IODP Expedition 340: Lesser Antilles Volcanism and Landslides

Site U1395 Summary

Background and Objectives

Integrated Ocean Drilling Program (IODP) Site U1395 (CARI-04D, 16°29.60'N; 61°57.09'W, 1191 m below seafloor [mbsl]) is located between Guadeloupe and Montserrat.

According to the site survey data Site U1395 is located just outside, next to the front, of deposit 2. The sedimentary reflectors shown in the seismic data retrieved during the pre-site survey indicated that Site U1395 might penetrate through a succession of hemi-pelagic sediments and turbidites. The proposed total depth on this site is 244 mbsf.

The objective of Site U1395 is to characterize the sedimentation processes related to volcanic activity in the Boullante–Montserrat half graben. It is planned to drill through hemi-pelagic sediments, turbidites, and tephra retrieving a complete record of sediment down to a depth of ~244 m. Work around the Canary Islands has shown that distal volcaniclastic turbidites generated by collapse events can be used to study the gross character of the initial landslide emplacement (Wynn and Masson, 2003). Results from the ODP Hole 1223A around Hawaii identified the association of several turbiditic deposits associated with landslides, showing that the Koolau Volcano collapsed repeatedly as well as that landslides constituted a greater risk than previously assessed (Garcia et al., 2006). Analysis of cores taken during JCR123 suggested that distal turbidites provide a record of all the main pyroclastic flow events from the on-going eruption that entered the ocean, recording also the waxing and waning phases of individual dome collapses (Trofimovs et al., 2006). Turbidites in these distal cores should therefore provide a record of dome and flank-collapses. With the retrieved material it will be also possible to better constrain the long-term sedimentation rate in the north part of the arc.

Scientific Results

Site U1395 (CARI-04D) consisted of 2 holes. The original plan called for 2 holes to a depth of ~244 mbsf. Because the coring was challenging and slightly lengthier than originally anticipated, the first hole was shortened to 231.3 mbsf. The second hole was shortened up to 203.3 mbsf because of time constraints. Hole U1395B was successfully logged with both the FMS-sonic and triple combo logging strings. A total of 53 cores were recovered at this site with an average recovery rate for of 62% for Hole U1395A and 69% for Hole U1395B, retrieving a total of 284 m of material.

The main lithologies cored at this site resemble those cored at Site U1394. Based on abrupt or gradational changes in the abundance of these lithologies or on distinct marker horizons (e.g. tephra layers) the material was divided into nine lithostratigraphic units (Unit A to I). Generally, each unit consists of various combinations of hemipelagic muds, turbiditic sands and muds, and tephra. Unit A is about 10 m (Hole U1395A) and 12 m (Hole U1395B) in thickness and is similar to the Unit A described at Site U1394. It consists of volcaniclastic and mixed bioclastic/volcaniclastic turbidites interbedded in a mainly hemipelagic background sediment. Unit A is subdivided into seven subunits (A-1 to A-7). Unit B is about 2 m (Hole U1395A) and 4 m (Hole U1395B) in thickness, and consists of a sequence of thick, stacked volcaniclastic turbidites, showing normal grading from very coarse to very fine sand. The matrix of these turbidites is mainly composed of dense to vesicular lava fragments, pyroxenes, amphiboles and feldspars with a very low to none carbonate fraction. Occasionally, larger pumice clasts (up to 2 cm large) are present in this unit. Unit C consists of a 65 cm thick layer of hemipelagic sediment. Unit D, being about 3 m (Hole U1395A) and 2 m (Hole U1395B) in thickness, is composed of another sequence of thick, stacked volcaniclastic turbidites similar in appearance as the turbidites in Unit B. However, in Hole U1395B the turbidites of Unit D show a much higher content in large pumice (1 to 4 cm in diameter) particles being dispersed throughout the entire matrix of the turbidites. Unit D is followed by a thick sequence (45 m in Hole U1395A; 43 m in Hole U1395B) of mainly hemipelagic sediments, defined as Unit E. Intercalated throughout this sequence are a small number of relatively thin, sandy turbidites, consisting of volcaniclastic, bioclastic or mixed bioclastic/volcaniclastic particles. Additionally, several volcanic fine sand layers are identified in this unit as well as some pumice deposits being partly well sorted. Unit F is about 19 m thick and is again composed of thick, stacked turbiditic sequences interrupted by hemipelagic sediment. Unit F is subdivided into three subunits (F-1 to F-3). The upper part of Unit F is composed of a thick, dark, homogenous turbidite consisting of mixed bioclastic-volcaniclastic material. The majority of this turbidite is ungraded, with normal grading occurring only in the uppermost part. Followed by a layer of hemipelagic sediments with intercalated layers of sand sized bioclastic and volcaniclastic particles. These layers are massive to normally graded, changing from very fine to medium sand. The lower part of Unit F consists again of a thick volcaniclastic turbidite sequence. Unit G (~21 m thick) is subdivided into two subunits (G-1 and G-2) and consists in the upper parts dominantly of hemipelagic sediments. Interbedded in this background sediment are numerous layers of sand sized volcanic material consisting of lava fragments, scoria, plagioclase, pyroxene and rarely amphibole. The amphibole appears only in a few layers (without clinopyroxene), and is characteristic for tephra deposits originating from the volcanoes in the central part of Guadeloupe. Tephras are particularly abundant at a depth of between 90 and 100 m (Core 12H for both holes). In Hole U1395B, a succession of volcaniclastic turbidites occurs also in the upper parts of this unit. The lower part of Unit G is

characterized by highly contorted and deformed hemipelagic sediment. Unit H, being about 8 m in thickness, is composed of a thick sequence of pumice-rich, turbiditic deposits, showing normal grading, with a matrix being dominantly composed of crystals, lava clasts, and minor pumice and carbonates. Unit I (located at 120 mbsf to base of both holes) represents the top of a succession of indurated muddy to silty hemipelagic sediments. These sediments are semi-consolidated silt- and mudstones. Most of them are heavily bioturbated.

XRD and carbonate analysis performed on 44 individual samples taken throughout the entire cored interval showed similar results as the samples analyzed on the last site. Samples of the pelagic sediments are characterized by calcite, high-Mg calcite, plus or minus aragonite, and minor volcanic phases, such as plagioclase, orthopyroxene and hornblende. The clay minerals that have been detected are kaolinite, smectite and glauconite. Samples from the volcanic-rich horizons contain dominantly plagioclase and lesser amounts of orthopyroxene and hornblende, and minor carbonate.

The $CaCO_3$ content is again much higher in the largely pelagic sections in the upper part of the hole (average approximately 60 wt%) than in the largely volcanic turbidites, but the presence of 3.5 to 7.5 wt% $CaCO_3$ in the latter indicates a significant biogenic component. The $CaCO_3$ content is highest (up to 88 wt%) in the semi-lithified sediments towards the base of the hole. 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 turbidite sections (<0.2 wt%). The organic carbon concentrations also increase towards the base of the hole (up to 1.5 wt%). The ratio of organic carbon to $CaCO_3$, however, remains relatively constant in the hemipelagic intervals throughout the hole, suggesting that the concentrations increases simply reflect less dilution by volcanic material at depth.

The biostratigraphic studies of the cored material have been again challenging due to the coarse nature of the material. Core catcher samples at Site U1395 contain calcareous nannofossils and planktic and benthic foraminifera of varying abundances and at varying levels of preservation. Generally, preservation deteriorates with depth, making the samples increasingly difficult to date. Both nannofossil and planktic foraminifera biostratigraphic datums for this site indicate deposition ages ranging from Late Pleistocene to Early Pleistocene. The nannofossils identified in the upper parts at this site are *Geophyrocapsa oceanica*, *Rhabdosphaera claviger*, *Gephyrocapsa muellerae*, *Helicosphaera kampnteri*, and *Helicosphaera hyaline*. *Pseudoemiliania lacunosa* was not found in the upper core at this site, dating the sample to less than 0.289 Ma. In the middle part *Pseudoemiliania lacunosa*, *Ceratolithus cristatus*, *Helicosphaera hyalina*, *Calcidiscus leptoporus*, *Rhabdosphaera claviger*, *Calciosolenia murrayi*, *Syracosphaera pulchra,* and *Scyphosphaera sp*. have been detected. Samples obtained from the deeper parts of this hole show a nannofossil assemblage typical for the Early Pleistocene, with

Gephyrocapsa caribbeanica, *Pseudoemiliania lacunosa*, *Crenalithus leptoporus*, and *Crenalithus doronicoides*. The latter was detected from Sample U1395A-12H-CC, which also showed the disappearance of *Geophyrocapsa oceanica*, indicating that these sediments are within the nannofossil zone CN13b. The assemblage of planktic foraminifera observed in the cored material is generally characteristic for sub-tropical waters and is dominated by *Globigerinoides ruber* (white) and *Globigerinoides sacculifer*. Other abundant species include *Globigerina falconensis*, *Globigerinita glutinata*, *Globigerinoides elongatus*, *Globorotalia tumida*, and *Neogloboquadrina dutertrei* (dextral). Three primary bio-zones were recorded, PT1b, PT1a, and PL6, PL6 at the bottom sample of this site. The primary marker between PT1a and PL6 was not recorded, however, zone PL6 was recognized based on the presence of *Globorotalia exilis* (top of occurrence at 2.1 Ma) instead, a secondary datum within PL6. Several additional secondary datums were recorded as well, *Globorotalia flexuosa* (0.07-0.40 Ma), *Globigerinella calida* (base of occurrence at 0.22 Ma), *Globorotalia tosaensis* (top of occurrence at 0.61 Ma). The presence of the benthic foraminiferal species *Osangularia*, *Uvigerina auberiana* and *Bulimina aculeata* suggests a bathyal paleodepth for this site. In addition to the micro- and nannofossils obtained at this site sponge spicules, pteropods and heteropods are also abundant and generally well preserved in the upper samples. Otoliths are present throughout the core samples and four different morphotypes are present. Ostracods are rare to absent in most samples.

Results of the study of the natural remanent magnetization (NRM) of the recovered cores are mainly based on the sampled hemipelagic sediments, because these are the least disturbed ones and most likely ones to hold information about the position of the geomagnetic field during deposition. The FLEXIT orientation tool was deployed in Hole U1395A with non-magnetic core barrels to retrieve the cores at this site, thus declination data could be corrected to true north for this site. Declination in Hole U1395B is rotated to a mean of zero and then the inclination data is used to plot reversal episodes at 180º to normal. Expected inclinations for the site are around 30.6° during normal polarity and -30.6° during reversed polarity assuming a Geocentric Axial Dipole (GAD). The inclination data obtained cluster and plot around the expected GAD for the site. With FLEXIT tool reorientation, both inclination and declination in Hole U1395A show the Brunhes/Matuyama (B/M) boundary at about 66 mbsf. A turbidite masks the B/M transition in Hole U1395B, with depths of 71.9 mbsf (reversed polarity) and 67.7 mbsf (normal polarity) either side of this unit. Based on inclinations obtained from the measurement of discrete samples in conjunction with the declination data obtained from the entire cores the transition from the Jaramillo (normal) into the Matuyama (reversed) seems to occur at a depth of about 90 mbsf. Using the reversal timescale of Cande and Kent (1995) this gives an age of 0.78 Ma for the B/M and 0.99 Ma for the end of the Jaramillo. Excellent agreement between discrete samples in both holes between 70 – 100 mbsf gives further confidence in the definition of the end of the Jaramillo at ~ 90 m in

both holes. Sedimentation rates for the site are therefore on the order of 8 cm kyr^{-1} during the Brunhes with slightly higher rates at the end of the Matuyama chron (around 11 cm kyr^{-1}). A sequence of unconsolidated tephras and turbidites severely faulted and altered sediments and poor recovery below 100 mbsf at this site makes further interpretation of polarity difficult. The deepest four discrete inclination samples indicate a polarity change indicative of the beginning of the Jaramillo normal (1.070 Ma) around 101 mbsf (Hole U1395A) and 116 mbsf (Hole U1395B).

Similar to Site U1394 the physical properties of the material retrieved at Site U1395 can be correlated to the lithological variations observed in the recovered material. This includes compositional variations as well as differences in grain size and lithification stage. Lithification seems to be linked to the carbonate content of the sediments. Carbonate is generally absent in the loose sediments that constitute turbidites. Based on magnetic susceptibility (MS) data it is possible to clearly identify the volcanic material retrieved in the cores. Volcaniclastic layers and turbidites exhibit pronounced positive anomalies up to $2800x10^{-5}$, ash layers show the same behavior but the magnitude of the signal is generally smaller, with typical values of $700x10^{-5}$ to $1500x10^{-5}$. The hemipelagic sediments as well as the bioclastic turbidites have generally low and relatively constant MS ($<350x10^{-5}$ and <700 $x10^{-5}$, respectively). Variations in the Natural Gamma Radiation (NGR) are usually antithetic to the magnetic susceptibility signature. NGR is generally low in the retrieved volcaniclastic material (about 3 counts/second) and relatively high in the hemipelagic sediments (about 10counts/second). Bulk densities vary in throughout the cored material with high values (up to 2.0 g/cm^3) in turbidites that contain dense volcanic clasts, but relatively low values for bioclastic turbidites. The lowest bulk density values are observed for the turbidite units containing coarse pumice clasts. Porosity ranges from about 48 to 67% displaying a weak negative trend with depth. Bulk Density shows a clear negative correlation with porosity. Grain density of the hemi pelagic samples has a narrow range between 2.65 and 2.8 g/cm^3. Grain density of the pumice-rich turbidite is lower, ranging between 2.45 and 2.55 g/cm^3. The P-wave velocities obtained throughout the entire cores show a well-defined trend, increasing from 1530 m/s to 1630 m/s downhole. This trend corresponds to carbonate-rich, hemipelagic sediments, probably reflecting increasing degrees of lithification and/or compaction of the material going downhole. Generally, volcaniclastic turbidites have higher velocities (1750-1800 m/s) than hemipelagic sediments (1500-1600 m/s). P-wave velocities obtained from discrete samples of the split core generally agree with the velocities obtained on the whole core.

The in situ measurements of physical properties obtained by the downhole logging operations resulted in the differentiation of three different downhole logging units termed Unit 1, 2 and 3. Unit 1, ranging from 85 to 112 mbsf, is characterized by relatively consistent downhole profiles in density, resistivity, and P-wave velocity, all of which

exhibit a low-amplitude variability. P-wave velocities show a slight increase with depth from about 1550 m/s at the top to about 1620 m/s at the base of the unit. Unit 2 (further subdivided into Unit 2A and 2B) is generally distinguished from Unit 1 by a sharp decrease in gamma ray and increases in density and resistivity, as well as a broad change in the character of the logging profile. Gamma ray, density, resistivity and P-wave velocity all show high amplitude variations. The drop in the gamma ray intensity associated with an increase in density and resistivity might be an indication for turbidites in this interval. Unit 3 (163-202 mbsf) is characterized by a return to lower frequency variations in all physical property measurements, similar to what is displayed in Unit 1. P-wave velocities show a subtle increase with depth, with the average value being higher in this lower unit than in the upper one, this is most likely consistent with a classical compaction trend.

In addition to the studies down on the retrieved sediments headspace gas samples as well as 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. In addition, the sediment close to base of the hole was semi-lithified, which also precluded pore water extraction. Alkalinity values increased from 3.5 meq in the uppermost two sections to a maximum value of 11.5 meq at 52.9 mbsf, before decreasing to relatively constant values of 5.4 meq from 72.7 mbsf to the deepest sample at 195 mbsf. The pH values are more variable (8.0 to 7.1) than observed in Hole U1394B, but no consistent pattern is observable in the data, suggesting that there may be some analytical artifacts in the data. Ammonia concentrations increased from 30 μM in the uppermost sample to 1200 μM at 72.7 mbsf and only increase gradually to a value of 1330 μM at 185 mbsf. These values are lower than observed in Hole U1394B and are consistent with the greater water depth of Site U1395 that results in greater oxidation of the organic matter before it reaches the seafloor. Calcium concentrations are only slightly lower than bottom water values in samples from the upper 106 m of the hole, but show an excursion to higher values between 117.4 mbsf and 185.6 mbsf, before decreasing to close to seawater values in the deepest sample (195 mbsf). In contrast, magnesium concentrations show a distinct decrease at the same depth interval. This simultaneous increase in calcium and decrease in magnesium is typical for pore waters influenced by water-rock interaction processes with basaltic glass. Hence, it is possible that the co-variation in the calcium and magnesium concentrations in the deeper section of Hole U1395B may reflect a higher basaltic component in the volcanogenic material at this horizon. Sodium concentrations do not show a clear trend with depth, but potassium concentrations show a marked decrease with depth that is consistent with reaction of pore waters with volcanic material. Sulfate concentrations are slightly depleted relative to seawater and show no consistent trend with depth. Chloride concentrations fluctuate within the normal range (550-570 mM) expected for pore waters obtained from squeezing carbonate sediments.

References

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