IODP Expedition 340: Lesser Antilles Volcanism and Landslides
Site U1397 Summary

Background and Objectives

Integrated Ocean Drilling Program (IODP) Site U1397 (CARI-10B, 14°54.41'N; 61°25.35'W, 2482 m below sea level [mbsl]) is located west of Martinique.

The bathymetric survey for site U1397 revealed a region with a topographic high bound by large canyons. The site survey seismic data indicate that this site might in the upper part penetrate regular (non-perturbed) sedimentary reflectors, whereas in the lower part some chaotic reflectors are visible. The proposed drill site is located directly on the topographic high to try to avoid perturbations (e.g., related to turbidity currents). Site U1397 has been chosen very close to core CAR-MAR4 (7 m long) taken during the *Caraval* cruise in 2002. The CAR-MAR4 core provides a sedimentary record that extends back ~32 ka, as determined by ^{18}O chronostratigraphy. The sedimentation rate (including tephra) is ~20 cm/k.y. (Boudon et al., submitted). Correlating the tephra sampled in the core to on shore deposits of the Montagne Pelée volcano on Martinique shows that a significantly greater number of tephra is deposited in the marine environment than has been identified during onshore studies (e.g., 25 tephra layers were identified in the core between 5 and 15 ka, whereas only 10 magmatic events were previously recognized based on on-shore studies). However, with conventional coring it is only possible to sample the recent activity of this volcanic island.

The objective of Site U1397 is to characterize the eruptive history of Martinique as well as the chaotic units appearing in the seismic profiles of this site. The cores to be retrieved will significantly improve our understanding of the eruptive history of Martinique in space and time, as we will sample material reaching more than 1 Ma back (assuming a sedimentation rate of 20 cm/k.y. and a total target depth of 314 mbsf). We expect to identify and date layers related to the emplacement of debris avalanches from Montagne Pelée and Pitons du Carbet volcanoes as well as to sample the region related to the transition of volcanism from the Pitons du Carbet and Mont Conil volcanoes to the

Montagne Pelée. The end of their volcanic activity (~0.3-0.5 Ma) precedes the beginning of the Montagne Pelée activity. We also want to test the hypothesis that more mafic and denser magmas are erupted for a several thousand year interval following edifice collapse until a new lave cone reaches a sufficient volume to erupt more evolved lavas (Pinel & Jaupart, 2000; Boudon et al., 2007). This site may also contain tephra from volcanoes of Dominica, which will be distinguished on the basis of their geochemistry and micro-textural characteristics (Machault, 2008). Volcanism on Dominica is dominated by andesitic to dacitic eruption products since the Pleistocene (Lindsay et al., 2005).

Scientific Results

Site U1397 (CARI-10B) consisted of two holes. The original plan called for two holes to be cored to ~314 mbsf. The first hole, Hole U1397A, was successfully cored but was terminated at 265.5 mbsf. The second hole, Hole U1397B, was cored to 253.5 mbsf. Logging plans originally included a vertical seismic profile experiment, but this was canceled when the diameter of the hole proved too large to use the VSI tool. A total of 66 cores were retrieved on this site and two short intervals had to be drilled without coring. Thirty-five APC cores penetrated 225.7 m and recovered 226.17 m (100%). Thirty-one XCB cores penetrated 284.1 m and recovered 49.49 m (17%). The overall percentage recovery for Site U1397 was 54.1%. Hole U1397B was successfully logged with both the FMS-sonic and triple combo logging strings. Total time spent on Site U1397 was 127.0 hours.

A continuous stratigraphic record was only retrieved for the upper 120 m at this site due to the generally poor XCB recovery below this depth. The sediments retrieved at this site have been divided into 8 lithostratigraphic units (Units A to H). Similar to the other sites each unit consists of various combinations of hemipelagic muds, volcaniclastic or mixed (volcaniclastic-bioclastic) turbidites, and various tephra layers. Generally, the unit boundaries as well as the material cored are similar in both holes, except that a larger proportion of turbidites and a lower proportion of tephra is observed in some units of Hole U1397B compared to Hole U1397A. It is likely that most of the missing tephras were eroded during the emplacement of the turbidites. The boundaries for each of the

lithostratigraphic units are defined by abrupt or gradational changes in the abundance of lithologies, by distinctive marker horizons, by different mineralogical compositions of tephra, and/or unusually thick turbidites. Unit A (0 to 28 mbsf) is composed of a thick sequence of hemipelagic sediment with interbedded tephra and volcaniclastic layers. The tephra layers (at least 200) are well sorted and either massive or normally graded. The few turbidites observed in this unit are poorly sorted. Unit B (28 to 53 mbsf) is composed of tephra layers and volcaniclastic turbidites intercalated in a hemipelagic mud. The proportion of turbidites is higher than in Unit A. The turbidites are normally graded and contain variable amounts of fresh pumice. The matrix of the turbidites is mainly composed of crystals, and very low proportions of carbonates and lava clasts. Most of the tephra layers are dark and fine-grained, and frequently normally graded. Unit C (23 m thick) is divided into two subunits (Unit C1 and C2). Subunit C1 is dominated by thick turbidite sequences of mixed (bioclastic-volcaniclastic) composition. Crystals, massive lava fragments and pumice particles (sometimes in higher proportions) comprise the volcanic component of these turbidites. The proportion of hemipelagic mud is very low between turbidites, and intervening hemipelagic mud is frequently absent. Subunit C2 (< 3 m thick) comprises a debris flow deposit and a section of deformed sediment. The debris flow deposit consists of very abundant, deformed mud clasts and large fragments of hydrothermally altered and fresh andesitic lava. Unit D (15 m thick) is composed of a series of volcaniclastic turbidites and few tephra layers, which are interbedded in a hemipelagic mud. The proportion of hemipelagic sediment is very low in this unit attesting to the erosional character of the turbidites. Unit E (~29 m thick) is composed of a series of thick massive to normally graded volcaniclastic turbidites containing a large amount of massive to poorly vesiculated lava fragments. The base of this unit is not observed and below this unit the stratigraphy is more uncertain as core recovery was very low. Unit F (~17 m thick) can be divided in two subunits on the basis of the compaction of the sediments. Subunit F1 is composed of a package of hemipelagic muds with a few interbedded tephra layers, whereas Subunit F2 is composed of the same sequence of sediment, being weakly compacted at the top showing progressive lithification into mudstones towards the base. Unit G (60 to 70 m thick) is composed of mud-rich sandstone layers and semi-consolidated, highly fractured, and contorted mudstones. It

contains abundant lava clasts, few pebbles and a larger block being composed of andesitic lava containing large phenocrysts of amphibole and quartz. Similar lavas are generated by the Piton du Carbet volcano, south of Montagne Pelée, and are unique to the area of Martinique and Dominica. The period of activity that generated this type of magma is dated to be around 330 ka to 350 ka (Germa et al., 2011, Samper et al., 2008). Unit H (230-265m) is only represented in Hole U1397A since Hole U1397B was terminated at 230 mbsf. Unit H consists of heavily bioturbated hemipelagic mud. A few layers of bioclastic sandstone are interbedded within the mudstone.

Forty-four samples were taken to characterize the mineralogy of the volcanic material cored and the carbonate content. The volcanic material retrieved contains mainly plagioclase, hornblende, quartz and amphibole. The hornblende appears to be more alkali-rich than observed in samples from around Montserrat. Clay minerals are ubiquitous throughout the hole and are also more abundant than in samples from the Montserrat sites. The dominant clay minerals are smectites, kaolinite, and glauconite. At the base of Hole U1397A, the abundance of clay minerals (mainly smectite) is especially high, and dolomite is also present in significant quantities, possibly reflecting the presence of hydrothermal alteration products. $CaCO_3$ concentrations are lower than in the sites around Montserrat, and the main carbonate minerals identified are calcite with minor aragonite. This likely reflects the greater water depth at this location and the absence of any significant aragonite preservation. With the exception of the uppermost sample from 4.1 mbsf, that yielded an organic carbon concentration of 0.62 wt.%, all the other samples yielded values of less than 0.5 wt.% and most lacked any measureable organic carbon concentrations.

The results of the detailed study of the nanno- and microfossil content of the sediments described above are consistent with their intensely reworked nature, because many of the studied samples contained poorly preserved shallow water reef benthic foraminifera and coral fragments. Generally the sediments contained only low abundances of calcareous nannofossils and planktic and benthic foraminifera with varying levels of preservation. Where obtainable, biostratigraphic dates are generally not sequential, however, an overall

a trend to older material with depth is observed. Biostratigraphic datums derived from both calcareous nannofossils and planktic foraminifera show that Site U1397 contains many levels of reworked sediment from the Late Miocene to Late Pliocene amidst a background of Late Pleistocene sedimentation. Overall only a few datum species could be used as an age constraint for the cored material. These were the planktic foraminifera *Globigerinella calida* and *Globorotalia flexuosa* and the nannofossil *Emiliania huxleyi*. The resulting age model resolves an age younger than 220 ka for the top ~25 mbsf, younger than 250 ka from ~50 to ~100 mbsf, younger than ~350 ka from 100 mbsf to nearly the base, and about 400 ka at the bottom of this site. It should be noted that these ages are only a maximum age estimate, and that any constraint on the youngest material is inappropriate given the prolific reworking of sediments.

Generally, the retrieval of a magnetostratigraphic record for this site was as complicated as the retrieval of the biostratigraphic record due to the nature of the cored material and the recovery. Using the detailed core description logs, only data measured on identifiable hemipelagic sediment layers were used for interpretation. The FlexIt orientation tool was used on cores U1397A-1H through -9H together with non-magnetic core barrels, thus between 0–67 mbsf in Hole U1397A declination could be corrected to true north. Expected inclination for the site is 28.2° during normal polarity and -28.2° during reversed polarity assuming a Geocentric Axial Dipole (GAD). The occurrence of hemipelagic sediment is highly discontinuous at Site U1397, particularly below ~55 mbsf. Shallower than ~55 mbsf inclination data obtained on discrete samples show scattered but positive inclination, clustering around the expected GAD inclination. Declination shows little variation suggesting that all sediment and tephra down to a depth of ~55 mbsf was deposited in the Brunhes Chron (<780 ka). Below this depth the record becomes increasingly discontinuous making confident interpretation of ages based solely on paleomagnetic data difficult.

The physical properties of the material retrieved at Site U1397 can generally be correlated to the lithological variations observed throughout the cored material. Bioclastic and volcaniclastic turbidites as well as thick tephra layers can be distinguished from

background sedimentation (hemipelagic mud) by most of the physical proprieties. The magnetic susceptibility data show large variations, with maximum values (6880 x 10^5) being more than twice as high as obtained from the measurements at the other sites. Peaks in the magnetic susceptibility values correlate with tephra layers and volcaniclastic turbidites. Measured bulk densities increase slightly with increasing depth, whereas the natural gamma radiation data show no consistent trend. P-Wave velocities also increase slightly with depth (~1500 to ~1600 m/s, on average). Generally, within thick turbidite deposits, P-wave velocity, density, and magnetic susceptibility typically increase with increasing depth. All three physical properties have a sharp boundary at depths that correspond to the base of the turbidites. The shear strength of the sampled sediments increases with depth (1 kPa/m) for the upper ~55 mbsf at Site U1397. No shear strength measurements could be performed in the interval between ~55 to 65 mbsf, because of the coarse nature of the retrieved sediments (mainly sands). Between 65 and 80 mbsf shear strength increases up to 200 kPa and decrease from 80 to 95 mbsf. The interval between 95 mbsf and 150 mbsf was again not favorable for the performance of shear strength measurements. The last interval from which shear strength measurements were obtained is between 150 and 180 mbsf. Shear strength is quite variable in this interval with values ranging from <50 kPa to >450 kPa, reflecting the variable nature of the sampled sediments. Porosity data show, as was observed for Site U1396, no consistent trend with depth. Porosity ranges from about 40 to 68%. Bulk Density ranges from 1.55 to 2.40 g/cm^3 and shows clear linear, negative correlation with porosity. The dark-colored volcaniclastic turbidites have systematically higher bulk densities (1.75 to 2.40 g/cm^3) than the other retrieved sediments. Grain density ranges between 2.48 and 3.17 g/cm^3, with hemipelagic sediments showing grain densities between 2.6 and 2.85 g/cm^3. To obtain a geothermal gradient for this site formation temperature was measured by APCT-3 at the bottom of Cores U1397A-5H, -6H and -7H (36.5, 46.0, and 55.5 mbsf, respectively) and the bottom of Cores U1397B-3H, -4H and -7H (25.6, 35.1, and 61.3 mbsf, respectively). Downhole temperature was monitored for 652 s, 626 s, 671 s, 647 s, 685 s, and 647 s, respectively. A best-fit linear relationship between depth and the six temperature measurements gives a temperature gradient of 70.0±8.8ºC/km. Using the thermal conductivity of 1.037±0.135 W/mK measured on the cored material, the implied

heat flow, if conductive, is 72.5±13.1 mW/m^2. This estimate has not been corrected for bathymetry (which may be a significant correction because the site is on a ridge) or sedimentation (possibly a large correction owing to high sedimentation rates). It has to be noted that the temperatures obtained from the downhole measurements show a considerable scatter upon the linear trend, which might be indicative of fluid flow.

The in situ measurements of physical properties obtained by the downhole logging operations on Hole U1397B have to be taken with caution, because of the large diameter of the borehole, which makes a reliable positioning of the tool string difficult and especially impact measurements such as the natural gamma radiation and the FMS images. Measurements of the electrical resistivity, the magnetic susceptibility and P-wave velocity are less effected and the general trends and relative changes displayed by those measurements should be reliable. Generally four different logging units have been identified based on specific characteristics observed across the physical properties measured. Unit 1 (85 to 90 mbsf) is characterized by relatively consistent values of resistivity and gamma ray and average values of P-wave velocity of ~1650 m/s. Magnetic susceptibility decreases with depth. Unit 2 (90 to 127 mbsf) is characterized by four intervals that each exhibits increasing resistivity and P-wave velocity with depth. The boundaries of these intervals are characterized by distinct changes in the magnetic susceptibility (local peaks superimposed on the general decreasing trend with depth). Unit 3 (127 to 185 mbsf) shows a return to less variable resistivity and P-wave velocity values. This unit has been divided into two subunits (Unit 3A and 3B) based on subtle changes in the character of the recorded physical properties, which are most distinctive in the magnetic susceptibility. The amplitude of variations of the magnetic susceptibility is much higher in Subunit 3A than in Subunit 3B. In addition P-wave velocity is slightly higher in Subunit 3B (mean ~1760 m/s) than in Subunit 3A (average ~1710 m/s). Unit 4 (185 to base of hole) is characterized by higher values of resistivity and magnetic susceptibility compared to Unit 3. P-wave velocity is also higher in this unit (average of ~1900 m/s) completing the downhole trend of increasing P-wave velocity.

Samples for headspace gas analyses were taken from 18 depths throughout Hole U1397A.

Samples from the upper 76 m tended to have slightly higher methane concentrations (3.1 to 4.4 ppm) than those from 94-266 mbsf (2.3 to 3.7 ppm). No higher hydrocarbons were detected. Pore water alkalinity values increase with depth in the upper part of the sediments at this site and reach a maximum of 5.1 meq between 23-46 mbsf, before decreasing to 3.9 meq in the deepest samples (164-182 mbsf). The pH values vary between 7.3-8.2, but no consistent pattern is observable in the data. The ammonia concentrations are lower than at comparable sites around Montserrat (Sites U1394 and U1395), which likely reflects the greater water depth of this site. The shape of the ammonia profile is similar to that of the alkalinity profile, suggesting that diagenetic processes in the sediment column dominate both. Calcium concentrations decrease from the seawater value to 9.3 mM at 23 mbsf and then increase to 11.5 mM in the deepest sample (182 mbsf). The magnesium concentrations (which scatter around values slightly higher than seawater) and potassium concentrations (which are higher in the upper 75 mbsf and show a weak trend to lower values between 164-182 mbsf) suggest that alteration of volcanic matter does not play a dominant role in defining the major element pore water concentrations. Sulphate concentrations decrease from the seawater value to 26 mM at 43 mbsf and then increase to near seawater concentrations in the deepest samples, again suggesting that organic carbon driven diagenesis is the major process in the upper part of the hole. Chloride concentrations are within the normal range (560-570 mM) expected for pore waters obtained from squeezing carbonate-rich sediments, and show a slight increase in the upper part at this site.

References

Boudon, G., Villemant, B., Le Friant, A., Paterne, N., Cortip, E. (submitted) Role of large flank collapse events on magma exsolution of volcanoes: insights from the Lesser Antilles Arc.

Boudon, G., Le Friant, A., Komorowski, J.-C., Deplus, C., Semet, M.P (2007) Volcano flank instability in the Lesser Antilles Arc: diversity of scale, processes, and temporal recurrence Journal of Geophysical Research, 112, B08205, doi:10.1029/2006JB004674.

Germa. A., Quidelleur, X., Lahitte, P., Labanieh, S., Chauvel, C. (2011) The K-Ar Cassignol-Gillot technique applied to western Martinique lavas: A record of Lesser Antilles arc activity from 2 Ma to Mount Pelée volcanism. Quaternary Geochronology 6: 341-355.

Lindsay, J.M., Smith, A.L., Roobol, M.J., Stasiuk, M.V. (2005) Dominica. In Volcanic Hazards Atlas of the Lesser Antilles. Seismic Research Unit, The University of the West Indies, Trinidad and Tobago, W.I.

Machault, J. (2008) Les éruptions ponceuses des volcans actifs de la Guadeloupe et de la Dominique (arc des Petites Antilles). Corrélation entre dépôts à terre et en mer, Unpublished Master's Thesis, Université d'Orsay, France, 1-29 pp.

Pinel, V., Jaupart, C. (2000) The effect of edifice load on magma ascent beneath a volcano. Philosophical Transactions of the Royal Society, London, A358: 1,515-1,532.

Samper, A., Quidelleur, X, Boudon, G., Le Friant, A., Komorowski, J.-C. (2008) Radiometric Dating of Large Volume Flank-collapses in the Lesser Antilles Arc. J. Volcanol. Geotherm. Res. doi:10.1016/j.jvolgeores.2008.04.018.