IODP Expedition 340: Lesser Antilles Volcanism and Landslides

Site U1394 Summary

Background and Objectives

Integrated Ocean Drilling Program (IODP) Site U1394 (CARI-03C, 16°38.43'N; 62°2.29'W, 1115 m below seafloor [mbsl]) is located offshore the island of Montserrat (about 24 km from point Shoerock, the SE tip of Montserrat).

The site survey data obtained for Site U1394 revealed the presence of debris avalanche deposits (deposit 2 and underlying deposit 8). The site survey seismic data indicate that Site U1394 might penetrate through different units of debris avalanche deposit 2 (Lebas et al., 2011, Watt et el., 2012). Our plan was to drill 244 m through volcanic and biogenic sediments with intercalated chaotic debris avalanche deposit 2.

The objective of Site U1394 is to characterize the processes occurring during debris avalanche emplacement and associated erosional processes. The sediments overlying the avalanche deposit will allow us to date this collapse event using $\delta^{18}O$ chronostratigraphy. We will be able to determine whether the avalanche occurred as a single event, or in a series of closely spaced, separate events. Based on a detailed lithological, sedimentological, and textural fabric analysis of the cored debris avalanche material, we will be able to test the hypothesis that the debris avalanche incorporated sediments eroded from the sea floor during its emplacement. We hope to reach the bedded units below the chaotic debris avalanche unit and thus have access to the textural and structural characteristics of the base of the debris avalanche (Komorowski et al., 1991; Glicken, 1991, 1996). Existing numerical models of debris avalanche emplacement currently do not sufficiently considerate the interaction of the avalanche with the substratum and its influence on the mobility of the flow. We will be specifically looking for structural evidence of the development of shear zones from the base of the avalanche into the overlying plug and fluidization structures (clastic dykes) described in terrestrial avalanche deposits (e.g. Glicken, 1996; Voight et al., 2002; Gee et al., 1999; Clavero et al., 2002, Shea et al., 2008).

Scientific Results

The vessel arrived at Site U1394 (CARI-03C) after a 5.3 nautical mile transit in DP mode from Site U1393 (CARI-02C). Site U1394 consisted of 2 holes. The original plan called for 2 holes to a depth of ~244 mbsf. Hole U1394A was advanced 235 m into the formation, whereas Hole U1394B was shortened to ~180 mbsf due to challenging coring conditions, after ensuring that the lower 60 m at this site were scientifically less interesting. Hole U1394B was successfully logged with both the FMS-sonic and triple combo logging strings, but an attempt to perform a VSP experiment was canceled when all efforts to deploy the VSI tools through the BHA failed. A total of 48 cores were retrieved at Site U1394 with an average recovery rate of 23% (57 m of material) in Hole U1394A and 78% (162 m of material) in Hole U1394B.

The main lithologies cored at Site U1394 are (1) hemipelagic mud, (2) turbiditic sand and mud, (3) mafic volcaniclastics, and (4) tephra. (1) The hemipelagic mud mainly consists of fine-grained calcareous biogenic fragments and siliciclastic sediment. It is often pale yellowish gray to dark gray in color, and varies from fine silt to fine mud in grain size, being moderately to poorly sorted. (2) The turbiditic sand and mud is characterized by normal graded, massive, well-sorted, mud (for thin deposits with a few centimeters in thickness) to very coarse sand (for thick deposits with meters in thickness) consisting of volcaniclastic and bioclastic particles. Volcaniclasts include fragments of fresh andesitic lava and pumice, altered lava, and crystals (feldspar, amphibole, etc.). Bioclasts include fragments of carbonate materials such as corals and shells. The ratio of volcaniclastic to bioclastic components varies. (3) The mafic volcaniclastics consist of basaltic turbidites. (4) The tephra deposits retrieved from this site are composed of fining upward units of normally graded (from pebble to fine sand) basaltic particles and basaltic scoria. The fining upward units vary in thickness from 6 to 13 to 30 cm.

Investigation of the main lithologies by X-ray diffraction shows that the pelagic sediment intervals predominantly contain calcite, high-Mg calcite, plus or minus aragonite, together with minor volcanic phases (mostly plagioclase with lesser orthopyroxene and hornblende), and amorphous clay minerals. Samples from the volcaniclastic horizons contain dominantly plagioclase and lesser amounts of orthopyroxene and hornblende, and minor sedimentary carbonate. One of the investigated tephra layers contains abundant smectite in addition to the volcanic minerals and background pelagic phases noted above. Analysis of the $CaCO_3$ content of the cored material shows that the $CaCO_3$ content is much higher in the largely pelagic sections (average approximately 60 wt.%) than in the largely volcanic turbidite units, however the presence of 3.5 to 7.5 wt.% $CaCO_3$ in the latter indicates a significant biogenic component and is consistent with the optical inspection of the core. Organic carbon concentrations in the pelagic sections are similar to those expected in this area (average approximately 1 wt.%), and are much lower in the turbiditic sections (<0.2 wt.%).

Based on abrupt or gradational changes in the abundance of these lithologies and distinctive marker horizons (tephras and turbidites), 6 main lithostratigraphic units, termed Unit A, B, C, D, E, and F, have been defined. Unit A is further divided into seven subunits (A-1 to A-7). Unit A (~ 7 m in thickness) basically consists of a series of volcaniclastic turbidites with varying proportions of bioclastic particles separated from each other by variably thick hemipelagic sediments consisting of mud to rarely silty mud. The turbidites mainly fine upward from a sandy base into a muddy top. A basaltic tephra layer resides at the base of Unit A. Unit B is ~ 1.5 m thick. The upper part of Unit B consists of a fairly thick interval of mainly relatively coarse grained, stacked and amalgamated turbidites ranging in composition from mainly bioclastic to volcaniclastic. The turbidites are massive such that planar or ripple cross-lamination is always absent, suggesting rapid deposition that prevented bed-load reworking into laminae. Below this the turbidites are flay lying, relatively thin and sometimes mildly deformed. The thick turbidite interval is separated from the thin layer turbidites by an interval of very contorted hemipelagic silty mud with fine laminae. The lower part of Unit B has not been recovered. Unit C (~24 m thick) contains alternating sequences of hemipelagic sediment and volcaniclastic turbidites. Individual intervals of the hemipelagic sediment can be up to 130 cm long. Unit D (~ 18 m thick in Hole U1394A, 36 m thick in Hole U1394B) is dominated by massive coarse-grained turbiditic sandstones composed of variable amounts of volcaniclastic and bioclastic material. The turbidites are either graded or ungraded. Chaotically distributed clasts (andesitic and biogenic) up to several centimeters in length in some ungraded sections may suggest en-masse emplacement by debris flow. Unit E contains significant amounts of hemipelagic mud alternating again with turbidites consisting either mainly of volcaniclastic or bioclastic material or a mixture of it. The upper part of Unit E contains relatively thick and coarse-grained turbidites; turbidite abundance and thickness is lower in the middle part of Unit E. Turbidite thickness seems to increase again near the base of the unit. Distributed throughout Unit E there are massive brown ash layers, some of which are 20 cm thick, and layers of pumice clasts (up to 5 cm in diameter). Unit F has been only retrieved in core catcher samples at the base of Hole U1394A and consists of coarse-grained andesitic clasts.

A closer investigation of the volcaniclastic and fall out deposits based on thin section microscopy shows that the recovered clasts of andesitic lava and the pumice fragments consist of plagioclase (70%), amphibole (25%), FeTi oxides (4%), and orthopyroxene (1%) phenocrysts. In the case of the andesites, the phenocrysts are contained in a microcrystalline matrix of plagioclase, oxides, and pyroxene microlites. The groundmass of the investigated pumice particles is significantly different. It consists of glassy material exhibiting considerable flow lineation. No flow lineation was observed in the lava clasts. The groundmass to phenocrysts ratio is approximately 60:40 and 70:30 for andesite and pumice, respectively. The microscopic investigation of the tephra layers revealed that the uppermost tephra layer is basaltic in composition, containing fragments of plagioclase, olivine, clinopyroxene, and oxides in descending abundance. The deeper ones are of basaltic andesitic or andesitic composition, containing fragments of plagioclase, amphibole, orthopyroxene, and FeTi oxides.

The results of the detailed study of the nannofossil and microfossil content of the sediments described above are consistent with their intensely reworked nature. Calcareous nannofossils and planktic and benthic foraminifera of varying abundances and varying levels of preservation have been observed. Large volcanic clasts, coral fragments, abundant reef-dwelling benthic foraminifera as well as highly fragmented foraminifera, are characteristically observed in the majority of the core catcher samples. Biostratigraphic datums derived from both calcareous nannofossils and planktic foraminifera show that Site U1394 contains many levels of reworked sediment from the Early Pleistocene amidst a background of Late Pleistocene sedimentation.

The observed nannofossils generally show an extreme poor preservation and their abundance is low. The species observed throughout the entire cored sediments are *Gephyrocapsa oceanica*, *Gephyrocapsa caribbeanica*, *Pseudoemiliania lacunosa*, *Calcidiscus leptoporus*, *Helicosphaera kamptneri* as well as *Helicosphaera inversa*. *Helicosphaera inversa* is a very important species due to its short range through the Early and Late Pleistocene (Late CN13 to CN14), placing the cored materials within the Pleistocene. Pleistocence age of the sediments is also indicated by the occurrence of *Helicosphaera sellii* (CN10 to CN13) in a number of samples. *Pseudoemiliania lacunosa*, a species indicative of Early Pleistocene sediments, was also abundant in several samples, with particularly large specimens (over 7 μm) in sample U1394A-24XCC. *Globigerinoides ruber* (white) and *Globigerinoides sacculifer* dominate the planktic foraminifera observed at Site U1394. Other abundant species include *Globigerina falconensis*, *Globigerinita glutinata*, *Globigerinoides elongatus*, *Globorotalia tumida* and *Neogloboquadrina dutertrei* (dextral). The species present in all samples are indicative of warm sub-tropical waters. Three datum species were commonly encountered, *Globorotalia flexuosa* (0.07-0.40 Ma), *Globigerinella calida* (base of occurrence at 0.22 Ma), and *Globorotalia tosaensis* (top of occurrence at 0.61 Ma), placing the investigated sediments, in accordance with the nannofossil observations, within the Pleistocene. The presence of the benthic foraminiferal species *Osangularia*, *Globocassidulina*, *Cibicides*, and *Laticarinina spp.* suggests a bathyal paleodepth for site U1394.

Generally, the ages obtained based on the nanno- and microfossil community observed in the core catcher samples of this site are similar to the ones obtained by measuring the natural remnant magnetization of the cored sediments. Expected inclination for the site is ~31° assuming a geocentric axial dipole (GAD). The data plot close to or steeper than GAD. Inclination steepening is probably related to bioturbation. All of the data show normal polarity indicating that the sediment higher than ~210 mbsf at this site was deposited within the Brunhes Chron. However, due to the lack of a continuous record this is only a tentative result.

The physical properties of the material retrieved at Site U1394 can generally be correlated to the lithological variations, including composition, grain size and lithification observed. Bioclastic and volcaniclastic turbidites as well as thick tephra layers can be discerned from background sedimentation (carbonate ooze) by most of the physical proprieties. In total, at least 12 turbiditic units, including 3 very thick ones, can be identified from the continuous physical property logs. The hemipelagic muds overall show little variations and have a low magnetic susceptibility, low P-wave velocity and relatively high natural gamma radiation. In contrast, the physical properties of the turbidites are relatively heterogeneous, with overall high values of magnetic susceptibility and P-wave velocity but low natural gamma radiation and density. Single bioclastic and volcaniclastic turbiditic units throughout the entire holes can be traced by there monotonically up-hole decreasing values in magnetic susceptibility, P-wave velocity, and density, mimicking basically their grading in grain size. A sharp drop in each of these values occurs at the boundaries of the turbiditic units. Where sufficiently thick, ash layers give positive peaks in magnetic susceptibility. Between 10 and 15 mbsf the magnetic susceptibility, density, and natural gamma radiation data systematically differs from the "A" to the "B" hole. This is consistent with the differences in the lithologies retrieved from both holes. Hole U1394A is dominated by dark, dense turbidites with andesitic composition at this interval, whereas lighter-colored pumice-rich deposits were cored in Hole U1394B. The thermal conductivity data obtained at this site range from 0.564 W/mK (at 111.2 m) to 1.07 W/mK (at 197.4 m); the mean is 0.94 W/mK. These values are similar to expected values for high porosity sediments. Measured porosity of hemipelagic samples ranges from 48 to 66%. Turbidites display porosity values between 42 and 60%. For hemipelagic samples, there is a poorly constrained trend with depth ranging from about 61% at the mud line to about 54% at 200 mbsf. Bulk density of the hemipelagic sediments ranges from 1.52 to 1.85 g/cm^3, whereas bulk density in the turbiditic sediments ranges from 1.65 to 2.08 g/cm^3. Generally, the turbidites display a good, negative linear correlation between porosity and bulk density with depth; no similar correlation is found for hemipelagic sediments. Grain density values of the hemipelagic sediments exhibit a narrow range between 2.63 and 2.79 g/cm^3, whereas the grain density values obtained from the turbidite samples show a slightly larger range between 2.6 and 2.9 g/cm^3. Turbidites consisting of a mixture of bioclastic and volcaniclastic material have grain densities $\leq$ 2.79 g/cm^3.

The in situ measurements of physical properties obtained by the downhole logging operations are in general agreement with the physical property data obtained from the cores. The natural gamma radiation data do not exhibit a clear downhole trend over the measured interval, but generally the fine scale variations in total gamma ray have a higher frequency above 110 mbsf than below this depth. This change appears to be coinciding with a change from stacked turbidites into a series of alternating turbidites and hemipelagic sediments. The sonic velocities generally increase downhole ranging from ~1650 to 1900 m/s. There are distinctive local peaks in compressional velocity (Vp) that coincide with increased resistivity and magnetic susceptibility, corresponding most likely to similar scaled turbiditic units identified in the cores.

In addition to the studies done on the retrieved sediments pore water samples obtained from the hemipelagic sediments have also been analyzed. Pore water samples from the turbiditic units have not been obtained, since it is not possible to collect meaningful pore water data from such permeable material. Pore water samples were largely taken from intervals dominated by pelagic carbonate. Alkalinity values increased from 3.3 mM in the uppermost section to a consistent value of 11.5 mM at roughly the middle of the hole, before decreasing to 7.5 mM at the base of the hole. The pH values remained relatively constant at 7.4 to 7.5 throughout the hole. Of the major cations, calcium decreases from values close to bottom water in the uppermost sample to a minimum at roughly the middle of the hole before increasing towards the bottom, whereas magnesium shows a monotonic decrease in concentration with depth, apart from the deepest sample. Neither sodium nor potassium concentrations show clear trends with depth. Sulfate concentrations show a similar pattern to those of calcium. Chloride concentrations fluctuate within the normal range (540-580 mM) expected for pore waters obtained from squeezing carbonate sediments. Overall, the pore water data are consistent with diagenesis of carbonate-rich sediments with organic carbon concentrations that are typical of an open marine setting. The slight change in pore water concentrations in the deepest sediments reflect non-steady state diagenetic conditions that may be due to water advecting through the relatively permeable volcanic-rich turbidite that lies at the base of the hole.

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