IODP Expedition 334: Costa Rica Seismogenesis Project (CRISP)

Site U1381 Summary

Background and Objectives

One of the primary objectives of Expedition 334 was to determine the characteristics of the down going plate entering the Costa Rica Subduction Zone. Fundamental to this objective is an understanding of the nature and the hydrologic system of the igneous section entering the zone. In this context Site U1381 serves as a reference site. Site U1381 is located along BGR99 Line 7, offshore Osa Peninsula and Caño Island on a basement relative high at CMP 5750 (Lat. 8º 25.7150' N, Long. 84º 9.4690' W) at 2067 m below sea level. This location is critical because basement relative highs are thought to act as major fluid discharge areas and have the best potential to record traces of vigorous fluid flow. The seismic section is showing a 120-m-thick sediment section on a high reflective basement interpreted as Cocos Ridge igneous crust. Paleomagnetic data constrain the age of this portion of the Cocos Ridge to be 14 Ma (Barckhausen et al., 2001). The sedimentary section has been interpreted as formed by pelagic and hemipelagic sediments. The sediment thickness along the seismic transect (SW to NE direction) is variable. This is in accordance with the relief of the Cocos Ridge (basement). This relief can be partly correlated with normal faulting, even though faulting is not a particularly strong charactertistic of the subducting plate.

Site U1381 is a key to characterize the material input into the subduction zone, considering both the composition and mass of the sediment cover and basement rocks as well as the fluids. In erosive margins fluids are thought to trigger the hydro-fracturing processes of the upper plate and to control the strength of the plate boundary. According to existing models of erosive margins, sediments are inferred to play a minor role in the input to the seismogenic zone. The role of the igneous basement of the incoming plate is less well established. Here we target the fluids circulating in the upper oceanic crust, since a vigorous hydrologic system was discovered offshore Nicoya during ODP Legs 170 and 205 (Kimura et al., 1997; Morris et al., 2003). The importance of the hydrological activity in the subducting oceanic plate is just beginning to be recognized (Silver et al., 2000). The igneous crust of the incoming Cocos plate has a significant variability along trench strike related to different origin, either EPR or CNS, and is definitely different is the hydrologic system. Heat flux measurements revealed high heat flow in the Cocos Ridge area in contrast with the low values of the Nicoya smooth crust (Fisher et al., 2003)(Grevemeyer, unpublished data). Cocos Ridge upper crust is well layered and probably very porous (von Huene et al., 2000), the contribution from the lower plate to the fluid circulation could be significant and its definition has important consequences for the fluid system at the aseismic-seismic boundary that will be investigated during CRISP Program B.

Scientific Results

Two holes were drilled at Site U1381. Hole U1381A was drilled with the plan to recover as much from the sediment cover and the basement rock as possible in the specified time window. Hole U1381B was drilled to retrieve the first 30 m of sediment for detailed geochemical sampling and to take 5 in situ temperature measurements to determine the geothermal gradient and the heat flux at this site. Overall 54.15 m of sediment and 35.69 m of basement were retrieved at this site with an average recovery rate of 42.3 and 54.8 %, respectively.

The material cored at Hole U1381A can be divided into three lithostratigraphic units. Unit I, about 46.14 m thick, consists mainly of light greenish gray, soft, clay sediments with minor layers of silty clay, and 3 tephra layers, ranging in thickness from 2 to 4 cm thick. In general, Unit I is massive with minor changes in the proportions of clay and silt. Biogenic components, especially nannofossils and diatoms are abundant throughout the unit. Foraminifers, spicules, and radiolarians are present in trace abundances. Smear slide investigations show that the main accessory components observed in this unit are silt-sized grains of feldspar, chert, chlorite, pyroxene, amphibole, opaque minerals, calcite, glauconite, fragments of radiolarians, foraminifers, sponge spicules, glass and rare quartz. Unit II is about 49.64 m thick and consists of mainly dark grayish to yellowish brown, soft to hardened clay/(stone) with abundant, intercalated tephra layers. The base of the sediment section is partly silicified. Unit II is clearly distinguishable from Unit I by its abundant biogenic components and by an abrupt color change. Unit II sediments are >70% composed of spicules, diatoms, radiolarians, and nannofossils. The dominantly felsic tephra layers range in thickness from 0.5 to 35 cm, from massive to soft, show a normal gradation and are well sorted. One notable exception is a 35 cm thick silicified mafic tephra layer (Mary) in Interval U1381A-7R-1, 92 cm to 7R-2, 9 cm) that shows parallel and cross lamination. With the exception of one tephra layer (Interval U1381A 5R-5, 29 to 34 cm) all other tephras show devitrification structures within the glass shards and severe signs of alteration. Grain size ranges from very fine to coarse ash (up to mm size). The mineral assemblages observed in the tephra layers consist of plagioclase, pyroxene (hypersthene, augite), hornblende, and biotite. Bedding dips, identified at compositional boundaries or grain size differences, of the entire cover sediment sequence are almost horizontal (mostly ≤ 5°). Unit III, the basement unit starting at a depth of about 103 mbsf, is composed of very dense, tough basalt ranging from almost aphyric to moderately phyric. Identified phenocrysts are plagioclase and pyroxene. The phenocrysts are euhedral to subhedral and of variable size (up to 5 mm in diameter). This phenocryst assemblage exhibits a number of changes with depth ranging from plagioclase dominated to pyroxene dominated. The groundmass of the basalt is fine grained and varies from light to dark gray color. A crosscutting vein network characterizes the majority of the observed basalts. The veins are preferentially straight with some irregularities. Offsets along the vein boundaries indicate that they were emplaced along faults (fault veins). Some of the veins do not show any displacement parallel to the vein boundaries indicating that some of them were emplaced in mode I fractures. In the recovered core fragments subvertical green veins of unknown mineralogy represent the oldest generation followed by subhorizontal white veins and high angle white veins. Alteration is restricted to halos along fractures, veins and around the phenocryst/groundmass interface. The secondary mineral assemblage, most likely a result of hydrothermal processes, is composed of clay minerals, zeolites and pyrite.

The physical property data obtained on the cored material are quite variable, consistent with the different lithologies we have cored at this site. Wet-bulk densities determined from whole round gamma-ray attenuation (GRA) measurements are relatively constant throughout the cored sediment section at this site, with a mean density value of 1.40 ± 0.14 g/cm^3. GRA derived bulk densities of the basement are highly variable due to variable filling of the core liner, having a maximum value of 2.3 g/cm^3. Grain densities determined by mass/volume measurements on discrete samples of the cored sediment, although showing a large scatter, generally decrease with depth from approximately 2.7 to 2.5 g/cm^3. Porosities, obtained by mass/volume measurements on discrete samples are relatively constant through the cored sediment interval with a value of 76%. Generally, porosity is expected to decrease with depth, the observed constant values could be an artifact caused by the RCB coring system. The magnetic susceptibility measured in the sedimentary sequence is low, with a mean value of 0.009 ± 0.016 SI. The magnetic susceptibility measured in the basement rocks is generally higher (maximum values varying between 1 and 2 SI), increasing from the sediment/basement interface down to a depth of 140 mbsf followed by a slow decrease towards the bottom of the hole. The thermal conductivity is relatively constant throughout the cored interval, with a mean of 0.79 ± 0.08 W/m·K and 1.45 ± 0.07 W/m·K in sediment and basement, respectively. These values are quite low for basalt and might be an artifact of the samples not being water saturated before measurement because of time constraints. Downhole equilibrium temperatures acquired using the SET tool increase linearly with depth, and give a least-squares geothermal gradient, coupled with the average bottom water temperature, of 222ºC/km. The heat flow calculated using the mean thermal conductivity of 0.8 W/m·K is 178 mW/m^2. This value is significantly larger than the half space prediction for a 15 Ma old crust (130 mW/m^2) and than the observed global average heat flow for crust of this age (77 mW/m^2; Stein and Stein, 1992). This high heat flow value is an indicator for significant fluid flow within the underlying crust.

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 of the cored sedimentary sequence is about 10–3 A/m and decreases slightly with depth. The depth interval between ~30 and 35 mbsf shows higher NRM intensity values. NRM intensities of the cored basement range from ~1 to 8 A/m. NRM inclination and intensity show a correlated down hole variation. The relatively fresh samples from the top of the basalt section (Cores U1381A-12R to 16R) frequently show shallow inclinations (consistent with the low latitude) and are characterized by strong NRM intensities. The basalts below Core U1381A-16R are relatively altered and show NRM with an inclination of ~50°, (indicating a stronger effect from drilling-induced demagnetization) and lower intensities. The majority of the measured basalts have a NRM with a positive inclination; however, several blocks reveal a NRM with negative inclinations, possibly reflecting prolonged igneous activity at this site. The mean carriers of the magnetic signal in the retrieved basement rocks seems to be titano-magnetite with a low Ti-content as deduced from thermal demagnetization experiments on discrete samples. Generally, the remanence of the recovered material is too weak for the shipboard experiments to determine characteristic magnetization. Thus, establishment of the magnetic stratigraphy for Site U1381 will be done during shore-based studies.

Even though a magnetic stratigraphy could not be established for Site U1381 on the ship, the nannofossil and foraminifera community observed at this site provided a significant biostratigraphic control of the cored sediment sequence above the basaltic basement of the Cocos Ridge. Based on microfossil biostratigraphy, the sedimentary layers are tentatively divided into an upper part of Pleistocene age, and a lower part of Middle Miocene age. Thus, the sediments just above the basement are tentatively estimated to be of Middle Miocene age. The sediments just above basement basalt would be younger than 16 Ma. The zonation of planktonic foraminifers is approximately concordant with that of the calcareous nannofossils.

Two different environments, based on species, abundance and preservation, are represented in the cored sediments at Site U1381. The upper interval (3.69 to 49.62 mbsf) represents a hemipelagic environment mixed with terrigenous material, whereas the lower interval (53.86 to 95.5 mbsf), a silicic to calcareous ooze, represents a pelagic environment. The nannofossil assemblage observed in the upper 31.9 mbsf is characteristic of the Early Pleistocene Zones NN20-NN19 and contains *Geophryocapsa oceanica, G. caribbeanica, Helicosphaera carteri,* and *Calcidiscus leptoporus*. However, due to poor preservation and the lack of zonal markers this interval cannot be biostratigraphically zoned. The interval up to a depth of 41.5 mbsf is tentatively assigned to nannofossil Zone NN19 based on the occurrence of *Pseudoemiliana lacunosa* and the absence of *Discoaster brouweri*. However, the top boundary, defined by the last occurrence (LO) of *Pseudoemiliana lacunosa* is undetermined. Sample U1381A-6R-CC (49.62 mbsf) contains a diverse nannofossil assemblage of mixed ages, ranging from the Pleistocene Zone NN19 into the Late to Middle Miocene. This diverse assemblage is dominated by Pleistocene species including *Geophryocapsa oceanica, G. caribbeanica, Helicosphaera carteri,* and *Calcidiscus leptoporus*. Also present, but rare to a few in abundance, are Miocene species including *Discoaster bellus, D. exilis, D. quinqueramus, D. variabilis*, and unidentifiable 5- and 6-rayed discoasters. The *discoasters* are poorly to moderately preserved, whereas the *placoliths* exhibit moderate to good preservation. The condition of the *discoasters* and the rarity or lack of biostratigraphic markers prevents the further delineation of the Pliocene and Miocene Zones.

The depth interval between 53.86 and 95.5 mbsf is assigned to the Middle Miocene Zone NN5 based on the occurrence of *Helicosphaera heteromorphus* and the absence of *H. ampliaperta*. The top and bottom of this zone cannot be constrained due to the uncertainty of the last occurrences (LOs) of the biostratigraphic markers. Typical species found in the samples include *Sphenolithus heteromorphus, S. moriformis, Calcidiscus leptoporus, Cyclicargolithus floridanus, Coccolithus miopelagicus, Discoaster exilis, D. variabilis, D. deflandrei,* and *Reticulofenestra pseudoumbilicus*.

Planktonic foraminifers were analyzed in 9 core catcher samples. Foraminifera are abundant to common in the sediments of Hole U1381A. The preservation of the foraminifers is good to moderate. Fragmentation of foraminifera caused by carbonate dissolution is observed in the samples of sediments coming from lower bathyal depths. Planktonic foraminifers, being abundant to common in this hole, are much more abundant than benthic foraminifers. These trends are quite different from the trends observed in the cored sediments of the other drilling sites. Similar to the observed nannofossil communities in this hole, the foraminiferal assemblages of the upper part of the sediment sequence are quite different from those of the lower parts. This is either caused by a hiatus or by very low sedimentation rates. The foraminifera community of the upper sediment sequence (3.69 mbsf to 49.62 mbsf) is characterized by tropical fauna (*Globigerinoides quadrilobatus (Globigerinoides sacculifer), Globigerinoides ruber, Orbulina universa, Globorotalia menardii,* and *Neogloboquadrina dutertrei*). Sample U1381A-3R-CC (13.34 mbsf) contains pink *G. ruber* and is assigned to the Pleistocene (older than 0.12 Ma). Sample U1381A-6R-CC (49.64 mbsf) contains sinistral coiling *Pulletiatina* and is assigned to be older than 0.8 Ma but younger than 4 Ma. From 53.86 to 95.55 mbsf the planktonic foraminiferal assemblages are composed of *Dentoglobigerina altispira, Globigerinoides quadrilobatus, Globigerinoides obliquus, Globoquadrina dehiscens, Globorotalia peripheronda, Globorotalia peripheroacuta, Paragloborotalia siakensis, Orbulina suturalis*. This sequence is tentatively assigned to planktonic foraminiferal zone M7 (14 Ma). However, the occurrence of *Praeorbulina circularis* at a depth of about 95.55 mbsf may be a sign that the sediments just above the basement basalt are much older (either zone M5 or M6).

The geochemical trends displayed by the analyzed pore water samples (17 whole rounds) are generally controlled by the following processes: (1) organic carbon cycling, (2) volcanic ash alteration, and, to a lesser extent, (3) clay-ion exchange reactions in the upper 40 m of the cored sediments and (4) by ongoing ash alteration, (5) ion exchange reactions and (6) diffusive exchange with a basement fluid below this depth. Salinity is lower than the seawater value (SW = 35) between 13 and 24 mbsf, but increases gradually below this depth to the base of the sediment column. Chloride concentrations are slightly below modern seawater value. A similar dilution of Cl concentrations of about 2.5% lower than modern seawater was observed in the upper 100 m of the sediment column cored at the reference site (ODP Site 1039) offshore the Nicoya Peninsula (Kimura et al., 1997). Sodium concentrations are below the seawater value throughout the cored section and reach a minimum of at 35 mbsf. K and Mg show a similar decrease at this depth, suggesting local alteration of volcanic ash, which is consistent with the lithostratigraphic observations made. Sodium concentrations are relatively constant below this depth. Sulfate concentrations decrease to a minimum at 23 mbsf and then increase nearly linearly with depth. The alkalinity concentration-depth profile is a mirror image of the sulfate profile reaching a maximum at 23 mbsf and then decreasing towards the base of this hole. Organic matter diagenesis in the upper part of the sediment section is also observed in the ammonium profile, which reaches a maximum value at 23 mbsf. Ammonium concentrations remain nearly constant to 35 mbsf, and then decrease nearly linearly. Calcium concentrations reach a minimum value just below the sulfate minimum at 23 mbsf, suggesting precipitation of authigenic carbonates in the zone of active sulfate reduction and alkalinity production. Below this depth Ca concentrations increase gradually towards the base of the cored sediment. This increase with depth most likely reflects both ash alteration in the sediment column and diffusive exchange with a basement fluid.

Potassium and boron concentrations decrease gradually with depth reaching minimum values at the base of the sediment cover, whereas dissolved Mn concentrations increase with depth reaching maximum values at the base. Magnesium concentrations exhibit a minimum at 35 mbsf, consistent with alteration of the volcanic tephra that are abundant in this interval. Magnesium concentrations remain relatively constant between 45 and 81 mbsf, and then decrease again at the sediment/basement interface. Dissolved Si concentrations are elevated throughout the cored section and the profile is primarily controlled by lithology. Si concentrations increase slightly from 13 to 46 mbsf, then increase abruptly from 46 to 68 mbsf reflecting the change from the clay dominated terrigeneous sediments in the uppermost sediment column to the hemipelagic sediments dominated by calcareous nannofossils and diatoms below. Silica concentrations remain elevated and constant throughout the hemipelagic nannofossil ooze section. Strontium concentrations increase slightly with depth reaching a maximum at the base of the sediment section. The only slight increase in Sr concentrations in the calcareous nannofossil rich sediments suggests they are relatively unaltered and have not undergone significant diagenetic modification. This interpretation is corroborated by the pristine appearance of the nannofossils within these sediments.

References

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