IODP Expedition 340: Lesser Antilles Volcanism and Landslides
Site U1399 Summary

Background and Objectives

Integrated Ocean Drilling Program (IODP) Site U1399 (CARI-08B, 14°23.24'N, 61°42.69'W, 2900 mbsl) is located west of Martinique. The objective of Site U1399 is to characterize the processes accompanying debris avalanche emplacement and associated erosion. The seismic and bathymetric survey for Site U1399 revealed that this site is located on one of the main chaotic deposits and that coring at this site will most likely retrieve volcanic and biogenic sediments with intercalated, large, chaotic debris avalanche deposits of the so called debris avalanche deposit 1. In detail, we hope to be able to characterize and quantify the erosional processes of the upper sedimentary layers deposited in the Grenada Basin associated with such debris avalanches and their subsequent incorporation into the flow. Finally, we are going to compare the characteristics of debris avalanches deposits from Dominica and Martinique to constrain possible differences in erosional capability and mobility. The sediments above the debris avalanche deposit 1 will be used to better constrain the age of the slide event.

Scientific Results

Site U1399 (CARI-08B) consisted of three holes. The original plan called for two holes to be cored to ~290 mbsf. The first hole was successfully cored and was terminated at 275 mbsf. The second hole was piston cored to 183 mbsf and abandoned when the hole became too unstable to continue coring operations. Thus the planned logging operations for this hole were abandoned too. Instead the decision was made to drill a dedicated logging hole to 240 mbsf – Hole U1399C. The logging program, including the triple combo, FMS-sonic and VSI tool strings, was completed as planned. A total of 393 m of core (101% recovery) was obtained with the APC coring system, whereas 9 m of core (14% recover) was obtained with the XCB coring system. The overall core recovery for Site U1399 is 89%. The total time spent on Site U1399 was 160.00 hours.

The sediments cored at Site U1399 are again dominated by a combination of hemipelagic mud with interbedded tephra and volcaniclastic turbidites as well as various types of deformed sedimentary intervals that occur at different depths. Eight lithostratigraphic units (Unit A to Unit H) have been defined based either on characteristic changes throughout the cored material or distinct marker layers. Unit A (0 to 24 mbsf in Hole U1399A; 0 to 12 mbsf in Hole U1399B) is mainly composed of hemipelagic mud with abundant interbedded tephra layers. In Hole U1399A, several small turbidites are also interbedded in the hemipelagic mud, whereas only one turbidite could be identified in

Hole U1399B. Most of the tephra and turbidite layers contain pumice in variable abundances (5% to 65%). Unit B (24 to 50 mbsf in Hole U1399A; 12 to 29 mbsf in Hole U1399B) is composed of a thick sequence of variably deformed hemipelagic sediment with several areas of inclined and convoluted banding. This unit also contains debris flow deposits (debrites) with a muddy-sand matrix. Dispersed lava clasts and deformed tephra layers are often found within the debrites. Unit C (50.5 to 72 mbsf in Hole U1399A; 29 to 53 mbsf in Hole U1399B) consists of hemipelagic mud with interbedded tephra layers and thin turbidites (less than 1 m thick). The base of Unit C is composed of a 1 m thick interval of hemipelagic mud overlain by a turbidite. This basal turbidite is 8.2 m thick in Hole U1399A and 2.1 m thick in Hole U1399B. In Unit D (72 to 76 mbsf in Hole U1399A; 53 to 68.5 mbsf in Hole U1399B) the upper part is composed of deformed sediment with inclined contacts between zones of different colored mud, whereas the lower part is composed of weakly deformed hemipelagic mud with inclined green laminae. Unit E (76 to 112 mbsf in Hole U1399A; 68.5 to 102.7 mbsf in Hole U1399B) consists of a succession of alternating layers of non-deformed hemipelagic mud with interbedded tephras and thin turbidites, deformed hemipelagic mud, debrites, and thick turbidites. Unit F (114 to 142.5 mbsf in Hole U1399A; 102.7 to 129 mbsf in Hole U1399B) is composed of a thick sequence of highly deformed and contorted sediment, including some turbidites and contorted tephra layers. Unit G (142.5 to 191.7 mbsf in Hole U1399A; 129 to 182.3 mbsf in Hole U1399B) is mainly composed of thick sequences of pumice-rich turbidites with interbedded hemipelagic mud containing a few tephra layers. The proportion of hemipelagic mud in this unit is low. Unit H (191.7 to 270 mbsf in Hole U1399A) is mainly composed of hemipelagic mud, with interbedded tephra layers and pumice-rich turbidites. The proportion of hemipelagic mud (70%) is higher than in preceding units, and tephra layers are frequently observed.

As shown by the carbonate analysis of 33 samples throughout the entire cored interval calcium carbonate concentrations are highly variable and are lower in intervals with higher proportions of volcanic material and presumably terrestrial clay. The maximum concentration is about 35%, which partly also reflects the absence of significant aragonite preservation.

The core catcher samples taken from Site U1399 for biostratigraphic studies contain calcareous nannofossils and planktic and benthic foraminifera of varying abundances and at varying levels of preservation. The calcareous nannofossil and planktic foraminifera datums obtained from the cored material indicate that the sediments sampled have been deposited during the Late Pleistocene, indicating an extremely high sedimentation rate for this site. Reworking of much older (Early Pleistocene and Late Pliocene) material is evident in several samples. Many of the core catcher samples at Site U1399 consisted of very coarse-grained material, containing numerous shallow water benthic foraminifera and fragments of shell and coral. Well preserved pteropod and heteropod shells, otoliths

and sponge spicules (Demospongiae) were also found in some of the hemipelagic samples. Observed nannofossil species are *Gephyrocapsa oceanica*, *Gephyrocapsa parallela*, *Helicosphaera hyalina, Emiliania huxleyi* as well as *Ceratolithus cristatus* and *Ceratolithus telesmus*. Encountered reworked specimens are *Pseudoemiliania lacunosa*, *Calcidiscus macintyrei*, *Sphenolithus neoabies/abies* and *Binatholithus sparsus*. The assemblage of observed planktic foraminifera was diverse, but dominated by *Globigerinoides ruber* (white and pink), *Globigerinoides sacculifer* and *Neogloboquadrina dutertrei* (dextral). Other abundant species include *Globorotalia truncatulinoides* and *Globorotalia tumida*. The assemblage does not change significantly throughout the site and all species present are indicative of warm sub-tropical waters. Several datum species were found, however, reliable datum species were generally not found in samples with low planktic foraminifera abundance. *Globorotalia flexuosa* (0.07-0.40 Ma) and *Globigerinella calida* (base of occurrence at 0.22 Ma) were only found in low numbers. The last occurrences of these datum species are not clearly defined and no reliable planktic foraminifera datum was found at the base of either holes. Reworked planktic foraminifera included *Globorotalia tosaensis* (top of occurrence 0.61 Ma), *Globorotalia exilis* (top of occurrence at 2.10 Ma), *Globorotalia miocenica* (top of occurrence at 2.39 Ma), *Dentoglobigerina altispira* (top of occurrences at 3.13 Ma), *Sphaeroidinellopsis seminulina* (top of occurrence at 3.16 Ma), and possibly *Globigerinoides mitra* (Early to Late Miocene).

Interpretation of the behavior of the geomagnetic field during the deposition of the cored sediments to derive at a magnetostratigraphy is solemnly based on the data from the non-chaotic intervals. This is roughly 20% of the paleomagnetic directional data obtained from Site U1399. Between 0 and 207.5 mbsf in Hole U1399A and all of Hole U1399B SRM and discrete inclination data show scattered but positive values, clustering around the expected Geocentric Axial Dipole (GAD) inclination. Expected inclination for the site is 27.2° during normal polarity and -27.2° during reversed polarity assuming a GAD. Declination shows some scatter but coupled with the positive inclination data suggests all sediments were deposited under normal polarity conditions. Using the geomagnetic polarity timescale of Cande and Kent (1995) these sediments were deposited in the Brunhes Chron and are younger than 780 ka.

Different from the previous sites, the magnetic susceptibility data obtained from the cored material at Site U1399 show not clear variation with the material recovered. Only two strong peaks correlating to thicker layers of coarse-grained volcaniclastic material have been observed throughout both holes. Bulk density data scatter around an average value of 1.7 g/cm^3 and generally increase with depth. Reduction of the bulk density data using a moving average, extending over 20 m, shows that significant difference in density exist between the two holes, consistent with difference in sedimentation rate. The analysis of the smoothed data implies large swings in density between the hemipelagic

and volcaniclastic zones. Bulk density obtained from the measurement of discrete hemipelagic samples ranges between 1.5 and 1.8 g/cm^3, displaying a weak positive correlation with depth. Sandy samples have bulk densities as high as 2.05 g/cm^3. As in all previous sites, porosity and bulk density display a clear negative correlation. Grain density varies between 2.65 and 2.8 g/cm^3. The volcanic sands have a similar grain density compared to the hemipelagic samples. Porosity obtained from the measurement of discrete hemipelagic samples ranges between 53% and 73%. In contrast to the previous sites, Site U1399 shows a weak negative porosity-depth correlation from ~70% at mud line to ~60% at 270 mbsf. Porosity in volcanic sand samples ranges between 40% and 50%. The porosity of the loose sands may be underestimated up to 20% due to draining of pore-water during coring, splitting and sampling. The natural gamma radiation data show the differences expected measuring hemipelagic sediment and volcanic material. Count rates in the hemipelagic material vary between 15 and 50 counts per second, whereas the count rates in the volcanic material are below 15 counts per second. P-wave velocities obtained from hemipelagic sediment shallower than 140 mbsf range from 1500 to 1550 m/s, whereas the volcaniclastic material shows velocity values between 1650 and 1800 m/s. Between the depth interval of 140 to 180 mbsf P-wave velocities increase gradually from 1550 and 1650 m/s to 1650 and 1900 m/s in the hemipelagic and volcaniclastic sediment, respectively. Shear strength of the studied material generally increases downhole in both holes. Downhole formation temperature was measured by APCT-3 at the bottom of Cores U1399A-3H, -4H, -5H, and -6H (24, 34, 43, and 53 mbsf, respectively) and the bottom of Cores U1399B-3, -6H, and -9H (25, 53, and 81 mbsf, respectively). The geothermal gradient calculated based on the obtained temperatures is 65.4±0.9°C/km. Using the thermal conductivity of 1.045±0.080 W/mK obtained from the cored material, the implied heat flow, if conductive, is 68.3±5.8 mW/m^2. This estimate probably needs to be corrected, based on the high sedimentation rate observed at this site. Despite a separation of 410 m between the two holes cored at this site, all temperature measurements lie on a single line. This suggests that fluid flow is not disturbing the temperature gradient.

The in situ measurements of physical properties obtained by the downhole logging operations on Hole U1399C are generally of good quality. Four different logging units have been identified based on specific characteristics observed across the physical properties measured, especially gamma ray, resistivity and magnetic susceptibility obtained by the tools in the triple combo tool string. Logging Unit 1 (80-106 mbsf) is characterized by an overall increase in gamma ray with depth from ~25 to ~50 gAPI. The magnetic susceptibility and electrical resistivity profiles are similar in character with a small net decrease with depth. At 106 mbsf, the transition from Unit 1 to Unit 2 (106-150 mbsf) is marked by a sharp decrease in gamma ray that coincides with sharp increases in resistivity and magnetic susceptibility. Similar to Unit 1, Logging Unit 2 shows a net increase with depth in gamma ray. Between 140 and 150 mbsf there is an

interval of increased gamma ray values, this is reflected in both the total gamma ray and spectral gamma ray measurements. Interestingly this increase is not shown in the corresponding NGR data from cores recovered in Hole U1399A. Resistivity generally decreases with depth through this logging unit with localized high resistivity features. This trend is repeated in the magnetic susceptibility curve. Logging Unit 3 (150-181 mbsf) is characterized by higher amplitude variability in gamma ray, resistivity and magnetic susceptibility. Similar to the transition between Logging Units 1 and 2, the transition from logging Unit 2 to Unit 3 is marked by a step-wise decrease in gamma ray and increases in resistivity and magnetic susceptibility. Generally lower values of gamma ray coincide with higher values of both resistivity and magnetic susceptibility. Logging Unit 4 (181 mbsf to total hole depth) is characterized by more regular gamma ray variations, of the order ~15 gAPI, continuing through the upper 25 m of this unit, after which variations decrease in amplitude. In addition this unit exhibits the most variable magnetic susceptibility profile in Hole U1399C, including some significant peaks, the largest of which (~205-208 mbsf) corresponds to similarly elevated values of resistivity. Check-shot travel times obtained by the seismic experiments range from 0.128 seconds two-way time at 87.8 mbsf to 0.279 seconds at the bottom of the hole (225.7 mbsf).

Twenty-eight samples for headspace analyses were taken throughout the hole. Methane concentrations were only a few ppm in all but the deepest sample. The deepest sample (276 mbsf in Hole U1399A) yielded a methane concentration of 690 ppm. This is slightly deeper than the zone of high methane concentrations observed at Site U1398. The major ion pore water profiles are characteristic of a deep-sea diagenetic sequence. Sulphate concentrations gradually decrease over the same interval over which alkalinity and ammonia shows steady increases. Calcium concentrations show a steady decrease with depth, reflecting precipitation of secondary carbonate. Magnesium concentrations also show a decrease with depth being most likely caused by alteration of volcanic material. The slight increase in chloride concentrations also reflects uptake of water into secondary mineral phases at depth. The shape of the pore water profiles suggests that the main oxidation of organic carbon takes place in the upper 60 m of the sediment column. Generally organic carbon concentrations decrease with depth. The upper 115 m of the interval cored contain several samples with organic carbon concentrations close to 1 wt.%, whereas the maximum concentration observed in the lower 155 m is about 0.7 wt.%. The change in organic carbon concentrations between the upper 115 m and the lower 155 m of the sediment column may reflect a change in the input of organic carbon to the system rather than changes in preservation. There is, however, a strong caveat to this hypothesis as the percentage of volcanic material can also vary with depth, and this may act to cause variable dilution of a constant input flux of organic carbon to the sediments.

References

Cande, S.C., and Kent, D.V. (1995) Revised calibration of the geomagnetic polarity timescale for the late Cretaceous and Cenozoic. Journal of Geophysical Research, 100: 6093-6095.