IODP Expedition 385: Guaymas Basin Tectonics and Biosphere

Site U1547/U1548 Summary

Background and Objectives

Sites U1547 and U1548 (proposed Sites GUAYM-12A and GUAYM-03B, respectively) are located ~27 km northwest of the axial graben of the northern Guaymas Basin. Site U1547 lies within a circular hydrothermal mound called Ringvent that rises ~20 m above the seafloor and has an ~800 m diameter. Site U1548 lies just outside Ringvent's southeastern edge. Seismic profiles across Ringvent show a prominent subseafloor mound feature, at ~0.06 s two-way traveltime (TWT), that is characterized by brightly reflective strata within a central bowl-shaped region. A bright reflector underlying the base of the "bowl" (at ~0.18 s TWT below the seafloor) is interpreted as a sill intrusion. It is hypothesized that this and previous similar intrusions have provided the heat that formed Ringvent, keeping it active today. Ringvent is the best-characterized active, sill-associated, hydrothermal system at an off-axis site in Guaymas Basin, with 20°–75°C vent fluids. Site survey data suggested that the central portion of Ringvent may thus function as a hydrothermal recharge zone, in which case Site U1547 was intended to sample sediments in a recharge setting and Site U1548, just outside of Ringvent, was intended to sample sediments at a discharge setting. The sill at Ringvent represents a shallow-emplacement end member. The primary objectives for Sites U1547 and U1548 were thus to characterize the physical, chemical, and biological processes driven and affected by this end-member type of sill/sediment system, with a particular focus on the response of microbial communities to the expected large temperature gradients at these sites. Moreover, an area nearby Ringvent was added to Site U1548 during the expedition, with the joint objective of characterizing the geochemical signature of the abrupt lateral change in seismic character observed in strata between ~2.39–2.42 s TWT, which may be related to a diagenetic change caused by the proximity to the igneous intrusions at Ringvent.

Operations

We cored a total of ten holes at and nearby the Ringvent structure to characterize closely associated Sites U1547 (proposed Site GUAYM-12A) and U1548 (proposed Site GUAYM-03B).

We cored five holes at Site U1547. Hole U1547A is located at 27°30.4561′N, 111°40.6980′W in a water depth of 1733.7 m. In Hole U1547A, we used the advanced piston corer (APC), half-length APC (HLAPC), and extended core barrel (XCB) coring tools to advance from the seafloor to a final depth of 141.3 m below seafloor (mbsf) with a recovery of 145.3 m (103%). We made formation temperature measurements at several depths using the advanced piston corer temperature tool (APCT-3) and Sediment Temperature 2 (SET2) tool. In Hole U1547B, located at 27°30.4128′N, 111°40.7341′W in a water depth of 1732.2 m, we deployed the APC/HLAPC/XCB coring systems. Cores penetrated from the seafloor to a final depth of 209.8 mbsf and recovered 161.3 m (77%). Formation temperature measurements were made at several depths using the APCT-3 and SET2 tools. Next, we deployed the Kuster Flow Through Sampler (FTS) tool to successfully recover two borehole fluid samples from 109.7 and 135.7 mbsf, respectively. We then conducted downhole wireline logging in Hole U1547B with the triple combination ("triple combo") and the Formation MicroScanner (FMS)-sonic logging tool strings. In Hole U1547C, located at 27°30.4455′N, 111°40.7064′W in a water depth of 1732.2 m, we first drilled without core recovery from the seafloor to 81.3 mbsf. Then we used the rotary core barrel (RCB) coring system to advance from 81.3 mbsf to a final depth of 159.2 mbsf with a recovery of 9.0 m (12%). In Hole U1547D, located at 27°30.3947′N, 111°40.7483′W in a water depth of 1732.2 m, we first drilled without core recovery from the seafloor to 81.3 mbsf. Then we used the RCB coring tool to advance from 81.3 mbsf to a final depth of 193.0 mbsf with a recovery of 34.9 m (31%). The Elevated Temperature Borehole Sensor (ETBS) tool was deployed to make a temperature measurement at the bottom of the hole. In Hole U1547E, located at 27°30.3598′N, 111°40.7756′W in a water depth of 1732.1 m, we first drilled without core recovery from the seafloor to 61.8 mbsf. Then we used the RCB coring system to advance from 61.8 mbsf to a final depth of 191.2 mbsf with a recovery of 44.9 m (35%). Holes U1547B–U1547D 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. A total of 235.0 h, or 9.8 d, were spent at Site U1547.

We cored five holes at Site U1548. Hole U1548A is located at 27°30.2466′N, 111°40.8665′W in a water depth of 1739.9 m. In Hole U1548A, we deployed the APC/XCB coring system. Cores advanced from the seafloor to a final depth of 103.4 mbsf and recovered 114.0 m (110%). We made formation temperature measurements at several depths using the APCT-3 tool. In Hole U1548B, located at 27°30.2540′N, 111°40.8601′W in a water depth of 1738.9 m, we deployed the APC/XCB coring system to advance from the seafloor to a final depth of 95.1 mbsf with a recovery of 87.7 m (92%). We made formation temperature measurements at several depths with the APCT-3 and SET2 tools. We then deployed the Kuster FTS tool to recover a borehole fluid sample successfully from 70.0 mbsf. In Hole U1548C, located at 27°30.2698′N, 111°40.8476′W in a water depth of 1737.0 m, we deployed the APC/XCB coring system to advance from the seafloor to a final depth of 69.8 mbsf with a recovery of 71.0 m (102%). We made formation temperature measurements at several depths with the APCT-3 and SET2 tools. In Hole U1548D, located at 27°30.5316′N, 111°41.3855′W in a water depth of 1729.3 m, we deployed the APC and HLAPC coring systems. Cores penetrated from the seafloor to a final depth of 110.0 mbsf and recovered 120.5 m (110%). Formation temperature measurements were made at several depths using the APCT-3 tool. In Hole U1548E, located at 27°30.4829′N, 111°41.2922′W in a water depth of 1729.9 m, we deployed the APC coring system. Cores penetrated from the seafloor to a final depth of 110.0 mbsf and recovered 115.2 m (105%). We conducted formation temperature measurements at several depths using the APCT-3 tool. Holes U1548B and U1548C were dedicated to extensive microbial and biogeochemical sampling that required the deployment of PFTs downhole on all cores to monitor drilling fluid (seawater) contamination. A total of 94.6 h, or 3.9 d, were spent at Site U1548.

Principal Results

Lithostratigraphy

This lithostratigraphic summary characterizes both Sites U1547 and U1548, which are located only a few hundred meters from each other (maximum distance between holes ~600 m). While Site U1547 and Holes U1548A–U1548C were drilled inside or adjacent to the Ringvent structure, Holes U1548D and U1548E were drilled 800 m northwest of Ringvent. The sediments recovered at Sites U1547 and U1548 are Upper to Middle Pleistocene and mostly biogenic (mainly diatom ooze), although the siliciclastic component is more significant compared to previously drilled Sites U1545 and U1546 in northwest Guaymas Basin. The sequence recovered at Sites U1547 and U1548 shows downhole changes in the lithologic characteristics of the sediment that are related to changes in the ratio between diatoms and clay minerals, carbonate precipitates, and, to a lesser extent, the diagenetic changes of biogenic silica. Downhole changes in lithology at Sites U1547 and U1548 are not significant enough to require a subdivision into more than one lithostratigraphic unit, but are sufficient to warrant the subdivision of Unit I into four subunits at Site U1547 and three subunits at Site U1548. The uppermost, Subunit IA, is made up of a similar lithology at both sites, mainly consisting of more or less laminated diatom ooze mixed with different amounts of clay minerals. The boundary between Subunits IA and IB is located at ~40 mbsf at both sites except for Hole U1548C where it occurs at ~27 mbsf. Subunit IB is mainly composed of varying proportions of diatoms and clay, with the addition of significant (>5%) micrite (euhedral to subhedral, micrometer-sized, authigenic carbonate particles). Gray silty beds, often showing erosional bottom contacts, are also frequent and some of these beds can attain thicknesses of up to 1.2 m. The top of Subunit IC (only observed in Hole U1548C) is very thin and coincides with a significant drop in micrite content in the sediment, although limestone/dolostone intervals still persist. The main lithologies are diatom clay and clay-rich diatom ooze. Sandy and silty intervals are also common, with some displaying evidence of syndepositional deformation. Subunit ID was only recovered at Site U1547 and is a dusky yellowish-brown siliceous claystone. Diatoms are absent and X-ray diffraction (XRD) mineralogy indicates the onset of silica phase transition from opal-A to opal-CT. Basalt occurs at shallow depth at Sites U1547 (130.5–150 mbsf) and U1548 (90–100 mbsf). However, poor recovery provides only limited observations of contact zones with the surrounding sediment.

Igneous Petrology and Alteration

Mafic rocks from sill intrusions underlying the Ringvent structure were recovered in Holes U1547A–U1547E (inside Ringvent) and Holes U1548A–U1548C (outside of Ringvent but close to its margin). The sill bodies were encountered at different depths with varying recovery rates. Sills recovered at Site U1547 are mostly composed of aphyric to clinopyroxene-plagioclase phyric basalt. A ~20 m thick dolerite section was recovered from the bottom part of Hole U1547E (down to a depth of 191 mbsf), showing plagioclase and pyroxene phenocrysts of 2 to 5 mm in size. Basalts are slightly to moderately vesicular while dolerites are nonvesicular to slightly vesicular. The subangular to subrounded vesicles range from 1 to 25 mm (in diameter). Some vesicles are empty and some are partially/fully filled with carbonate that is often associated with pyrite (<0.5 mm). Empty vesicles are often coated by secondary bluish-gray silicate material. The recovered basalts show variable degrees of alteration. Monomineralic carbonate veins are often surrounded by thin halos of pyrite. Occasionally, the latter also occurs as subordinate vein-filling material in association with carbonate. In terms of modal composition, basalts recovered at Site U1548 resemble those from Site U1547, but they are darker in color and usually nonvesicular. Injected sedimentary veins, contacts between sedimentary breccia and basalt, sediment-magma mingling (peperite facies), and glassy chilled margins are other common features observed in cores from both Holes U1547A–U1547E and U1548A–U1548C. The presence of glassy chilled margins suggests direct contact of the magma with very wet sediment.

Structural Geology

We made structural observations at all ten holes within (Site U1547) or near (Site U1548) the Ringvent structure. Structural information was sought from sedimentary units in four of the five holes at Site U1547 and all five holes at Site U1548. Hole U1547A was lithologically the most complete hole for examining the sedimentary succession. Bedding and lamination in sediments show no significant folds and few brittle fractures and faults, although in some cases fractures are seen much more easily in the X-ray images than on the cut surfaces of the cores. Additional structural information came from basaltic rocks of Subunit ID, which were cored in eight of the holes. Holes U1547B, U1547D, and U1547E recovered the most basalt. Structural features observed within the basalts include preexisting fractures and faults, mineralized veins, glassy margins, sediment-filled veins, and fragments of columnar joints. Where possible, these features were measured for true dip and await possible reorientation using shore-based paleomagnetic results. Networks of veins with irregular branching patterns were not measured as planar features. No macroscopic shortening or folding of the veins was evident.

Biostratigraphy

Calcareous nannofossils are abundant to common above 43.51 mbsf at Site U1547 and in Holes U1548A–U1548C. This is followed by an alternation between intervals with few or barren occurrences of nannofossils and intervals with abundant/common populations from 43.73 to 151.93 mbsf at both sites. Nannofossil preservation varies from good to poor throughout the entire sedimentary sequence, and is generally good and moderate in samples with abundant and common abundances and poor in those with few and barren abundances. In general, marine diatoms are dominant and abundant with good to moderate preservation above 131.21 mbsf in Hole U1547A, above 101.15 mbsf in Hole U1547B, above 81.6 mbsf in Hole U1547C, and above 91.25 mbsf in Hole U1547D. The barren intervals in the bottom of Site U1547 and in Holes U1548A–U1548C might be due to diagenetic alteration. In Hole U1548A, marine diatoms are mostly abundant with moderate preservation above 84.1 mbsf, whereas they are abundant to few and poorly preserved in the bottom interval (90.9–99.0 mbsf). In Holes U1548D and U1548E, calcareous nannofossils are common to abundant, showing moderate and poor preservation in most samples examined, except for three sampled depths (31, 92.29, and 101.58 mbsf) in Hole U1548D. Marine diatoms are dominant and abundant with good and moderate preservation throughout Holes U1548D and U1548E. The occurrence of calcareous nannofossil species *Emiliania huxleyi* downhole to the bottom of all holes dates the entire sediment sequence to Holocene–Middle Pleistocene or 0–0.29 Ma in age (Hole U1547A: 0–137 mbsf, Hole U1547B: 0–151.93 mbsf, Hole U1547C: 0–121.13 mbsf, Hole U1547D: 0–101.33 mbsf, Hole U1548A: 0–99 mbsf, Hole U1548D: 0–110.24 mbsf, Hole U1548E: 0–91.81 mbsf). This age assignment is consistent with the absence of calcareous nannofossil species *Pseudoemiliania lacunosa* (Top: 0.44 Ma) and *Fragilariopsis reinholdii* (Top: 0.62 Ma) in all examined samples. The estimated average sedimentation rate is >524 m/My (>52.4 cm/ky).

Paleomagnetism

We conducted alternating field (AF) demagnetization up to 20 mT with the superconducting rock magnetometer (SRM) on all sediment archive-half core sections from Holes U1547A, U1548A, and U1548C–U1548E (APC, HLAPC, and XCB cores). The drilling-induced overprint was successfully removed on all cores upon demagnetization. Mean inclination values after demagnetization at 20 mT cluster around 46° and vary between ~43° and 47° for Sites U1547 and U1548, respectively, which is comparable to the expected geocentric axial dipole (GAD) inclination at the latitude of the site (46.4°). A detailed analysis of the remanence of discrete samples from Sites U1547 and U1548 shows that the drilling-induced overprint is removed by 10 mT, and the characteristic remanent magnetization is in agreement with the SRM measurements. Natural remanent magnetization (NRM) of archive-half sections decreases at ~30–35 mbsf in Holes U1547A and U1548A and at ~65–70 mbsf in Holes U1548D and U1548E. The magnetic mineral assemblage becomes coarser and low-coercivity minerals, likely (titano-)magnetite, are dominant. In Holes U1547B–U1547E, U1548A, and U1548C, we measured the NRM of igneous rock archive-half core sections. As the AF demagnetization protocol was not appropriate for the igneous sections, no AF demagnetization was conducted at these sites. We assigned all cores at Sites U1547 and U1548 to the normal Brunhes Chron C1n (<0.78 Ma).

Inorganic Geochemistry

A total of 32 and 68 interstitial water (IW) samples were collected at Holes U1547A–U1547B and U1548A–U1548E, respectively. In addition, 27 and 20 IW samples were collected using Rhizon samplers in Holes U1547A and U1548A, respectively. The holes from Sites U1547 and U1548 are divided into two groups: one includes holes inside Ringvent (Holes U1547A, U1547B, U1548A–U1548C) and the other includes holes nearby Ringvent (Holes U1548D and U1548E). Above the encountered sills at Ringvent, the IW profiles show similar trends in all Site U1547 holes and in Holes U1548A–U1548C, with slight differences mainly in sulfate, alkalinity, phosphate, and sulfide concentrations. Abrupt changes are observed for many elements in the contact interval with the sill: sulfate sharply decreases over a few meters, coincident with increases in Li^{+}, Ba^{2+}, B, Sr^{2+}, Ca^{2+}, and Na^{+}, and decreases in Mg^{2+}, K^{+}, and $H_4Si(OH)_4^{+}$. Similar excursions were observed at Sites U1545 and U1546 above the sills. The IW chemical properties are likely to be influenced by combined biogeochemical processes and sediment/fluid interaction associated with the sill intrusion as well as precipitation/dissolution processes, including Opal-A dissolution, authigenic carbonate precipitation, and dolomite formation. Northwest of Ringvent, the IW profiles in Holes U1548D and U1548E show quite different behavior from the holes located inside Ringvent. The sulfate/methane transition zone (SMTZ) is well defined around 75 mbsf with a concave downward decrease in sulfate and a concomitant increase in alkalinity, HS^{-}, NH_4^{+}, and PO_4^{3-}. In general, the concentrations of alkalinity, HS^{-}, NH_4^{+}, and PO_4^{3-} produced by organic matter mineralization are higher in Holes U1548D and U1548E than in Ringvent Holes U1548A–U1548C. Compared to the Ringvent holes, the lower concentrations of dissolved $H_4Si(OH)_4^{+}$ in Holes U1548D and U1548E may reflect the lower alteration state of diatoms due to the lower thermal gradient in Holes U1548D and U1548E.

Organic Geochemistry

At Sites U1547 and U1548, organic geochemists sampled and analyzed gas and solid phase samples. For all holes, one headspace gas sample was analyzed per 9.5 m of advancement for routine hydrocarbon safety monitoring. Void spaces were measured on the core receiving platform, and void gases were characterized for their hydrocarbon content. The carbon, nitrogen, and sulfur contents of particulate sediment were characterized, and source rock analysis was performed on solid-phase samples. When sampling was focused on microbiology and biogeochemistry objectives, H_2 and CO contents were measured, and gas and solid-phase materials were sampled for shore-based analyses. During igneous rock recovery, whole-round (WR) core pieces of rock were incubated in sealed trilaminated foil barrier bags to examine degassing of hydrocarbons. Methane and higher hydrocarbons were found throughout Sites U1547 and U1548. Elemental analysis reveals the primary source of organic matter for these sites is marine in origin, although some intervals may be influenced by terrestrial inputs. Source rock analysis indicates that thermal maturity of organic matter varies based on sill proximity. H_2 and CO are present in nanomolar concentrations and exhibit varying trends with depth.

Microbiology

Sediment cores for microbiological studies were obtained from Holes U1547B, U1548B, and U1548C using the APC/XCB coring system. In addition, samples of igneous rock with indications of fluid/rock interaction, such as veins, sediment injections, and vesicularity with amygdules, were taken for microbiological studies from Holes U1547C–U1547E, U1548A, and U1548B. Syringe samples for cell counts, 3D structural imaging, and RNA analyses were taken on the core receiving platform, preserved, or frozen and stored for further analyses. 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 core sample processing was conducted either inside a Coy Laboratory Products anaerobic chamber or on the bench with a KOACH open clean zone system to maintain as sterile conditions as possible. Samples for PFT measurements were taken on the core receiving platform by syringe from eight cores in Hole U1547B and four cores in Hole U1548B. Cell abundance was 1.0×10^9 cells/cm^3 in seafloor sediment within the perimeter of Ringvent (Hole U1547B), and 5.4×10^8 cells/cm^3 outside of Ringvent (Hole U1548B). Below the seafloor, cell abundance gradually decreased at both Sites U1547 and U1548.

Physical Properties

Physical properties measured on WR and split core sections were compared between Holes U1548A–U1548E, Holes U1547A–U1547E, and downhole logging measurements in Hole U1547B for lithostratigraphic characterization and correlation between core description, logging data, and preexpedition seismic survey profiles. In total, 31 in situ formation temperature measurements were taken with the APCT-3 and SET2 tools at Sites U1547 and U1548. The resulting geothermal gradient together with thermal conductivity measurements were used to estimate heat flow. Conductivity measurements at Site U1548 show values in the sediment layers that are similar to Site U1547. Sites U1548 and U1547 show similar profiles in density, porosity, strength, natural gamma radiation (NGR), magnetic susceptibility, and *P*-wave velocity in the upper 90 m of sediment. Three main depth intervals can be defined at Site U1548: (1) between the seafloor and 40 mbsf; (2) a transition at 70 mbsf marked by a change in density from 1.45 g/cm^3 above to 1.31 g/cm^3 below that depth; and (3) between 125–155 mbsf in Hole U1547B, where sediments have a relatively low density of ~1.3 g/cm^3 and lower NGR values. Mafic sill material recovered from Site U1547 shows thick continuous intrusion sheets of up to ~110 m cored thickness in Hole U1547E, without any bottom contact encountered.