IODP Expedition 344: Costa Rica Seismogenesis Project (CRISP-A2)

Site U1380 Summary

Background and Objectives

The primary objective of Expedition 344 is to sample and quantify the material comprising the seismogenic zone of an erosive subduction margin. Site U1380 is located on the middle slope of the Costa Rica margin along seismic line BGR99-7. Interplate earthquakes and geodetic measurements indicate that this site is seaward of the updip extent of seismicity and that the plate interface is not locked. At Site U1380 the margin consists of a 550 m thick section of slope sediments overlying upper plate framework rock. Hole U1380A was drilled on Expedition 334 to a depth of ~480 mbsf, but because of poor drilling conditions was terminated prior to reaching the framework rock (Vannucchi et al., 2012). The primary goals for revisiting this site were to determine the nature, composition, and physical properties of the upper plate framework rock, to understand the nature of the landward-dipping seismic reflectors, and to estimate the state of stress. Seismic reflection line BGR99-7 shows that this site is above the seaward edge of one of the high-amplitude reflectors.

Principal Results

After an 11.4-nmi transit from Site U1381, the vessel stabilized over Site U1380 at 1715 h on 27 October 2012 (all times in this report are ship local time which is UTC – 6). Hole U1380B was spudded at 0118 h on 28 October (8°35.9952'N, 84°4.3908'W, 502.7 m water depth). The purpose of this hole was to conduct a jet-in test with a 14-3/4 inch tri-cone bit to verify the length of 16 inch casing that could be jetted into the formation with a reentry cone.

Hole U1380C was spudded at 1145 h on 29 October (8°35.9879'N, 84°4.3918'W, 502.7 m water depth). The operations plan for this hole included a reentry system with two strings of casing to an undetermined depth, followed by RCB coring to 800 mbsf. The reentry cone and 16 inch casing string were installed to 48 mbsf. A 14-3/4 inch bit was used to drill a hole to 438 mbsf. The initial plan was to run 10-3/4 inch casing string to 430 mbsf. After drilling the 14-3/4 inch hole, it became impossible to keep the hole open to run casing to 430 mbsf. A new casing length of 405 m was selected to try to bridge a problematic zone from 337 to 396 mbsf. The hole was reamed and cleaned repeatedly prior to running casing. Eventually the problematic zone was cemented and re-drilled. After several days of hole cleaning, the 405 m long 10-3/4 inch casing string was run into the hole. With the end of the casing 18 m above the desired depth, we were unable to advance the casing any further and were forced to pull the casing back to the surface. To avoid disassembling the entire casing string, we secured the casing string to the moonpool doors and tripped back in the hole with a 9-7/8 inch tri-cone bit with a 14-3/4 inch underreamer. We then attempted to ream the hole back to bottom. During this process, 391 m of casing parted just below sea level and followed the drill string down into the formation. To determine the condition of the casing string inside the hole, we switched to a coring bottom-hole assembly (BHA) with an RCB bit and drilled down carefully from 336 to 438 mbsf. RCB coring commenced at 1745 h on 7 November and continued without interruption until 0400 h on 10 November to a total depth of 800 mbsf. Non-magnetic RCB core barrels were used starting with Core 11R. In an effort to improve recovery we started cutting half cores with Core 25R. The total cored interval in Hole U1380C was 362.0 m with 202.4 m recovered for an overall recovery of 56%.

The hole was prepared for logging, the bit dropped on the seafloor and the triple combo-UBI logging string was rigged up. During the first logging attempt, the logging tools were unable to advance past 398 mbsf, which coincided with the estimated depth of the casing shoe. The tools were pulled from the hole and the drill pipe was advanced to 467 mbsf without difficulty. The drill pipe was pulled back to 394 mbsf, and a reconfigured triple combo string without the UBI was run into the hole at 2310 h. This time the logging tools made it to 458 mbsf before encountering an obstruction. A review of the logs showed that the casing had slipped further down. After retrieving the logging tools, a BHA with a used RCB bit was deployed, the hole was washed down to 781 mbsf, the hole conditioned for logging, and the bit dropped in the bottom of the hole. The triple combo logging tool string was rigged up for the third time and run into the hole at 1310 h on 13 November. However, the logging tools encountered a similar obstruction as before at 462 mbsf. After several attempts to get the tools to reenter the open hole, logging operations were terminated. The hole was plugged with a 10-barrel cement plug and the acoustic beacon was recovered. The drill string was pulled from the hole, clearing the rig floor at 0055 h on 14

November and ending Hole U1380C operations. A total of 17.3 days were spent on Site U1380.

Hole U1380C was cored to investigate the lithostratigraphy and structural geology of the lower portions of the upper slope sequence and the uppermost portions of the basement, as interpreted in multichannel seismic reflection data. This hole deepens Site U1380 drilled during Expedition 334 (Vannucchi et al., 2012), and is a complementary hole to nearby Site U1378 where only the upper part (539.9 mbsf) of the slope sediments was drilled during Expedition 334. After deploying casing and washing down to 438 mbsf we cored to the target depth at 800 mbsf, and recovered 362 m of sedimentary rocks (Cores 344-U1380C-2R through 52R; 438 to 800 mbsf). Overall core recovery was moderate at 56%. The majority of the sedimentary sequence consists of clayey siltstone (~59%) and silty claystone (~25%) with common interlayered centimeter to decimeter-sized beds of fine to medium-grained sandstone (~15%). The siltstone sedimentary sequence is disrupted by coarse-grained, shell-rich sandstones, two conglomerates (~1%), and 25 dispersed tuff layers (<1%). Three lithostratigraphic units are distinguished based on lithological compositional changes.

Unit I extends from 438 to 553 mbsf (Sections 344-U1380C-2R-1 to 13R-7, 55 cm) and is characterized by massive dark greenish gray silty clay and three sandstone-rich horizons with centimeter to decimeter-sized sandy layers. These sandy layers increase in abundance, thickness, and grain size with depth. Matrix components comprise lithic fragments (sedimentary and magmatic), feldspar, glass shards, and amphiboles. Biogenic components include rare nannofossils, diatoms, and foraminifers.

Unit II extends from 552.72 to 771.62 mbsf (Sections 344-U1380C-13R-7, 55 cm, to 47R-3, 106 cm) and is visually defined by a relatively sharp lithologic change into a greenish gray clayey siltstone with intercalated sandstone and conglomerate layers. Unit II is further divided into two subunits based on compositional and depositional variations. Subunit IIA is characterized by poorly to weakly consolidated sand beds that contain abundant to common shell fragments. The matrix also contains abundant lithic fragments, feldspar, and zeolites, but the main mineralogical variation is an increase in the abundance of amphibole that is limited to this subunit. Low recovery hinders the precise measurement of the thickness of Subunit IIA (~11.38 m) but we assumed that the missing material is composed of the same loose sand as the recovered sections. The lithologic boundary between Subunit IIA and IIB (123.24 m thick) in Core 344-U1380C-15R (564.10 mbsf) was not recovered. Subunit IIB is a very dark greenish gray clayey siltstone characterized by two fining-upward sequences of centimeter to decimeter-thick, medium to coarse-grained sandstones and fine conglomerates. Matrix and sandstone components are predominantly terrigenous lithic fragments (magmatic more common than sedimentary), feldspar, glass, and rare heavy minerals. Biogenic material is mostly absent and none was observed towards the bottom of the unit. Highly altered tuff layers in the lower parts of Cores 344-U1380C-30R (688.04 mbsf) and 47R (770.56 mbsf) are characterized by color changes within the clayey siltstone to a reddish brown carbonaceous siltstone, and by variations in the matrix mineralogy.

Both subunits are characterized by normally graded sandstone beds that are often laminated, with abundant sapropel fragments that form several centimeter-thick conspicuous horizons between the laminae. The conglomerates are very thickly bedded and contain poorly sorted, pebble-sized, matrix supported lithic fragments. Top contacts between fine and coarse-grained sediments, when observed, are mostly gradational whereas the bottom contacts are erosional and commonly contain rip-up clasts, load clasts, and sand lenses.

Unit III (Cores 344-U1380C-47R to 52R) is a 29.44 m thick, fine-grained silty claystone with rare but thick (up to 1.20 m) intercalated fine to coarse-grained sandstones. The matrix contains mostly terrigenous material dominated by lithic fragments and feldspar but is nearly devoid of biogenic material.

Deformation structures increase gradually from Core U1380C-2R to 13R. Normal faults are present throughout the interval with reverse faults increasing downhole. Deformation culminates in Cores 11R-13R with the development of a pronounced foliation. Bedding is commonly steeply dipping. Deformation is moderate from Core 14R to 45R and there is no foliation. Bedding remains steep until Core 31R and from Core 32R it is subhorizontal to gently dipping. In the deeper cores there is an increase of discrete brittle shear zones.

The biostratigraphy of Hole U1380C was constrained by nannofossils because core catcher samples were barren in radiolarians. Four biostratigraphic zones were identified. The interval from Sample 344-U1380C-2R-CC to 4R-CC is assigned to nannofossil zones NN19-NN21. The second interval, between Samples 5R-CC and 8R-CC, is assigned to Zone NN19. The third Zone, NN18, is defined by the first downhole occurrence of *Discoaster brouweri*, which appears in Sample 9R-CC. The fourth biostratigraphic zone encompasses Samples 51R-CC to 52R-CC (791–797 mbsf) and is assigned to Zones NN15-NN17, based on the LO of *Discoaster pentaradiatus*, the FO of *Pseudoemiliania lacunosa* in Sample 51R-CC, and the FO of *Discoaster asymmetricus* in Sample 52R-CC. Therefore the oldest sediments found at this hole are older than 2.4 Ma.

Benthic foraminifers were studied in 44 of the 52 core catcher samples collected. Benthic foraminifers vary from “few” (Samples 344-U1380-2R-CC to 9R-CC) to “present” (Samples 31R-CC to 52R-CC) and preservation ranges from moderate, where abundance is higher, to poor, where foraminifers are present or rare. Overall benthic foraminifer assemblages are characterized by species generally associated with organic carbon-rich environments and low bottom water oxygenation such as *Uvigerina peregrina*, *Epistominella smithi*, *Brizalina* spp. and *Hansenisca altiformis*. Benthic foraminifer assemblage changes are relatively subtle downhole.

The most significant geochemical finding is the presence of fluid flow through a shear zone that extends from ~480 to 550 mbsf, at the boundary between lithologic Units I and II. The Cl, Li, and hydrocarbon data indicate that this fluid originated from a source depth where temperatures are >90°C. Below this horizon, there is a marked increase in C_1/C_{2+} ratio towards a more biogenic signature of the gases, which is consistent with pore water data (Sr, Mg, Ca, and K) that indicate lower temperature volcanic tephra alteration reactions within the sediments of lithologic Unit II. Both the inorganic and organic carbon concentration of the sediments is distinctly higher in lithologic Unit I than in the sediments underlying the 550 mbsf unconformity.

Within Unit I, magnetic susceptibility is generally low, NGR increases with depth to values of 38 cps, and bulk density and porosity appear to follow a steady compaction trend that is consistent with that observed in shallower sediments from Site U1378, located 1 km from Site U1380. *P*-wave velocity, thermal conductivity, and sediment compressive strength increase with depth.

Most of the physical properties show sharp changes at the Unit I/II boundary, near the major seismic reflector at 550 mbsf. Below this boundary, magnetic susceptibility becomes more variable and NGR counts decrease. Between 550 and 555 mbsf, bulk density increases from ~2.0 to 2.1 g/cm^3, porosity decreases from 43% to 35%, and thermal conductivity, *P*-wave velocity, and sediment strength increase.

The second major change in physical properties occurs at ~700 mbsf and is identified by a strong positive spike in magnetic susceptibility, a positive spike in *P*-wave velocity, and a slight negative excursion in NGR. In addition, bulk densities peak at 2.2 g/cm^3 and porosities reach their lowest values of 25% to 26%. This horizon could be correlated to a strong landward dipping reflector at ~700 mbsf. At the Unit II/III boundary, there is a notable change in magnetic susceptibility, *P*-wave velocity, and thermal conductivity.

We performed measurements of natural remanent magnetization (NRM) on all split-core archive half cores and on 60 discrete samples taken from the working halves in Hole U1380C. We subjected archive half cores to alternating-field demagnetization up to 30 mT and subjected discrete samples to stepwise thermal and AF demagnetization up to 475°C and 120 mT, respectively, in order to establish a reliable magnetostratigraphy at this site and to observe the magnetic properties of each lithology in the lithostratigraphic units recovered.

Several relatively well-defined polarity intervals have been identified in downhole magnetostratigraphic records in spite of the presence of some samples showing unstable and ambiguous magnetization. Based on biostratigraphic data, we were able to tentatively correlate certain parts of the magnetic polarity interval recorded in the sediments with the geomagnetic polarity timescale. The Matuyama/Gauss Chron boundary (2.581 Ma) is tentatively placed at ~770 mbsf, based on both discrete sample and pass-through results.

Reference

Vannucchi, P., Ujiie, K., Stroncik, N., and the Expedition 334 Scientists, 2011. *Proc. IODP*, 334: Tokyo (Integrated Ocean Drilling Program Management International, Inc.). doi:10.2204/iodp.proc.334.2012