alteration that is consistent with hydrothermal fluid/rock interaction. Plagioclase grains are slightly altered into sericite, whereas pyroxenes remain as pseudomorphs that are totally replaced by secondary magnetite and clay minerals. Vesicles are mostly filled with secondary minerals. These precipitates are dominantly carbonates (e.g., calcite, dolomite) and clay minerals (e.g., smectite) with minor magnetite and pyrite. Observed veins are predominantly filled with carbonates, pyrite, and zeolites, giving them a white color with black and golden patches. The portable X-ray fluorescence spectrometer (pXRF) analyses showed limited compositional variation throughout the whole aphyric basalt section (e.g., MgO = 7.0–9.4 wt%).

Structural Geology

Tilted sedimentary beds and deformation structures are found in some depth intervals of lithostratigraphic Subunits IA, IB, IC, and ID. The folds and tilted beds observed in two depth intervals above 109 mbsf are attributed to two slump events causing soft-sediment deformation. At greater depth, some preexisting brittle fractures are found. Some of the layers in Subunit IC exhibit fractures with apparent dips of 60° relative to the core axis. The mafic sill (Subunit ID) shows mineralized fractures that are subvertical in orientation.

Biostratigraphy

At Site U1545, preservation of calcareous nannofossils is good/moderate to poor throughout the entire sedimentary sequence. In general, preservation is good/moderate in samples with abundant or common nannofossils and poor in those with frequent or rare abundance. Preservation is better in working-half section samples than in core catcher samples. Overall, marine diatoms were observed to be dominant/abundant with good/moderate preservation down to ~300 mbsf, and barren to the bottom of Holes U1545A and U1545B as a result of diagenesis. One biostratigraphic datum was recognized and two additional stratigraphically underlying datums were estimated based on the absence of the zonal markers in the generally continuous succession from the Holocene to the Middle Pleistocene. The bottom (i.e., first occurrence datum) of *Emiliania huxleyi* dates the upper part of the sediment sequence to Holocene–Middle Pleistocene (0–0.29 Ma in age; Hole U1545A: 0–248.6 mbsf; Hole U1545B: 0–249.6 mbsf), while the absence of *Pseudoemiliania lacunosa* (calcareous nannofossil) and *Fragilariopsis reinholdii* (marine diatom) in samples examined from the underlying interval indicates a Middle Pleistocene age (<0.44 Ma) for the bottom of both holes. Hole U1545C was not sampled. The estimated average sedimentation rate is 863 m/my (86.3 cm/ky).

Paleomagnetism

We conducted alternating field (AF) demagnetization up to 20 mT with the superconducting rock magnetometer (SRM) on all archive-half sections from Hole U1545A. The drilling-induced overprint was successfully removed on APC and HLAPC cores (from the seafloor to ~280 mbsf) upon demagnetization. Inclination values after demagnetization at 20 mT cluster around 46°, which is similar to the expected geocentric axial dipole (GAD) inclination at the latitude of the site. This is supported by a detailed analysis of the remanence of discrete samples. The drilling-induced overprint is removed by 10 mT and the characteristic remanent magnetization is in agreement with the SRM measurements. Unfortunately, XCB cores were overprinted and too disturbed to yield reliable paleomagnetic data and no discrete samples could be collected. We assigned Cores 385-U1545A-1H to 50F (down to ~280 mbsf) to the normal Brunhes Chron C1n (<0.78 Ma). The natural remanent magnetization (NRM) of archive-half sections decreases from ~50 to 80 mbsf in a depth interval that corresponds to the sulfate/methane transition zone (SMTZ). The magnetic mineral assemblage becomes coarser and low-coercivity minerals, likely (titano)magnetite, are dominant. We tentatively made a correlation between Holes U1545A and U1545B based on the NRM and point magnetic susceptibility, which gives a possible offset of about 3 m between holes. No paleomagnetic measurements were carried out in Holes U1545B and U1545C.

Inorganic Geochemistry

A total of 80 interstitial water (IW) samples were collected in Holes U1545A, U1545B, and U1545C. Sulfate concentration decreases to almost zero and methane concentrations sharply increase at around 50 mbsf. The depth interval over which these changes are observed is referred to as the SMTZ. Biogeochemical processes in Subunit IA, including organoclastic sulfate reduction and anaerobic oxidation of methane (AOM), led to the accumulation of byproducts such as sulfide, ammonium and phosphate, a corresponding sharp increase in alkalinity, and a continuous increase in bromide. The decrease in calcium concentration in this subunit reflects the precipitation of authigenic carbonates. Chloride, silica, strontium, lithium, boron, and barium also continuously increase as a result of the dissolution of minerals such as silicate phases (mainly diatoms). The drop in alkalinity and magnesium at ~70–80 mbsf could correspond to the precipitation of authigenic dolomite, whereas the increase in calcium concentration could reflect the dissolution of other carbonate phases. Ammonium, calcium, silica, strontium, lithium, boron, and barium concentrations continuously increase between 220 and 320 mbsf. The maximum concentrations of silica and ammonium are seen at ~290 mbsf, where their profiles start to reverse. Around this same depth, bromide, lithium, boron, strontium, barium, and sodium sharply increase and potassium sharply decreases. Below ~320 mbsf, a number of significant excursions (increasing or decreasing) are observed for many dissolved elements (K^+, B, Sr^{2+}, Li^+, etc.), and these excursions could be related to a combination of diagenetic processes (opal diagenesis, smectite to illite transformation, or the dissolution/precipitation of other minerals), as well as thermally driven fluid migration through this interval (vertical and/or horizontal influences of nearby sills).

Organic Geochemistry

At Site U1545, we performed analyses of gas and solid-phase samples. In Hole U1545A, one headspace gas sample was analyzed per 9.5 m core for routine hydrocarbon safety monitoring. The carbon, nitrogen, and sulfur content of particulate sediment was characterized, and source rock analysis was performed on remaining residues. In Hole U1545B, hydrocarbons were analyzed on both headspace gas and void gas, the amount of void space was quantified, H_2 and CO content were measured, the carbon, nitrogen and sulfur content of sediment was characterized, and a comprehensive suite of gas and sediment samples was taken for postcruise analyses. The SMTZ is approximately at 40–50 mbsf in the three holes, and C_2–C_6 hydrocarbons are detectable at depths below 100 mbsf. In Hole U1545A, the low C_1/C_2 values observed necessitated the termination of drilling. From elemental and source rock analysis we infer that the primary source of organic matter is marine in origin, and the thermal maturity of organic matter varies based on the proximity of the sill. In Holes U1545B and U1545C, H_2 and CO are present in low concentrations, implying that biological cycling is the dominant control on these gases.

Microbiology

Sediment cores from below 480 mbsf in Hole U1545A and from the full depth range of Holes U1545B and U1545C span the complete or near-complete temperature range (from the cold seafloor to the hot [~89°C] subsurface) that is populated by psychrophilic, mesophilic, and thermophilic microorganisms, respectively. Thus, these cores were extensively sampled for microbiology and biogeochemistry, and those samples captured the entire spatial and thermal gradient within the penetrated sediment column at Site U1545. Syringe samples for cell counts, 3D structural imaging, and RNA analyses were taken on the core receiving platform and then preserved or frozen, and stored for further analyses. Whole-round (WR) core samples were either stored in a −80°C freezer or temporarily stored in a 4°C cold room and processed further for shore-based analyses. WR sample processing was conducted either inside a Coy Laboratory Products anaerobic chamber or on the bench with a KOACH open clean zone system in order to maintain as sterile conditions as possible. Samples for PFT measurements were taken on the core receiving platform by syringe at 11 distinct horizons. Cell abundance for selected samples was determined by direct counting with an epifluorescence microscope. Cell abundance at the seawater/sediment surface was 5.8×10^8 cells cm^{-3}, and gradually decreased to 8.2×10^5 cells cm^{-3} (at ~150 mbsf), after which cells were not observed in the 10 microscopic images.

Physical Properties

Physical properties of WR and split cores were measured in the laboratory, and in situ measurements were made with downhole logging tools. Measurements on WR and working-half sections were compared between Holes U1545A, U1545B, and U1545C, and with downhole measurements from Hole U1545A for lithostratigraphic characterization and integration of core description, borehole data, and seismic profiles. These measurements included WR bulk density estimated from gamma ray attenuation (GRA) bulk density, magnetic susceptibility (MS), natural gamma radiation (NGR, sensitive to mineral content), *P*-wave velocity, and discrete measurements of moisture and density (MAD, to estimate porosity), thermal conductivity, three-component *P*-wave velocity, and rheological properties (shear and compressional strength). Two types of changes were observed in the GRA bulk density. The first type is observed in the first 100 m of sediment, the second type to a depth of ~280 mbsf. Density generally increases by 0.11 g/cm^3 every 100 m. A steeper increase in density (0.14 g/cm^3 every 100 m) is observed from ~280 mbsf to the final curated depth of Hole U1545A at 507.7 mbsf. This density increase is particularly well correlated with NGR values and corresponds to a change in lithology identified as diatom clay and siliceous claystone. MS values show several peaks at 60, 170, and 482–483 mbsf, which are also seen in the bulk density and NGR data. Two downhole logging tool strings were run in Hole U1545A: the triple combo (NGR, porosity, and density sondes, including MS, resistivity, caliper, and logging head temperature) and the FMS-sonic (resistivity images, caliper, NGR) tool strings. Due to a malfunctioning caliper on the upward pass, only one pass was possible with the triple combo. In general, downhole measurements are consistent with results obtained from the WR and section-half cores. In addition to the logging tools, nine in situ formation temperature measurements were conducted with the APCT-3 and SET2 tools, indicating that the temperature increases with depth along a linear geothermal gradient of 225°C/km.