Item DR1: Drillcore Description

Although described as breccia, Unit V (881.75-947.52 mbsf – see Figure 2) consists of fine- to medium-grained vulcanoclastic sediment with intercalated breccia and coarser sand. The breccia is about 20% of the recovered material, it is matrix-supported with clasts of basalt and well-lithified limestone and mudstone. Mudstone is prevalent in the upper part of the section, while the fine sand/siltstone grading to massive clayey siltstone dominates m-thick intervals, in particular within the lower portions of the recovered interval. Parallel- and cross-lamination, convolution, grading (both fining and coarsening upward) of the silt/sandstone intervals suggest turbiditic deposition on a slope dominated by hemipelagic siltstone and mudstone. The breccia interval indicate that the slope was incised by canyons and gullies filled by channel deposit. Microfossils from Unit V are earliest Pleistocene (Calcareous nannofossil zone NN17), which corresponds to 2.5 Ma. The matrix-rich sequence at base of the recovered interval has abundant bioturbation and few convolute laminations. Sedimentary structures are undeformed, bedding is generally sub-horizontal and deformation features are generally absent in Unit V.

To define ranges of paleodepths we interpolate the information from the sedimentological and stratigraphical characteristics of the cored section with a quantitative analysis of benthic foraminifera. This method also provides a better definition of the trends of subsidence and uplift. To minimize the effect of environmental factors as flux of organic matter, temperature, carbonate and oxygen dissolution and substrate characteristics (Gooday, 2003) on the distribution of benthic fauna, we refer to modern assemblages studied along the Costa Rica margin (Bandy and Arnal, 1957; Cushman, 1927; Golik and Phleger, 1977; Heinz et al., 2008; McDougall, 1985; Smith, 1963, 1964). Paleocene-present paleobathymetry can be inferred from comparison between the distributions of fossil and modern benthic foraminifera in the same area (Gooday, 2003). Moreover while modern neritic and bathyal assemblages found along continental slopes reflect a more heterogeneous environment with distinct bathymetric successions, the assemblages living in the deeper part of the abyssal environment (>3.5-km of water depth) are generally more cosmopolitan.

Studies on Pliocene to Holocene benthic assemblages have been conducted onland on the Charco Azul Formation of Burica Peninsula (Corrigan et al., 1990) and offshore the Nicoya Peninsula (Vannucchi et al., 2003).

The explanation of the method used to analyze benthic foraminifera fauna as well as the complete dataset is reported in Proceedings of IODP Exp. 334 (Vannucchi et al., 2012). The vertical distribution of benthic foraminiferal assemblages was based both on the depth classification of Van Morkhoven et al. (1986) and Bandy (1960).
In Unit V, 17% of the benthic foraminifera, including *Gyroidina neosoldanii*, *Uvigerina peregrina* and *Bolivina argentea*, indicate deposition of the fine grained turbidites and hemipelagic sediment in the middle bathyal zone (600-1500) at a minimum water depths of a 800±100 m. Species displaced from shallower slope and shelf offer abundant evidence of the massive downslope reworking of these fauna in agreement with the turbiditic/channel sedimentary environment. Hard-rock clasts are concentrated in the upper part of Unit V. Basalt clasts have aphyric to moderately phyric compositions containing plagioclase, pyroxene and olivine phenocrysts. Some of the clasts contain prehnite and pumpellyite, indicating prehnite-pumpellyite facies metamorphic conditions, similar to the Osa mélange onshore the northwest coast of the Osa Peninsula (Vannucchi et al., 2006). Unit V has unique physical properties when compared to its overlying sequence. This is particularly evident in LWD (logging while drilling) measurements (Fig.2), where sharp shifts in baseline natural gamma radiation (Suess et al., 1988) photoelectric factor, density, and resistivity logs are found at the top of Unit V. Compared to its overlying slope sediments, Unit V shows a markedly higher average density and resistivity (2.3 g/cm³ and 2.5 Ωm vs. 1.9-2 g/cm³ and 1-1.3 Ωm) and lower porosity (~20% vs. ~45%).

The uppermost ~10 cm of Unit V are characterized by thin sediment-filled fractures (Fig. 2B). The filling material is formed by wallrock, bioclasts, and volcanoclastics in a greenish matrix. A disconformity, with a scoured erosion surface, marks the passage to overlying Unit IV. Unit IV (879.9-881.75 mbsf) corresponds to the base of an 880 m-thick shelf sequence that records continuous and extremely young (Pleistocene) sedimentation. This sedimentary record provides a unique opportunity to unravel the evolution of water depth through time, by use of the superposition of sedimentary facies containing different benthic fauna. Paleo-water depths, corrected for sea level changes, can ultimately be used to infer the distribution and rates of vertical tectonism on the overriding plate, which provides a good record of the events that occurred at this margin during the recent subduction of the Cocos Ridge and the large-offset fracture zones associated with its Eastern margin (Fig. 3).

Unit IV is comprised of <2 m of carbonate-cemented medium- to coarse-grained sandstone including basalt gravels, and shell fragments. The base of Unit IV is marked by thin wavy layers of calcium carbonate. Overlying the basal calcium carbonate accumulations is a ~0.5 m thick interval of matrix supported basalt clasts (≤ 11 cm) in a sandstone matrix. This passes to coarse-grained sandstone with frequent, cm-thick shell layers and dispersed imbricated shell fragments. Inclined laminated sandstones with shell debris occur within highly bioturbated horizons. Towards the top of Unit IV the sandstones are finer grained with a few mud drapings in horizontal layers. The sediment-filled fractures at the top of Unit V are interpreted as desiccation cracks. Emersion at this time is also supported by hardened deposits of calcium carbonate above the erosion surface. The sedimentary facies of Unit IV is consistent with a beach/nearshore environment. Coarse basalt gravels indicate the presence of basaltic cliffs near the coastline, while sedimentary structures are consistent with tractive currents on a highly bioturbated shallow seabottom. The benthic foraminifera association for Unit IV is composed of a single species, *Cibicides reflugens*, a foraminifer that lives mainly from the coast to 200 m water depth on shells, seaweeds or hard substratum in high energy and low sedimentation rate environment in agreement with a beach/nearshore paleo-environment. Considering the accumulation rates within Unit III and the age of Unit V, Unit IV was deposited at about 2.2 Ma. Unit III (651-880.07 mbsf) is ~230 m-thick. It is
composed of medium-grained sandstone layers alternating with finer sandstones. In particular there are three progressively thinner intervals of coarser sands with lithic granules/pebbles and shell fragments present towards the top of Unit III. Rip-up clasts, millimeter-scale laminations, convolute bedding, and chaotic mixing is observed throughout the coarser sequences at the base of the partly eroded fining-upward sequences. These sedimentary characteristics are consistent with turbiditic deposition. Samples from the top of Unit III contain microfossils of early Pleistocene (lower limit of Calcareous nannofossil zone NN19), corresponding to ~1.95 Ma. During the ~300 ky between Unit IV and the top of Unit III the benthic foraminifera assemblages change, indicating increasing water depth. The benthic fauna is dominated by the middle bathyal species (600-1500 mbsf) *Bolivina argentea* and *Uvigerina peregrina*. Assemblages of living benthic foraminifera studied offshore Costa Rica show high abundances of *Uvigerina peregrina* in samples collected from 900 and 1400 m of water depth, even though this species is present also at 2400 m of water depth (Heinz et al., 2008). *Bolivina argentea* is mainly present between 750 and 900 m of water depth, but this species is common also>1000 m (Bandy and Arnal, 1957; Smith, 1964). The recognition of the abyssal (2000-3000 m) species *Gyroidina neosoldanii*, *Oridorsalis umbunatus* and *Uvigerina senticosa* is too low to imply abyssal water conditions, but they certainly suggest depth shifted toward the deeper values of the middle bathyal zone with a general deepening trend (Fig. 2). In general the sediment recovered in the lower part of Site U1379 records deepening of water depth of about 1200±200 m occurring in ~600 ky.

The overlying unit, Unit II (0.93-651 mbsf), consists mainly of massive clay(stone) and silt(stone) mixed in various proportions with minor layers of sand(stones). In the upper portions of Unit II there are intervals with carbonate concretions, both calcareous and dolomitic, and carbonate mud sediments. The sediment is firm, with porosity significantly lower than that in the middle slope Site 344-1378, suggesting overconsolidation. Samples from ~470 mbsf contain microfossils of early Pleistocene (upper limit of NN19) corresponding to an age of ~0.45 Ma. Middle bathyal associations of benthic foraminifera species persist throughout the lower half of Unit II with *Globocassidulina subglobosa*, *Uvigerina peregrina*, *Gyroidina neosoldanii* and *Oridorsalis umbunatus* present. Less than about 400 mbsf, benthic foraminifera species indicate shallowing paleo-seafloor depths to the modern 130 m depth. Remarkably, the sediment accumulation rate is 1035 m/my for the topmost 600 m of Site U1379. Unit I (0-0.93 mbsf) is a loose coarse sand layer that caps the shelf sequence.

**References**


Suess, E., von Huene, R., and al., e., 1988, Proceedings of the Ocean Drilling Program, Initial Report, College Station, TX, Ocean Drilling Program.


Item DR2

Backstripping was performed using the 1D Airy isostatic model developed by Allen and Allen (1990). The goal of backstripping is to remove from each sedimentary layer the effects of sediment compaction, and of water and sediment loading. This allows us to more accurately infer the tectonic subsidence curve from the section. Each stratigraphic column was decompacted using a depth-dependent, exponentially decreasing function of porosity – $\Phi = \Phi_0 e^{-cy}$ where $c$ is the porosity decrease coefficient, $\Phi_0$ is the surface porosity and $\Phi$ is the porosity at depth $y$. To estimate the tectonic component, the subsidence driven by the sediment load was subtracted from the total (decompacted) subsidence. In addition, corrections for varying water depth and long-term eustatic sea level (Haq et al., 1987) were applied.

We note that the assumption of local isostasy gives the maximum possible effect of sediment loading. If the lithosphere has finite flexural strength, the amount of tectonic subsidence would be greater than the value we calculated.

The plot was created with the OSXBackstrip 2.9 software developed by Cardozo (2011).

Table DR1: Input parameters for backstripping and geohistory analysis of the Pleistocene stratigraphic section recovered at IODP Site 334-U1379

<table>
<thead>
<tr>
<th>NAME</th>
<th>base</th>
<th>Age$_b$</th>
<th>SL$_b$</th>
<th>WD$_b$</th>
<th>top</th>
<th>Age$_t$</th>
<th>SL$_t$</th>
<th>WD$_t$</th>
<th>$\rho_c$</th>
<th>$c$</th>
<th>$\Phi^0$</th>
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<tr>
<td>UNIT V</td>
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<td>2.5</td>
<td>-0.065</td>
<td>0.800</td>
<td>0.882</td>
<td>2.3</td>
<td>-0.050</td>
<td>0.800</td>
<td>2771.0</td>
<td>0.735</td>
<td>56.2%</td>
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<td>UNCONF.</td>
<td>0.882</td>
<td>2.3</td>
<td>-0.050</td>
<td>0.800</td>
<td>0.881</td>
<td>2.2</td>
<td>-0.027</td>
<td>0.000</td>
<td>0.0</td>
<td>0.000</td>
<td>0.0%</td>
</tr>
<tr>
<td>UNIT IV</td>
<td>0.881</td>
<td>2.2</td>
<td>-0.027</td>
<td>0.000</td>
<td>0.879</td>
<td>2.2</td>
<td>-0.027</td>
<td>0.050</td>
<td>2731.0</td>
<td>0.200</td>
<td>46.8%</td>
</tr>
<tr>
<td>UNIT III$_{BOT}$</td>
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<td>2.2</td>
<td>-0.027</td>
<td>0.050</td>
<td>0.757</td>
<td>2.0</td>
<td>0.020</td>
<td>1.200</td>
<td>2709.0</td>
<td>0.200</td>
<td>46.0%</td>
</tr>
<tr>
<td>UNIT III$_{TOP}$</td>
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<td>2.0</td>
<td>0.020</td>
<td>1.200</td>
<td>0.651</td>
<td>1.9</td>
<td>0.020</td>
<td>1.200</td>
<td>2709.0</td>
<td>0.200</td>
<td>46.0%</td>
</tr>
<tr>
<td>UNIT II$_{BOT}$</td>
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<td>0.020</td>
<td>2.000</td>
<td>0.480</td>
<td>0.5</td>
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<td>2.000</td>
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<td>0.123</td>
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<td>2.000</td>
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<td>0.0</td>
<td>0.000</td>
<td>0.125</td>
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<td>57.5%</td>
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</table>

Key - base: depth to base (km); Age$_b$: age of base (Ma); SL$_b$: Sea level at age of base (km); WD$_b$: Water depth at age of base (km); top: depth to top (km); Age$_t$: age of top (Ma); SL$_t$: Sea level at age of top (km); WD$_t$: Water depth at age of top (km); $\rho_c$: grain density (kg/m$^3$); $c$: porosity coefficient (1/km); $\Phi^0$: surface porosity (%)
Cardozo, N., 2011, OSXBackstrip v. 2.9.
Figure DR3. A) Post-stack depth migrated seismic section centered at Site 334-U1378 (detail of BGR99 Line 7, processed by Cesar R. Ranero). Hole drawn to drilled depth. IODP Site 1378 did not reach the target depth marked by the strong reflector at ~800 mbsf because of deteriorated hole conditions. B) Lithostratigraphy, age based on nannofossil analyses and benthic foraminifera distribution at IODP Site 1378. Bentic foraminifera distribution shows a rapid shallowing of water depth starting at about 0.5 Ma.
Item DR4

Figure DR4. A – Digital elevation model - http://www.geomapapp.org (2) - of the plate tectonic setting surrounding the Cocos Ridge and Costa Rica illustrating the large embayment in central Costa Rica formed by removal of forearc material during subduction of the Cocos Ridge (CCR) and the associated Fracture Zone complexes to its East. The original trench is restored as trending 305°. Along Nicoya Peninsula the coastline is located ~60 km from the trench (dashed black line). Moving SE the shelf break is located ~60 km from the trench. Finally in the embayment ~60 km is the distance from the shelf break to the restored trench at 305° (dashed & dotted red lines). We approximate the embayment to have a triangular form. The shaded green areas correspond to the geometrical constructions represented in panel B that were used to calculate the amount of eroded material. Shaded green areas are the portions of the forearc that are still preserved between Nicoya and Osa Peninsulas. We used the digital elevation model (http://www.geomapapp.org (Ryan et al., 2009) to describe the morphology of this region.

B – 3D cartoons illustrating the preserved (shaded green) vs. removed portions of the regions used to estimate the amount of forearc material removed by recent subduction erosion. Top: the amount of material preserved and removed behind the trench; middle: the amount of material preserved and removed due to trench retreat; bottom: the amount of material preserved within the slope.

References

Chord of CCR embayment at 305°