**IODP Expedition 334: Costa Rica Seismogenesis Project (CRISP)**

**Site U1380 Summary**

**Background and Objectives**

Site U1380 (CMP 2350, Lat. 08º 35.9980'N Long. 84º 4.4037' W, water depth 515 m) was drilled into the middle slope of the Costa Rica margin, 40 km offshore Osa Peninsula and Caño Island along BGR99 Line 7. It located above the unlocked portion of the plate boundary according to interplate earthquake relocation and geodetic measurements (Bilek, 2003; LaFemina et al., 2009). The margin here consists of an upper plate basement underlying about 550 m thick slope sediments. The seismic sections show that this site is located above the seaward edge of one of the high amplitude reflectors interpreted as displacement surfaces, which. Site U1380 was designed to penetrate. The primary purpose of drilling Site U1380 was to determine the nature, composition and physical properties of the upper plate basement and to understand the nature of the landward dipping seismic reflectors. Additional objectives included (1) a determination of the stress and strain regime of the unlocked portion of the margin (2) an understanding of the fluid-flow regime above the high amplitude reflector interpreted as a fault, and (3) an estimation of the quantity of tectonically eroded upper plate material.

The seismic interpretation of Site U1380 is based on the pre-stack depth migrated section BGR99 Line 7 processed by C.R. Ranero). The seismic stratigraphy of the sedimentary slope at Site U1380 shows a good continuity of reflection events. The upper 100 m of the slope sediment sequence shows rather clear horizontal reflections. The next 300 m of sediments below grade downward into a more highly reflective zone. The reflectors in this interval are gently dipping seaward, and the sequence is clearly cut upslope (toward the NE) by a younger sequence forming an angular unconformity. The bottom part of the sedimentary sequence is sharply marked by a irregular, high amplitude, seaward dipping reflector that is interpreted as the top of the upper plate basement. The surface marking the basement top is cut by several landward dipping, high amplitude reflectors that are interpreted as faults. At Site U1380 one of this high amplitude reflectors interpreted as faults is present at about 800 mbsf. This reflector does not clearly displace the basement top. The velocity in the basement increases from <2m/s in the sediments to 2.8 m/s in the fault zone to >3.3 m/s.

At Site U1380, the temperature at the plate boundary was interpreted to be at least 140°C (Grevemeyer et al., 2004). Recent new modeling of intraplate temperatures lowers the temperature to between 60°C and 90°C (Harris et al., 2010). Visual observations and the towed ocean bottom instrument (TOBI) detected several tens of mud mounds and vent

communities within few kilometers from the site (McAdoo et al., 1996; Weinrebe et al., 2003). Many of these structures seem to be related to active faults (Hensen et al., 2004; Ranero et al., 2008). Judging from the continuity of the landward dipping reflectors interpreted as faults, any fluid advection along these structures will originate in areas of at least 4 km depth.

**Scientific Results**

Site U1380 (CRIS-10A) was drilled as the alternate for Site U1378 (CRIS-3B) with the objective to core enough sediment to stratigraphically correlate Sites U1378 and U1380 and to core as much basement in the remaining time window as possible. Site U1380 is situated on the middle slope of the Costa Rica margin above the unlocked portion of the plate boundary according to interplate earthquake relocation and geodetic measurements. The margin here consists of an upper plate basement underlying about 550 m thick slope sediments. Operations at this site consisted of drilling down to a depth of 397 mbsf followed by coring to a total depth into the formation of about 480 mbsf, at which depth the condition of Hole U1380A was deteriorating so that it was necessary to terminate and plug and abandon it. Overall we retrieved 52.37 m of sediment at this site.

Generally, the sediments cored from Hole U1380A were assigned to a single lithostratigraphic unit, Unit I. It consists olive green, terrigenous, well-consolidated clayey silt(stone) and silty clay(stone) with minor layers of sand(stone), sandy silty clay(stone), clay, clayey silt(stone). Intercalated in the main background sedimentation are dm-scaled fining- and coarsening- upward sequences of sands as well as several tephra layers. The tephra layers range in thickness from 0.5 to 35 cm. Unconformable and/or inclined bedding of the tephra was observed throughout the entire cored material. In general, the tephra layers have a sharp basal sediment contact and a gradational top contact, and are mainly normally graded and well sorted. The tephra layers are mainly composed of felsic (>90 vol%), transparent, colorless, and very fine to coarse ash sized glass shards having an angular blocky, cuspate, flat or Y-shaped morphology. The majority of the glasses are altered, as shown by the undulous extinction under crossed polarized light. In the coarser sand layers rip-up clasts, rounded clay lenses and abundant shell fragments are commonly observed. Framboidal pyrite was observed macroscopically and in many of the smear slides throughout Unit I.

The physical property data obtained on the cored material display an expected behavior with depth and reflect that only a single sediment unit as well as a limited depth interval has been cored at this site. Wet bulk densities determined from whole round gamma-ray attenuation (GRA) measurements are relatively constant throughout the cored interval, with a mean density value of $1.87 \pm 0.05$ g/cm$^3$. Grain densities determined by

mass/volume measurements on discrete samples are also relatively constant with depth with an average value of 2.67 ± 0.08 g/cm$^3$, however the variability increases with depth. These values suggest a terrigenous origin of the deposited material. Porosities, obtained by mass/volume measurements on discrete samples, are also relatively constant through the cored interval with a value of 49%. The magnetic susceptibility measured in the sedimentary sequence is also relatively homogenous and low indicating an abundance of non-iron bearing clays. The thermal conductivity is relatively constant throughout the cored interval with a mean of 1.05 ± 0.22 W/m·K.

The demagnetization experiments made on the sediments cored at Site U1381 are in general agreement with the physical property data. The mean NRM (natural remanent magnetization) intensity is about $10^{-3}$ A/m and exhibits no significant variations down hole. The mean carriers of the magnetic signal in the retrieved sediments seem to be titanomagnetite or maghemite as deduced from thermal demagnetization experiments on discrete samples. Generally, the number of discrete samples analyzed up to now from the recovered cores is too limited to confidently define the magnetic polarity for the cores from Site U1380. Based on the characteristics of the physical and magnetic properties and based on lithostratigraphic characteristics the sediments deposited at Site 1380 are interpreted as a terrestrially sourced upper slope sequence that is consistent with high sediment accumulation rates throughout the depositional interval. The clay-rich deposits of Unit I at Site U1380 are similar to those observed in Unit II at Sites U1378 and U1379.

This is consistent with the biogenic components distributed within the cored sediments. The biogenic components observed at this site are similar to the ones observed in Unit II at Site U1378. Biogenic components have a bimodal distribution in Unit I: shell fragments, diatoms and nannofossils are sparse but ubiquitous throughout the unit, whereas foraminifers are partly enriched within the sediments and are a major constituent of the sand-sized fraction of the sediment. Preservation ranges from poor to moderate. Based on nannofossil biostratigraphy (Zone NN19) the sediments retrieved from the basal core were deposited in the early Pleistocene, thus the sediments cored at Site U1380 are younger than 2 Ma. However, the top and bottom boundaries of Zone NN19, defined by the last occurrences (LOs) of *Pseudoemiliania lacunosa* and *Discoaster brouweri*, respectively, could not be constrained. The dominant species observed at this site include *Helicosphaera carteri*, *H. sellii*, *H. neogranulata/hyalina*, *Coccolithus pelagicus*, and *Calcidiscus leptoporus*.

Planktonic foraminiferal zones could not be established in the sediments cored at this site, because of their rare occurrences. The benthic foraminifers, on the other hand, reflect continuous paleoenvironmental changes. Planktonic foraminifers were observed in limited horizons of 6 core catcher samples and they are characteristic of tropical fauna

(*Globigerinoides quadrilobatus (Globigerinoides sacculifer), Globigerinoides ruber, Orbulina universa, Globorotalia menardii, and Neogloboquadrina dutertrei*). The benthic foraminifers observed at this site are similar to modern assemblages that are characteristic of the oxygen minimum zone in this region. Thus, benthic foraminiferal faunas mainly represent bathyal species. The faunas include many species similar to those of the nearby Site U1378. In general, the following species have been observed: *Bolivina argentea, Epistominella smithi, Uvigerina peregrina, Cibicidoides mckannai,* and *Gyroidina*. Those species are characteristic of an upper to middle bathyal palaeoenvironments.

The geochemical trends displayed by the analyzed pore water and gas samples (10 whole rounds, 9 headspace samples, 8 void gas samples) follow mainly the same general trend with depth as the fluids observed at Site U1378. Salinity, Cl, Na, $H_4SiO_4$, and B concentrations show a monotonic decrease with depth. This indicates a diffusional communication with fluids at depth. The low chloride concentrations (380 mM) and low salinity (20 mM), ~60-67% of seawater respectively, reflect significant freshening of the fluid. Methane ($C_1$) concentrations range between 3346 and 11925 parts per million per volume (ppmv) in interstitial waters from sediments sampled between 398.1 to 475.1 mbsf at Site U1380. The gas at these depths is thermogenic in origin as indicated by the low ratios of methane to heavier homologues (ethane and propane), with $C_1/(C_2+C_3)$ values from 459 to 552. The $C_2$ concentrations range between 3.89 to 15.69 ppmv, with the highest concentration at 475.1 mbsf. Propane is also present in the cores with concentrations ranging from 1.39 to 7.33 ppmv at depth. Iso- and normal-butane are detected from 398.1 to 475.1 mbsf with concentrations between 0.55 to 3.45 ppmv. Iso-pentane concentrations ranged from 0.64 to 2.34 ppmv. Propane, butane, and pentane concentrations were all highest at 475.1 mbsf.

There is a clear offset in the Ca, Mg, Sr, K, $NH_4$, and alkalinity profiles from ~400-500 mbsf between Site U1380 and U1378. Ca and $NH_4$ concentrations at Site U1380 are lower than they are at Site U1378, whereas K, Mg, Sr, and alkalinity concentrations are higher at Site U1380. The Ca, Mg, and K concentrations were determined twice via ICP-AES at both Site U1380 and U1378, and the $NH_4$ and alkalinity concentrations are determined by different methods, thus the offset is not an analytical artifact. Site U1380 is located ~1 km northeast of Site U1378, and the lithostratigraphy at Site U1378 is only partially represented at Site U1380. The depth interval between ~400 and 500 mbsf at Site U1378 contains more and thicker sections of coarser-grained sediments than at Site U1380, indicating that these horizons are either not present at Site U1380 or were not recovered and sampled. It is likely that these coarser-grained horizons are the conduits for the laterally-migrating fluids observed at Site U1378, which may explain why the geochemical profiles at Site U1380 show a steady increase (Ca, $NH_4$) or decrease (Mg,

K) through the depth cored and do not display the marked anomalies observed at Site U1378.

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