IODP Expedition 340: Lesser Antilles Volcanism and Landslides

Site U1396 Summary

Background and Objectives

Integrated Ocean Drilling Program (IODP) Site U1396 (CARI-01C, 16°30.49'N; 62°27.10'W, 801 m below sea level [mbsl]) is the northwestern most site drilled during the Lesser Antilles Volcanism and Landslides Expedition (340).

The bathymetric survey for Site U1396 revealed a region bounded by a topographic high to the north and by two large canyons to the south. The site survey seismic data indicate that this site might penetrate regular (non perturbed) sedimentary reflectors. The proposed drill site is located directly on the topographic high to minimize any perturbations (e.g., related to turbidites). Site U1396 is located in the same area as the 5.75 m-long CAR-MON 2 core taken during the *Caraval* cruise in 2002. The sediments recovered at CAR-MON 2 provide a stratigraphic record extending back ~250 ka, as shown by ^{18}O chronostratigraphy. The calculated sedimentation rate (including tephra) is ~2.3 cm/1000 years (Le Friant et al, 2008). The recovered core also contained material from several plinian explosive eruptions, which have up to now not been identified on-land (Le Friant et al., 2008).

The objective of Site U1396 is to characterize the eruptive history of Montserrat. Volcanism started on Montserrat ~2.6 Ma at Silver Hills, moved to Centre Hills between 0.5-1.0 Ma, with the youngest volcanism situated at south Soufrière Hills (~ 170 ka-present). With conventional coring it is only possible to retrieve samples of the recent volcanic activity. Drilling to a target depth of 132 mbsf (meters below seafloor) at Site U1396 is designed to extend our knowledge of the volcanic history of Montserrat back to the birth of the island at around 2.5 Ma. Petrologic, lithologic, sedimentologic, and geochronologic analysis of volcanic rocks and volcaniclastic material from this site is expected to date as far back as 4 Ma (assuming a sedimentation rate of 2.3 cm/ky from the CAR-MON2 study) and will provide significant new constraints on the early development of volcanism on Montserrat and on the spatial and temporal distribution of volcanic activity.

Scientific Results

Site U1396 (CARI-01C) consisted of 3 holes. The original plan called for 2 holes to ~132 mbsf. Hole U1396A was successfully cored to 134.9 mbsf. Hole U1396B was a shallower penetration hole designed to capture a poorly recovered interval in Hole U1396A. The second core from Hole U1396A was recovered with a shattered core liner; Hole U1396B reached to 15 mbsf. Hole U1396C was cored to 139.4 mbsf. Due to the shallow penetration, no downhole logging scheduled at this site. The APC coring system was deployed 31 times, penetrated 283.8 meters, and recovered 296.38 meters of core (104% recovery). A single 5 m interval was drilled without coring in Hole U1396B.

The deposits cored at Site U1396 mainly comprise a series of hemipelagic sediments, tephra layers, and volcaniclastic sand. Even though the nature of the cored material at this site makes a division into lithostratigraphic units more difficult, five different lithostratigraphic units (Unit A, B, C, D, and E) were identified. Unit A consists of a ~40 cm-thick sequence of bioclast-rich fine sand with a high water content. The sand is massive, ungraded and probably represents a high-density turbidite. Unit B (~121.5 m thick) comprises mainly a sequence of tephra layers (~ 35 layers of varying thickness, being more abundant below 90-95 mbsf) intercalated in the hemipelagic background sedimentation. The hemipelagic sediment dominates the middle part of this unit. However, there may be many more layers of crypto-tephras, which are not visible to the naked eye, embedded in the hemipelagic mud. The tephra layers are of varying thickness (mostly <5 cm, a few >10 cm) and generally normally graded. The upper and lower parts of this unit layers contain a poorly sorted, massive, medium-sand sized mixture of bioclastic and volcaniclastic particles, which is interpreted as turbiditic sequences. Isolated pebble-sized volcanic clasts are observed in the hemipelagic mud, at a few locations. Unit C is ~4 m thick and only is observed in Hole U1396C. Unit C consists of massive medium-coarse volcaniclastic sand that is mainly andesitic in composition (85%), with in a finer matrix consisting of mineral particles. Unit D (122.0 to 123.9 mbsf) comprises a distinctive sequence of unusually coarse (commonly up to cm-scale clasts), pinkish breccias. Unit D is composed of five fining-upward units with well-sorted intervals of pebble-sized clasts (up to 2 cm), with little or no sand or mud-sized matrix material. Massive layers of fine sand or silt (1 to 5 cm in thickness) separate these normally graded intervals. Unit E (~16 m thick) consists again of a series of mainly well-sorted tephra layers intercalated with the hemipelagic background sediment.

Thirty samples were taken to define the mineralogical composition and carbonate content of the cored material. Even though the number of tephra layers sampled at this site is high, no purely volcanic samples were obtained. In contrast to the previous sites, high Mg-calcite was only present in one section (Section U1396C-6H-2). All other carbonate-rich layers contain pure calcite and aragonite in variable proportions, with calcite generally dominating the assemblage. Clay minerals are ubiquitously present throughout this site, with smectite and kaolinite present in all samples and glauconite commonly identified. Halloysite may be present in some samples, but the spectra are not clear enough to be certain. A large bulge beneath the main peaks in some of the volcanic-rich samples suggests that significant amounts of volcanic glass are present in some of the tephra layers. The $CaCO_3$ and organic carbon abundances indicate that the retrieved sediments are largely mixtures of carbonate-rich hemipelagic sediments with carbonate- and organic carbon-free volcanogenic material delivered by volcanic fallouts. The highest observed $CaCO_3$ concentration is 72 wt.%, with most samples being much lower than this, suggesting that volcanic material is dispersed throughout the entire cores even though it is not necessarily visible to the naked eye.

Based on the detailed biostratigraphic studies done on Site U1396, using calcareous nannofossil as well as planktic foraminifera datums, the cored material could be assigned to a time interval ranging from Late Pleistocene to Early Pliocene. Nannofossil preservation was generally good to moderate throughout the core catcher samples analyzed at this site. Samples obtained from about 6 to 44 mbsf yielded a nannofossil assemblage typical for the Pleistocene with e.g. *Gephyrocapsa caribbeanica*, *Gephyrocapsa oceanica*, *Helicosphaera hyalina*, *Emiliania huxleyi*, *Pseudoemiliania lacunosa* and *Crenalithus doronicoides*. The depth interval between about 44 and 67 mbsf yielded a characteristic Late Pliocene assemblage with few *Discoaster brouweri* and common *Calcidiscus macintyrei* in addition to *Discoaster pentaradiatus*, *Discoaster surculus*, and *Hayaster perplexus*. Between 67 and 91 mbsf the observed assemblages are characteristic for the Early Pliocene with a variety of *Discoaster* species, such as *Discoaster pentaradiatus*, *Discoaster surculus*, *Discoaster brouweri*, *Discoaster asymmetricus*, *Discoaster triradiatus*, *Discoaster tamalis*, *Discoaster variabilis* and *Discoaster challengeri*. From 91 mbsf to bottom the retrieved samples contained *S. abies/neoabies* and *R. pseudoumbilica*, which are indicative of the Early Pliocene zone CN11a, subzone S. neoabies.

Every primary planktic foraminifera biozone (PT1b, PT1a, PL6, PL5, PL4, PL3, PL2, and PL1), from the Recent to the Early Pliocene, has been recorded in the material deposited at Site U1396 and many different datums could be retrieved over this 135 m interval: *G. flexuosa* (0.07-0.40 Ma), *G. tosaensis* (top of occurrence at 0.61 Ma), *G. exilis* (top of occurrence at 2.1 Ma), *Globigerinoides extremus* (top of occurrence at 2.1 Ma), *G. miocenica* (top of occurrence at 2.39 Ma), *G. pertenius* (top of occurrence at 2.60 Ma), *Globorotalia multicamerata* (top of occurrence at 2.99 Ma), *S. seminulina* (Top of occurrence at 3.16 Ma), *Pulleniatina primalis* (Top of occurrence at 3.65 Ma), *Globorotalia margaritae* (top of occurrence at 3.84 Ma) and *G. nepenthes* (top of occurrence at 4.36 Ma). Though several more first appearance datums (base) are well calibrated through this interval as secondary datums, when compared against the datums listed above, they appeared to be largely unreliable as age determinations, and so were not used.

The magnetostratigraphic record obtained from the cored material is in excellent accordance with the biostratigraphic observations. The recorded declination data show 15 180° shifts in which declination stabilized before again reversing, the shortest of these durations interpreted as a reversal is 85 cm in Hole U1396A. We chose reversal horizons as the point at which the declination deviates greater than 90° from the previous state.

Using the Geomagnetic Polarity Time Scale (GPTS) of Cande and Kent (1995), 9 periods of normal polarity and 9 periods of reverse polarity could be identified for this site. The earliest polarity reversal we see in Hole U1396A is the beginning of C3n.1n (4.29Ma) at 129.4 mbsf giving this hole a basal age of 4.29-4.48 Ma. The longer Hole U1396C record contains the end of C3n.2n (4.48 Ma) at 4.48 Ma giving this hole a basal age of 4.48-4.62 Ma. Using a linear approach in conjunction with the depths of the dated reversals an age-depth model was created that indicates an average sedimentation rate at Site U1396 is ~3.1 cm kyr^{-1}. However, sedimentation rates vary over the observed depth interval cored at this site. Pliocene sedimentation rates are on the order of 4 cm kyr^{-1} whereas Pleistocene rates are about 1.7 cm kyr^{-1}, and rates from the base of the core to the beginning of the Gauss Chron (3.58 Ma) are around 5.3 cm kyr^{-1}.

The physical property data obtained for this site reflect the different material recovered relatively well. Magnetic susceptibility usually increases in areas where volcanic material has been recovered, whereas the natural gamma radiation decreases. This is a completely normal behavior for these materials, as the products of volcanic eruptions usually have an higher iron content than hemipelagic sediments and vice versa in terms of natural gamma radiation (e.g., the U content in hemipelagic sediments is higher than in the volcanic products). Bulk density obtained from the whole core shows no systematic trend depending on the recovered material and also shows not clear trend with depth at this site. The same is true for the measured P-wave velocities on the whole cores. Discrete measurements of P-Wave velocity show higher velocities for the volcanic layers (1650 to >1800 m/s) than for the hemipelagic background sediment (1550 to 1650 m/s). Shear strength measurements show a clear linear trend that increases with depth. Within this linear trend, a few decreasing values are observed at 85, 115 and 130 m depth. Porosity data obtained from discrete measurements range from 54 to 70 % and show no clear depth trend. However, the first 40 mbsf show a larger porosity range (50–70%) compared to the porosities obtained > 40 mbsf (60–70%). Bulk density data obtained from discrete samples range from 1.45 to 2.00 g/cm^3, grain density ranges between 2.65 and 2.80 g/cm^3. In addition to the thermal conductivity measurements conducted on the retrieved cores we also measured downhole formation temperature. Average thermal conductivity of the cored material is 1.041±0.070 W/mK. Formation temperature measurements were made at 24.6, 34.1, 43.6, and 53.1 mbsf in Hole U1396A as well as 55.9 and 103.4 mbsf in Hole U1396C. Using the downhole formation temperature measurements and the measured thermal conductivity we calculated a temperature gradient of 69.3±1.5°C/km and a heat flow, if conductive, is 72.1±5.1 mW/m^2.

Pore-water from the hemipelagic sediments as well as headspace gases were analyzed. Samples for headspace analyses were taken from 15 depths throughout the “A” hole. The uppermost sample (Sample U1396A-1H-3) had a methane concentration of 3.6 ppm, but all other samples had levels between 2.1 to 2.6 ppm. No higher hydrocarbons were detected. Samples for pore water extraction were taken from every core in Hole U1396C. Alkalinity values are generally low (<1.5 meq) throughout the hole. The pH values are generally lower (7.6 to 7.1) than at Sites U1394 and U1395, but no consistent pattern is observable in the data. Ammonia concentrations are much lower than at the previous two sites. These two observations may be related to the fact that Site U1396 is located at shallow depths on a basement high, where strong bottom currents have been observed on previous research cruises to the area. This effect tends to winnow out the finer-grained, more reactive organic matter and leads to less intense organic carbon-driven diagenesis. Calcium concentrations are consistently higher than bottom water values in samples from throughout the hole, and magnesium concentrations are consistently lower than seawater concentrations. These features are commonly seen in deep sediment pore waters as a result of alteration of basaltic glass and suggest that many of the tephra layers observed in the core may have a basaltic composition. This hypothesis is supported by the potassium concentrations, which are also lower than seawater. Overall, sulphate concentrations are slightly depleted relative to seawater, but do not show a consistent trend with depth. Chloride concentrations fluctuate within the normal range (550-570 mM) expected for pore waters obtained from squeezing carbonate-rich 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.

Le Friant, A., Lock, E. J., Hart, M. B., Leng, M. J., Smart, C. W., Sparks, R. S. J., Boudon, G., Deplus, C., Komorowski, J.C. (2008) Late Pleistocene tephrochronology of marine sediments adjacent to Montserrat, Lesser Antilles volcanic arc. Journal of the Geological Society of London: 165, 279-289.