Site U1393[1]

Expedition 340 Scientists[2]

Chapter contents

Background and objectives

Integrated Ocean Drilling Program (IODP) Site U1393 (proposed Site CARI-02C; 16°43.13′N, 62°5.06′W; 914 meters below sea level [mbsl]) is located close to the Soufrière Hills Volcano on Montserrat (7.4 nmi [13.7 km] from Point Shoe Rock, at the southeast tip of Montserrat) (Fig. **F1**).

The ongoing eruption of the Soufrière Hills Volcano on Montserrat started in 1995. Activity has included lava dome growth, pyroclastic flows from dome collapse, explosive activity with tephra fall and pumice flows, flank collapse with debris avalanches, and volcanic blasts. More than 70% of erupted material from the ongoing eruption has been transported to the sea (Le Friant et al., 2009, 2010; Trofimovs et al., 2006). The rapid deposition of volcanic material into the sea has caused small tsunamis (Herd et al., 2005).

Site survey data indicated that distal parts of the pyroclastic flows and some underlying, older chaotic deposits interpreted as debris avalanches have been deposited at Site U1393. The English's Crater event, which occurred ~2000 y ago, produced Deposit 1 (Boudon et al., 2007). The deeper deposit (Deposit 2) probably resulted from a combined submarine and subaerial mass-wasting process of the eastern flank of the volcano, which included failure and deformation of submarine sediment (Le Friant, 2004; Lebas et al., 2011; Watt et al., 2012). Seismic data indicated that drilling at Site U1393 could penetrate through the erupted material from the ongoing eruption and into the underlying Deposits 1 and 2.

The objective for Site U1393 was to characterize the processes occurring during debris avalanche emplacement, associated erosional processes, and tephra diagenesis. Analysis of 5 m piston cores taken in this area shows that pyroclastic material from the 2003 Soufrière Hills Volcano lava dome collapse mixed with seawater and immediately deposited the coarse components out of suspension (Trofimovs et al., 2006). Study of the coarse debris avalanche deposit will enhance our understanding of emplacement processes.

Comparing the geochemical signatures (pore water and sediment) of cored material with surface sediment (from the 2007 Natural Environment Research Council [NERC] cruise) will allow us to characterize the alteration rates of volcanic material in seawater. In addition, we will examine the dependency of alteration rate and style on grain size, layer thickness, and admixture of sediment.

[1] Expedition 340 Scientists, 2013. Site U1393. *In* Le Friant, A., Ishizuka, O., Stroncik, N.A., and the Expedition 340 Scientists, *Proc. IODP,* 340: Tokyo (Integrated Ocean Drilling Program Management International, Inc.).
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[2] **Expedition 340 Scientists' addresses.**

Cores from Deposit 1 (smaller volume) and Deposit 2 (larger volume) will allow us to compare the emplacement processes of mass-transport deposits of different magnitudes. We plan to undertake a detailed lithologic, sedimentologic, and textural fabric analysis of the retrieved material at macro- and microscopic scales to investigate transport and deposition processes, the nature and magnitude of erosional processes, and interaction with the substratum (e.g., bulking) (Komorowski et al., 1991; Glicken, 1991, 1996). These data will provide valuable insights into chronology (one or several pulses) and debris avalanche mobility, which have implications for tsunami genesis.

Operations

Transit to Site U1393

After a 347 nmi transit from San Juan, Puerto Rico, that included an unplanned diversion to a rendezvous point just off the coast of Antigua to pick up a Siem Offshore crew member, the vessel arrived at the first expedition location, Site U1393. The vessel stabilized over Site U1393 at 1800 h on 6 March 2012. All times reported in this volume are given in ship local time, which was Universal Time Coordinated (UTC) – 4 h. The position reference was a combination of GPS signals and a single acoustic beacon. The positioning beacon was deployed at 0112 h on 7 March. It was recovered at 1527 h on 8 March at the conclusion of operations at Site U1393.

Site U1393

For the Site U1393 coring summary, see Table T1.

Hole U1393A

The bottom-hole assembly (BHA) was picked up and drifted, followed by running drill pipe to bottom. There were no problems running the drill string into the hole. Prior to the start of coring operations, a seafloor survey was conducted to site a favorable location to spud possible holes at the site. A clockwise spiral on a 20 m center was conducted. The survey identified a large megablock southeast of the preliminary location, and our first hole was adjusted to 20 m west of the original location. The subsea camera system failed at the end of the survey, and the vibration-isolated television frame with camera was pulled back to the surface. A single hole was then cored at this site. Hole U1393A was cored to 47.5 meters below seafloor (mbsf) with an 11⁷⁄₁₆ inch diameter advanced piston corer (APC)/extended core barrel (XCB) BHA that was 135.75 m long. A mudline core with the APC established a water depth of 926 mbsl. The second APC core bounced off the formation, and we changed to the XCB bit. Coring conditions proved to be very difficult, and recovery was very poor. Coring was terminated at 0515 h on 8 March 2012 when the XCB failed, leaving part of the XCB core barrel in the hole. The remainder of the XCB BHA was retrieved by wireline. The drill string was then pulled clear of the seafloor, the top drive was set back, and the drill string was tripped to the surface while the vessel began its 5.3 nmi transit to Site U1394. At 1025 h on 8 March the bit cleared the rotary table, ending Hole U1393A. The depth objective at the site was 250 mbsf, and this appeared to be unreachable with the tools planned for the site. Overall core recovery for Site U1393 was 11% of the 47.5 m cored. Two APC cores were attempted before refusal was reached. Core recovery was 4.36 m for the 4.4 m advance. An additional five XCB cores were attempted to 47.5 mbsf with only 1.05 m of core recovered. Most of the recovery consisted of small-diameter pieces of volcanic debris. Two holes were originally planned for this site, but because of the poor drilling conditions, the second hole was canceled.

Lithostratigraphy

Unit A

Depth: Hole U1393A = 0–4.24 mbsf

Only one lithostratigraphic unit, consisting of volcaniclastic deposits, was identified at the top of Hole U1393A. Unit A extends to 4.24 mbsf and likely represents volcanic products from the recent (1995–present) dome-forming eruption of the Soufrière Hills Volcano on Montserrat. Because of limited core recovery in Hole U1393A, the base of the unit coincides with the bottom of the APC core barrel. As a result, the lower stratigraphic boundary was not identified.

The uppermost 10 cm of the unit (0–0.10 mbsf) contains mud clasts in a sandy matrix and is moderately disturbed. This disruption is mostly likely a result of coring. A second flat-lying mud clast was identified at 20 cm (0.20 mbsf). Below this clast, the unit consists of dark brownish gray-black volcaniclastic sand containing medium to very coarse sand-sized grains with occasional granules (≤4 mm). The grains themselves are subangular to angular and are predominantly andesitic lava with rare carbonate material. Occasional larger clasts (≤3 cm) of andesitic lava are present. Generally, the unit is moderately well to well sorted, massive, and normally graded. The only structures present are isolated patches (5–10 cm long) of coarse sand surrounded by finer medium sand. The origin of this particular structure is unclear. It is possible that it may have resulted from coring, as the patches of coarse sand were separated from the edge of the core by thin (<5 mm) bands of medium sand. Alternatively, the isolated patches could represent a soft-sediment deformation process of mixing between two fluidized regions. The lower 32 cm of the unit (3.92–4.24 mbsf) consists of andesitic lava clasts as large as 3 cm, set in a coarse sand matrix. Some clasts are slightly hydrothermally altered, and most are subangular in shape.

Overall, the single unit in Hole U1393A is similar in composition to volcaniclastic material previously found in the same area below seafloor (Trofimovs et al., 2008). The angular nature of the grains and the slight hydrothermal alteration present on some clasts suggest the unit originated as a subaerial pyroclastic density current from the collapse of a lava dome, with some rounding in a shallow subaqueous environment as the flow transitioned to a turbidity current on entering the sea (Trofimovs et al., 2006).

Below 4.24 mbsf, no continuous cores were recovered. Material recovered from the core catcher at 4.72, 12.96, 18.89, and 28.63 mbsf consists of a variety of andesitic lava clasts with occasional carbonate material. Most of the clasts are gray and angular, some of them are hydrothermally altered, and many were reddish brown in color, suggesting oxidation in a subaerial environment. Because of the depth from which they were recovered, these clasts likely originate from older volcanic activity on Montserrat.

Igneous and alteration petrology

Observations from thin sections showed that the larger clasts within Unit A contain an amphibole-rich andesite, typical of the lava erupted from the Soufriere Hills Volcano, Montserrat.

Alteration is rare and is restricted to occasional pebble-sized clasts present in material recovered from the core catcher. The yellow to white color of the alteration is indicative of fumarolic or shallow hydrothermal activity.

Paleontology and biostratigraphy

Core catcher samples from Site U1393 are largely composed of sandy to coarse volcanic material (see **"Lithostratigraphy"**) and contain very few micro- and nannofossils. Retrieved microfossils are consistent with reworked material, showing the presence of shallow-water reef species and high test fragmentation.

Calcareous nannofossils

Because of the coarse nature of sediment retrieved at Site U1393, nannofossil analysis was only appropriate for two of the seven core catcher samples collected. No datum marker species were found in either core catcher sample; thus, age determination could not be made. The species *Gephyrocapsa aperta* (few) and *Gephyrocapsa caribbeanica* (common) were found in the uppermost core (Sample 340-U1393A-1H-CC). *Ceratolithus* spp. was found in low numbers (few), possibly because of the poor preservation of the sample. Nannofossil content in Sample 340-U1393A-7X-CC was extremely low. Specimens present were very small and could not be identified using optical light microscopy. Further postcruise analysis with the use of scanning electron microscopy is required for this sample.

Planktonic foraminifers

The low number of calcareous microfossil specimens collected at Site U1393 was insufficient to provide any chronostratigraphic information. Four of the seven core catcher samples retrieved were analyzed for microfossil content. Only two samples contain calcareous microfossils. One fragment of an unidentifiable planktonic foraminifer was found in Sample 340-U1393A-1H-CC. Three specimens of planktonic foraminifers commonly found in the modern-day Caribbean Sea (Bé, 1977) (one of each species: *Globigerinoides ruber* [pink], *Globigerinoides sacculifer*, and *Neogloboquadrina dutertrei*) and one unidentifiable fragment of a planktonic foraminifer were found in Sample 340-U1393A-2H-CC. In addition, one heteropod and one bivalve specimen were found and the presence of large shell fragments was noted. The condition of the foraminifers is generally poor, suggesting transportation consistent with reworked material.

Benthic foraminifers

Four benthic foraminifers were recorded from two samples at Site U1393. Three of the foraminifers are from shallow-water reef environments (*Amphistegina lessonii*, *Cyclorbiculina compressa*, and *Asterigerina* sp.). A fourth specimen is encrusted with limestone, making identification impossible. The very low diversity (1–3 specimens/sample) and poor preservation of benthic foraminifers does not allow for proper paleobathymetric approximation. However, the species found are common in environments of <30 m water depth, suggesting transported and reworked material.

Physical properties

We measured physical properties from 0 to 4.7 mbsf at Site U1393, with the uppermost 2.6 mbsf providing the most reliable values. For the uppermost 4 m, magnetic susceptibility, grain density, *P*-wave velocity, and bulk porosity are consistent with expectations for moderately to well-sorted sands with an andesite bulk composition. Full core density and *P*-wave velocity agree well with single spot values made on the split core.

Results

Whole core

We measured magnetic susceptibility, gamma ray attenuation (GRA) bulk density, compressional wave velocity, and natural gamma radiation (NGR) on all core sections (Fig. **F2**), including those with water, air pockets, and loose clasts. We have no thermal conductivity measurements in Hole U1393A because the sediment was too coarse and its high permeability prevented reliable and meaningful measurements from being made. Of the 4.36 m recovered in the first core (340-U1393A-1H), depths between the core top and 2.6 m are free of gas and water pockets and thus provide the most accurate values. Magnetic susceptibility has a maximum value of 2550×10^{-5} SI at 1.07 mbsf. Mean *P*-wave velocity is 1750 m/s. Mean GRA density is 2.0 g/cm^3. NGR is typically around 13 counts per second (cps).

We used the handheld penetrometer to measure shear strength values of 1.35 and 1.16 kPa at 4.36 and 12.8 mbsf, respectively. Peak shear strength measured by the automated vane shear apparatus at 3.6 mbsf is 3 kPa (Fig. **F2**). This value is not representative of in situ shear strength because the material in the core is sandy and too permeable for measurements to be made at undrained conditions.

Split core

We obtained one discrete *P*-wave velocity measurement of 1780 m/s at 2.09 mbsf (Fig. **F2;** red circle). This value coincides with the value recorded by the *P*-wave logger on the full core. We collected two moisture and density measurements on samples at 0.75 and 3.25 mbsf. Mean values are as follows: bulk density is 2.06 g/cm^3, grain density is 2.80 g/cm^3, and bulk porosity is 42% (Fig. **F2**). Measurements from both samples are within a few percent of each other.

Paleomagnetism

Core 340-U1393A-1H was recovered using a standard steel APC core barrel; Core 2H was recovered using a nonmagnetic barrel. The FlexIt orientation tool was not used to orient declination at Site U1393 because of seafloor conditions. Expected inclination for the site is 31.0° during normal polarity and –31.0° during reversed polarity, assuming a geocentric axial dipole (GAD). Archive halves of cores from Hole U1393A were measured on the three-axis superconducting rock magnetometer (SRM) at 2.5 cm intervals. NRM was measured before (NRM_0) and after alternating field (AF) demagnetization ($NRM_{FIELD\ in\ mT}$) in peak fields as high as 20 mT. Section 340-U1393A-1H-1A was measured at $NRM_{0,\ 5,\ 10,\ 15,\ 20}$. Sections 340-U1393A-1H-2A through 4A were measured at $NRM_{0,\ 10,\ 20}$.

Results

NRM_0 intensity shows a similar signature to magnetic susceptibility (see **"Physical properties"**). These parameters, particularly magnetic susceptibility, are strongly related to the concentration of ferrimagnetic minerals (e.g., magnetite) and correlate well with depositional units of volcanic origin (see **"Lithostratigraphy"**).

Inclination, declination, and intensity of measured sections are shown in Figure **F3.** NRM_0 intensity reaches a peak of 5 A/m and inclines steeply and downward between 80° and 90°. This steep inclination is characteristic of a viscous remanent magnetization (VRM) overprint caused by the drill string. Typically this overprint is removed by demagnetization in alternating fields of 5 or 10 mT, accompanied by a large reduction in intensity. The similarity between NRM_{10} and NRM_{20} inclination suggests removal of this overprint. NRM_{20} intensities are approximately two orders of magnitude lower with median destructive fields typically <10 mT, indicating the soft coercivity of the sample and removal of the VRM. This overprinting explains the coherence between magnetic susceptibility and NRM_0, as both are related to the concentration of ferrimagnetic minerals.

Sand dominates the composition of the recovered material (see **"Lithostratigraphy"**). These grains are often too large to orient to Earth's magnetic field and are highly sensitive to disturbance during coring because of their largely unconsolidated nature. NRM_{20} inclination and declination are highly variable over several tens and even hundreds of degrees with little coherence to values predicted by a GAD. Paleomagnetic results from Hole U1393A are consistent with chaotic deposition of large clasts incapable of recording geomagnetic field variations and/or those that have experienced significant coring disturbance. In summary, no meaningful paleomagnetic interpretations can be made about behavior of the geomagnetic field at Site U1393.

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Figure F1. Site U1393 maps. **A.** Shaded image of topography-bathymetry, chaotic deposits (interpreted as debris avalanche deposits), and drill sites, Expedition 340. DAD = debris avalanche deposit. (Continued on next page.)

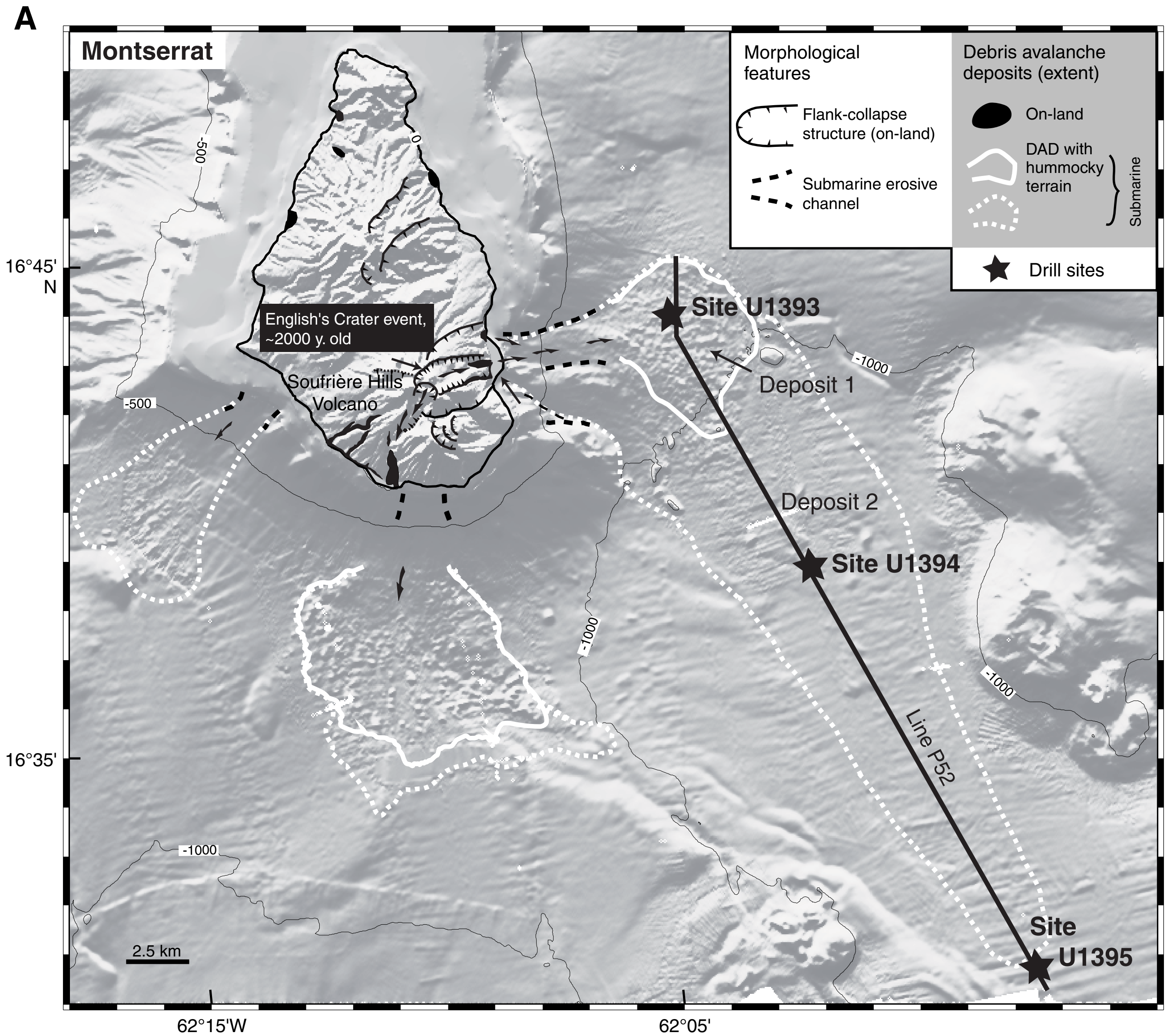

Figure F1 (continued). B. Location of seismic reflection lines, Site U1393. CDP = common depth point.

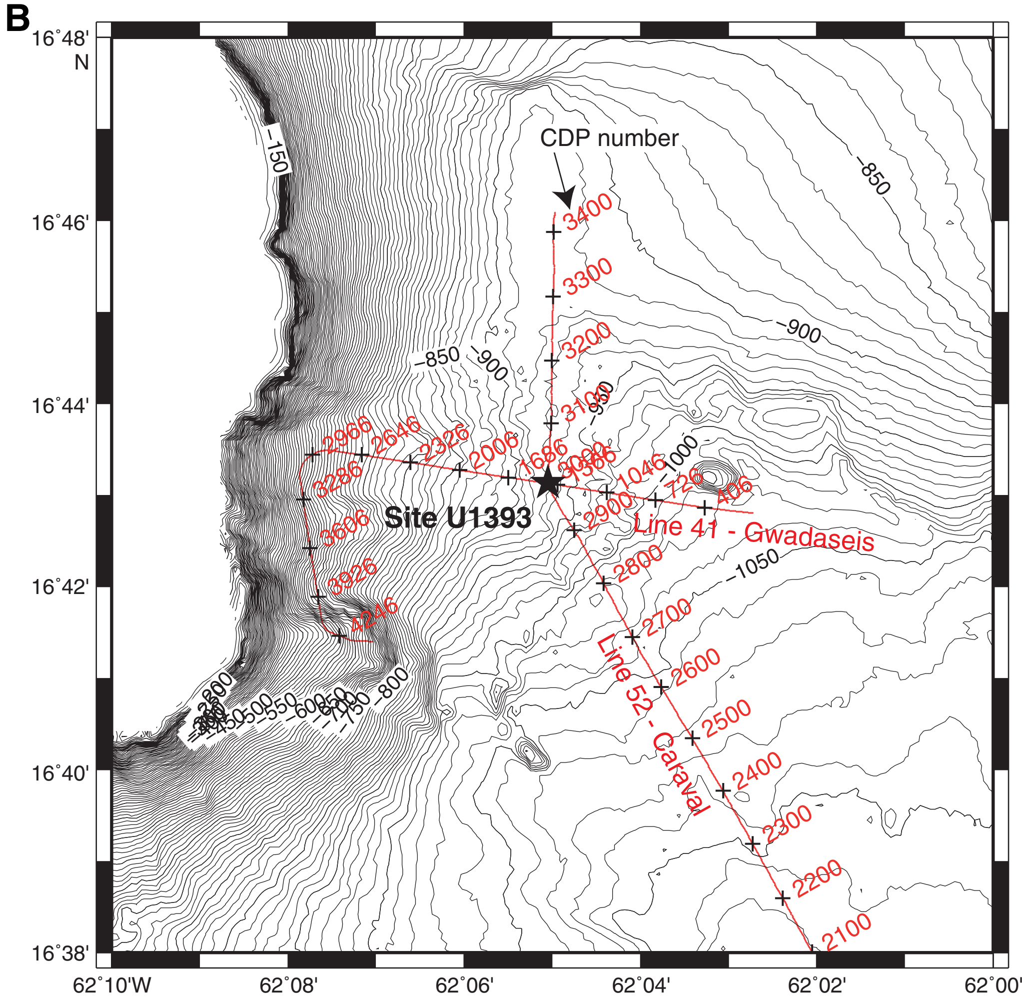

Figure F2. Physical properties measurements, Site U1393. Small blue points indicate measurements on whole cores using the Whole-Round Multisensor Logger (WRMSL) or Natural Gamma Radiation Logger (NGRL). Larger red circles indicate spot measurements obtained from samples of the split working half of the core. *P*-wave velocity was run on the WRMSL.

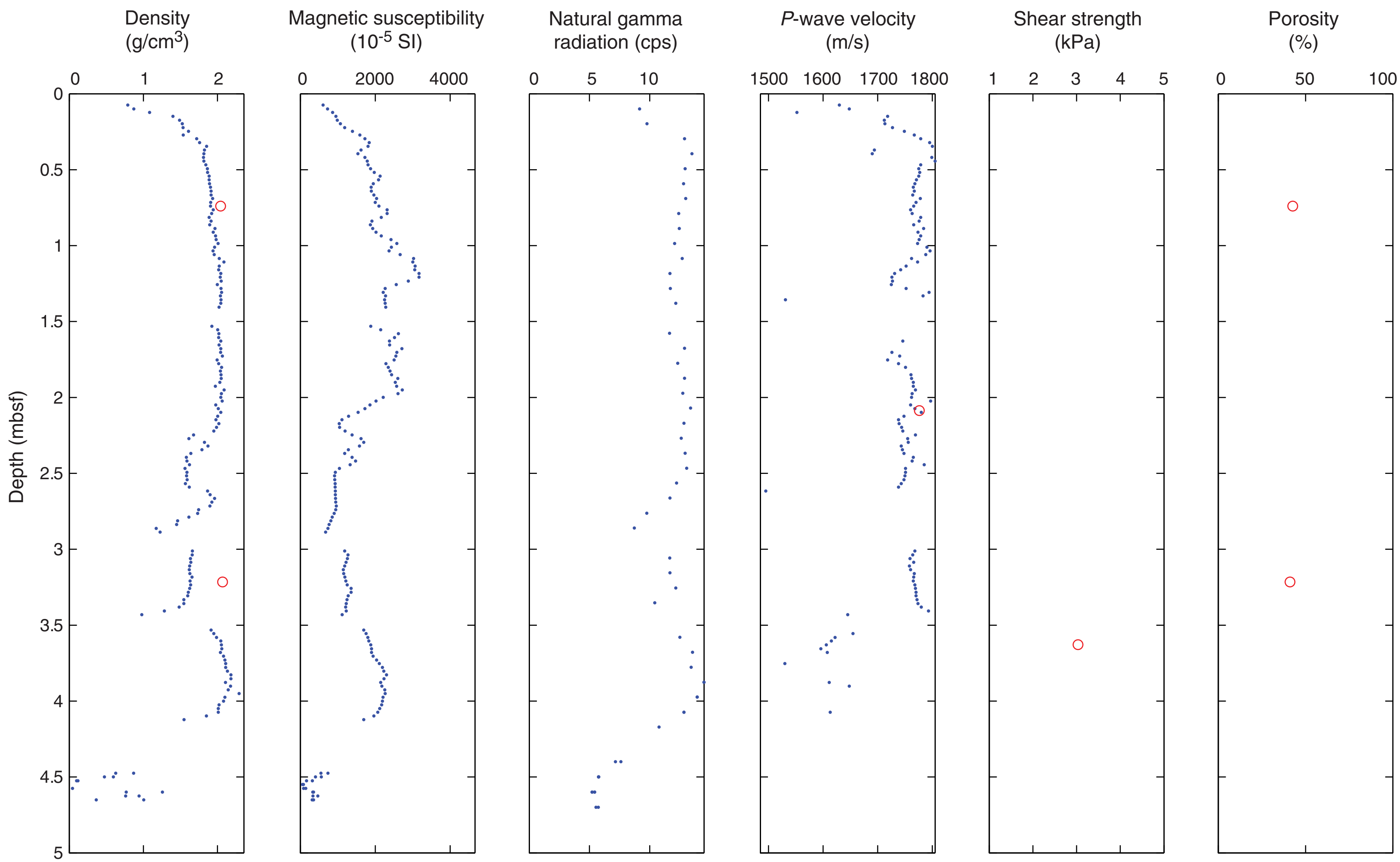

Figure F3. Plots of intensity of NRM_0 (red) and NRM_{20} (blue) and inclination and declination after 20 mT demagnetization, Hole U1393A. Inclination is shown against a geocentric axial dipole (GAD) inclination of 31.0°. Stand. = standard core barrels, N-mag = nonmagnetic core barrels.

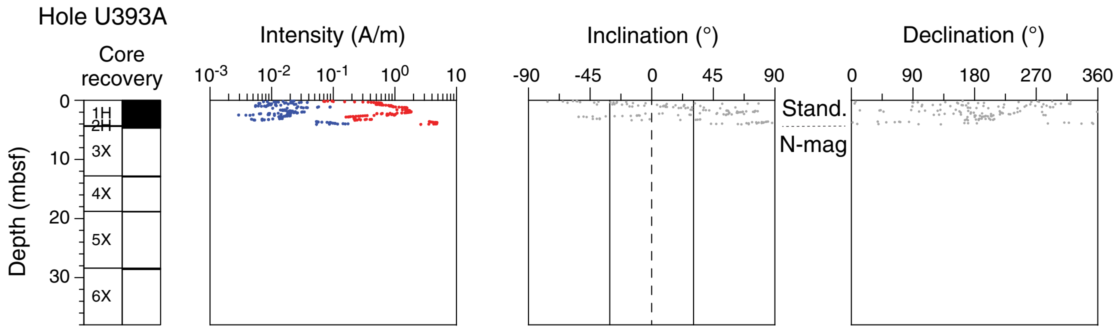

Table T1. Coring summary, Site U1393.

Hole:	U1393A
Latitude:	16°43.1316′N
Longitude:	62°5.0594′W
Water depth (m):	926.0
Date started (UTC*):	1430 h 6 March 2012
Date finished (UTC*):	0630 h 8 March 2012
Time on hole (days):	1.7
Seafloor depth DRF (m):	937.3
Penetration DSF (m):	47.5
Cored interval (m):	47.5
Recovered length (m):	5.42
Recovery (%):	11
Total cores (no.):	7

Core	Top depth drilled DSF (m)	Bottom depth drilled DSF (m)	Advanced (m)	Recovered length (m)	Curated length (m)	Top depth cored CSF (m)	Bottom depth recovered CSF (m)	Recovery (%)	Time on deck (UTC*)
340-U1393A-									
1H	0.0	4.3	4.3	4.36	4.36	0.00	4.36	101	3/7/12 0835
2H	4.3	4.4	0.1	0.01	0.01	4.30	4.31	10	3/7/12 0925
3X	4.4	12.8	8.4	0.15	0.32	4.40	4.72	2	3/7/12 1305
4X	12.8	18.8	6.0	0.20	0.16	12.80	12.96	3	3/7/12 1436
5X	18.8	28.4	9.6	0.10	0.09	18.80	18.89	1	3/7/12 1845
6X	28.4	38.0	9.6	0.22	0.23	28.40	28.63	2	3/7/12 2325
7X	38.0	47.5	9.5	0.38	0.51	38.00	38.51	4	3/8/12 0445
		Totals:	47.5	5.42	5.68				

* = ship local time was Universal Time Coordinated (UTC) – 4 h. DRF = drilling depth below rig floor, DSF = drilling depth below seafloor, CSF = core depth below seafloor. H = advanced piston corer, X = extended core barrel.