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13. Paleomagnetic and Rock Magnetic Properties of Sediment Samples from Ocean Drilling Program Leg 183, Kerguelen Plateau, Holes 1138A and 1140A[1]

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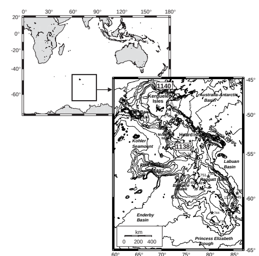
F1. Bathymetric map of the Indian Ocean showing the Kerguelen Plateau, p. 8.



ABSTRACT

The magnetic record of sediments of Sites 1138 and 1140 established by shipboard measurements is extended and corrected. About 600 sediment cubes were stepwise demagnetized with alternating fields to determine their characteristic remanence. For some samples from Site 1138, standard shipboard demagnetization at 20 mT turned out to be insufficient to obtain the characteristic remanence. Selected samples were examined by laboratory-induced magnetization analysis, hysteresis measurements, and thermomagnetic measurements. Titanomagnetites with varying Ti content are the main magnetic minerals in the sediments of Sites 1138 and 1140.

INTRODUCTION

Leg 183 of the Ocean Drilling Program in the southern Indian Ocean recovered ~465 m of sedimentary core from Holes 1138A (central Kerguelen Plateau) and 1140A (northern Kerguelen Plateau) (Fig. F1).

All material was obtained by drilling with a rotary core barrel, and the material was neither oriented with respect to geographic north nor intact. Some of the sampled sedimentary material was biscuited into 2- to 5-cm-thick, disk-shaped pieces whose azimuthal orientation was randomized by the coring process. However, a large amount of the material

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was recovered in long pieces in which only the azimuthal orientation was unknown and could be used to determine the magnetic inclination. As both sites are located at relatively high latitudes (Fig. F1), magnetic inclinations provide reasonable information for detecting reversals of the geomagnetic field recorded in the sediments.

Analyses of magnetic properties provided information on the nature of the remanence, the minerals responsible for stable remanence, and the relationship of these parameters to the variations in the lithology. In this paper, we examine the remanence properties and magnetic mineralogy of a suite of samples that cover a full stratigraphic range and are reasonably representative of the various lithologic types encountered in Holes 1138A and 1140A.

METHODS

The paleomagnetic data presented in this paper are of two different types: those obtained using the shipboard pass-through magnetometer and those derived from a conventional analysis of discrete sediment samples. Shipboard measurements were routinely taken on archive-core sections before and after stepwise alternating-field (AF) demagnetization up to at least 20 mT.

To avoid edge effects, measurements within 5 cm from the edges were removed from the data.

Discrete samples from soft material were taken by pressing 6-cm^3 plastic sample boxes into the working half of the cores. The harder sediments were precut with a sharp stainless steel spatula before they were sampled with a plastic cube. Typically, we obtained two samples per 1.5-m core section when the sediment was not disturbed. Scribe marks on the cubes were oriented parallel to the vertical axis of the core. Discrete samples were subjected to progressive AF demagnetization upon return to Munich. Paleomagnetic measurements were carried out in the Paleomagnetism Laboratory of the Universität München with a cryogenic magnetometer. All samples were stepwise AF demagnetized in three directions. Approximately 600 samples from Holes 1138A and 1140A were AF demagnetized in at least five steps up to at least 60 mT to isolate their characteristic remanence components.

A total of 21 sediment samples were selected from different lithotypes from Sites 1138 and 1140 for rock magnetic studies. Isothermal remanent magnetization (IRM), backfield, hysteresis curves, and thermomagnetic curves were measured in air using a variable frequency translation balance in the Paleomagnetism Laboratory of the Universität München.

SITE DESCRIPTION

Hole 1138A was drilled on the central Kerguelen Plateau in a water depth of 1153 m to 842.7 meters below seafloor (mbsf). One hundred forty-four meters of basalts is overlain by 698 m of sediments, of which 343 m was recovered.

In the following, a short description of the lithologies is given (after Coffin, Frey, Wallace, et al., 1999). For a more detailed description, see Coffin, Frey, Wallace, et al. (1999).

Units I–VI of Site 1138 are sedimentary rocks resting unconformably on the volcanic basement (Unit VII). The upper 650 m of sediment is biosiliceous and carbonate pelagic ooze. The lower ~50 m of the sedimentary section consists of shallow-marine and terrestrial sediments. Unit I (0–112.0 mbsf) consists of foraminifer-bearing diatom clay with interbedded foraminifer-bearing diatom ooze in the upper portion. Few volcanic ash layers were found. Unit II (112.0–265.9 mbsf) is composed of foraminifer-bearing nannofossil clay (Subunit IA) that overlies foraminifer-bearing nannofossil ooze (Subunit IB). Unit III (265.9–601.8 mbsf) consists of foraminifer-bearing chalk and contains scattered chert nodules in its lower part. Unit IV (601.8–655.6 mbsf) consists of cyclic alternations of foraminifer-bearing chalk with intervals of nannofossil claystone. Unit V (655.6–671.88 mbsf) consists predominantly of glauconitic calcareous sandstone. Unit VI (671.88–698.23 mbsf) consists of fossil-rich silty claystone with interbedded sandstone of fluvial or shallow-marine origin.

At Site 1140 on the northern Kerguelen Plateau, the sedimentary section above igneous basement rocks consists entirely of pelagic ooze and chalk (Coffin, Frey, Wallace, et al., 1999). Only one sedimentary unit (lithologic Unit I) overlying volcanic basement rocks was recognized. Unit I (0–234.5 mbsf) consists predominantly of foraminifer-bearing nannofossil ooze and nannofossil chalk. This unit was divided into two subunits (IA and IB).

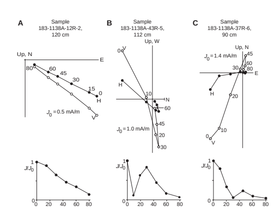
Subunit IA (0–10.0 mbsf) consists of white diatom nannofossil ooze with interbeds of dark brown silty diatom ooze. Subunit IB (10.0–234.5 mbsf) comprises most of the sedimentary section and is predominantly nannofossil ooze.

DEMAGNETIZATION BEHAVIOR

Site 1138

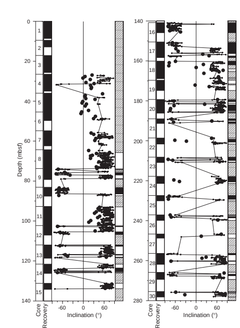
The analysis of the 450 discrete samples indicates various behaviors during demagnetization. Orthogonal vector projections of the direction of remanent magnetization during demagnetization are shown in Figure F2 (Zijderveld, 1967).

F2. Characteristic behavior of samples from Site 1138 during AF demagnetization, p. 9.



Samples with normal and reversed polarity without an overprint or with a small overprint were generally found (Fig. F2A). These overprints were destroyed at a demagnetization level of 5–10 mT. Hence, the overprint of these samples was easily destroyed during standard demagnetization at 20 mT of the archive halves aboard the *JOIDES Resolution,* and the shore-based analysis of the discrete samples confirmed the polarities that were found on board. In Figure F2B and F2C, an example of another type of demagnetization behavior is shown. The normal overprint of the reversed characteristic remanence is completely removed only at higher fields. Figure F2C shows the Zijderveld plot of a sediment sample with normal characteristic remanence and reversed overprint. Only after demagnetization to 45 mT has the overprint been removed. The standard shipboard demagnetization at 20 mT was not enough to obtain the accurate direction of the characteristic magnetization. Hence, in the parts of the site where that behavior was found, the magnetic polarity record had to be corrected after analysis of discrete samples. This occurred in Cores 183-1138A-17R, 18R, 37R, 48R, 51R and 53R.

F3. Inclination data for sediments from Site 1138, p. 10.



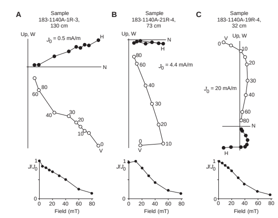
Data from the continuous and discrete measurements on sediments from Site 1138 are shown in Figure F3 together with the polarity record determined from the shipboard inclination data and the characteristic inclinations of single sample cubes.

For sites in the Southern Hemisphere, negative inclinations correspond to normal polarity of the Earth's magnetic field, and positive inclinations correspond to reversed polarity. The inclinations obtained from the discrete samples confirm, in most cases, the results obtained on board during Leg 183 from archive-half cores. An interpretation of the inclination record in terms of normal and reversed polarity is shown by black and white bars, respectively.

Site 1140

The AF demagnetization experiments on ~100 single samples from Hole 1140A confirmed the results obtained aboard the *JOIDES Resolution.* No additional information could be obtained for the polarity record from discrete sample measurements at this site. In Figure F4, representative examples of AF demagnetization and decay curves of samples from Site 1140 are shown. Some sediments carry a single component without overprint (Fig. F4A). Most of the sediments have a partial secondary magnetic component, which, however, was easily destroyed at 20 mT (Fig. F4B, F4C).

F4. Characteristic behavior of samples from Site 1140 during AF demagnetization, p. 13.



ROCK MAGNETISM

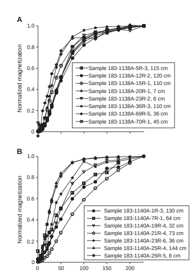
We carried out a series of rock magnetic investigations on small chips of sediment samples to characterize the carriers of magnetization. Thirteen samples were selected from Hole 1138A and seven from Hole 1140A. Differences in lithology and in AF demagnetization characteristics were used as a selection criterion.

IRM Analysis

The selected samples were used in IRM experiments in which the samples were placed in progressively stronger magnetic fields up to a maximum of 230 mT, and their magnetization was measured. The results of these IRM experiments (Fig. F5A, F5B) show that samples display two types of behavior.

Samples from Site 1138 (Fig. F5A) and most of Site 1140 (Fig. F5B) show a sharp increase in magnetization in fields <150 mT followed by a slow increase through 230 mT. The rapid increase of the magnetization in low fields is typical for magnetite or Fe-Ti spinel, which, because of its high spontaneous magnetization, tends to dominate the IRM even when it is less abundant than other minerals. The second type (e.g., Sample 183-1140A-21R-4, 73 cm) displays a more continuous increase up to 230 mT, and it might be caused by the presence of a high-coercivity mineral.

F5. IRM analysis of sediment samples, p. 14.



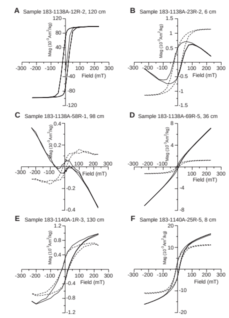
Hysteresis Analysis

Hysteresis parameters were obtained from hysteresis loops for a determination of the magnetic domain state. Of interest were the coercive force H_c and the ratio of saturation remanence I_{rs} over saturation magnetization I_s. The coercivity of remanence H_{cr} was determined by measuring the backfield curves of the 16 samples that contained sufficient ferrimagnetic material for a determination of hysteresis parameters.

Hysteresis loops of samples from Site 1138 show four different characteristic behaviors. Very broad hysteresis loops with high H_c could be caused by single-domain particles of magnetite (Fig. F6A).

Some samples clearly show a diamagnetic behavior at high fields and a ferrimagnetic component that dominates at smaller fields (Fig. F6B). Very weakly magnetic samples with a high content of calcite also show a strong diamagnetic component with a superimposed ferrimagnetic component (Fig. F6C). Hysteresis loops with strong paramagnetic components have been corrected for high field slope before interpretation (Fig. F6D).

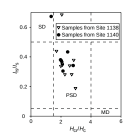
F6. Hysteresis curves of sediments, p. 15.



Hysteresis loops of samples from Site 1140 all show the same behavior with a paramagnetic component that differs from sample to sample (Fig. F6E, F6F).

Following the method of Day et al. (1977), we determined the domain status by plotting the I_{rs}/I_s ratio vs. H_{cr}/H_c (Fig. F7). The results from almost all samples are characteristic for pseudo–single domain (PSD) particles. Two of the selected samples show characteristics of single-domain particles.

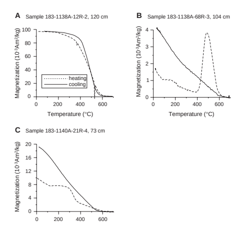
F7. I_{rs}/I_s ratio vs. H_{cr}/H_c, p. 16.



Thermomagnetic Analysis

For thermomagnetic analyses, some selected samples were heated between room temperature and 700°C and cooled to room temperature in the presence of a magnetic field (100 mT). For Site 1138, two examples are shown in Figure F8A and F8B.

F8. Thermomagnetic measurements on sediments, p. 17.



Sample 183-1138A-12R-2, 120 cm (Fig. F8A), shows reversible behavior during the heating-cooling cycle, indicating that no secondary mineral phase has been produced during heating. The constant intensity between 20° and 400°C is followed by a major, steep decline in intensity between 400° and 600°C that is consistent with the removal of a mineral whose blocking temperature lies within this range (magnetite or a low Ti magnetite). Irreversible behavior during the treatment cycle is shown by Sample 183-1138A-68R-3, 104 cm (Fig. F8B). The heating curve of this sample shows a sudden decrease in intensity between 20° and 80°C, which might be caused by the presence of goethite. This initial decrease is followed by a constant intensity up to 180°C and another decrease between 180° and 400°C, which is ascribed to the removal of a low blocking temperature mineral. The sudden high peak after 400°C is due to the formation of secondary magnetite.

For Site 1140, Sample 183-1140A-21R-4, 73 cm, is shown in Figure F8C. Its irreversible behavior, consistent with the conversion of a low-magnetization component to a higher magnetization component, is somehow similar to the one for Sample 183-1138A-68R-3, 104 cm. After a decrease between 20° and 100°C and a following constant magnetization up to 300°C, a sudden decrease from 300° to 350°C is observed and is ascribed to the removal of a low blocking temperature mineral. From 350° to 600°C, a somewhat continuous decrease is displayed.

CONCLUSIONS

The magnetic record of sediments from Sites 1138 and 1140 determined on board with the pass-through cryogenic magnetometer was confirmed, in general, by our land-based stepwise AF demagnetization of discrete samples. However, the analysis of discrete samples showed that for some parts of Site 1138, the shipboard demagnetization of 20 mT was not sufficient to obtain the characteristic direction of the magnetization, and the preliminary polarities had to be reviewed.

The rock magnetic investigation showed that titanomagnetites with varying Ti content are the main magnetic minerals in the sediments from Sites 1138 and 1140. IRM acquisition, hysteresis analyses, and thermomagnetic analyses have been conducted. The magnetic domain state for most of the investigated samples was determined as PSD.

ACKNOWLEDGMENTS

This research used samples provided by the Ocean Drilling Program (ODP). ODP is sponsored by the U.S. National Science Foundation (NSF) and participating countries under management of Joint Oceanographic Institutions (JOI), Inc. Funding for this research was provided by ODP/Germany, project numbers So72/63-2 and So72/63-3. M.A. wants to thank the crew of Leg 183 and the Munich Gang.

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Day, R., Fuller, M., and Schmidt, V.A., 1977. Hysteresis properties of titanomagnetites: grain-size and compositional dependence. *Phys. Earth Planet. Inter.,* 13:260–267.

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Figure F1. Bathymetric map of the Indian Ocean showing the Kerguelen Plateau with Ocean Drilling Program drill holes. Sediments from sites marked in bold (1138 and 1140) were used for the rock magnetic and paleomagnetic studies presented here.

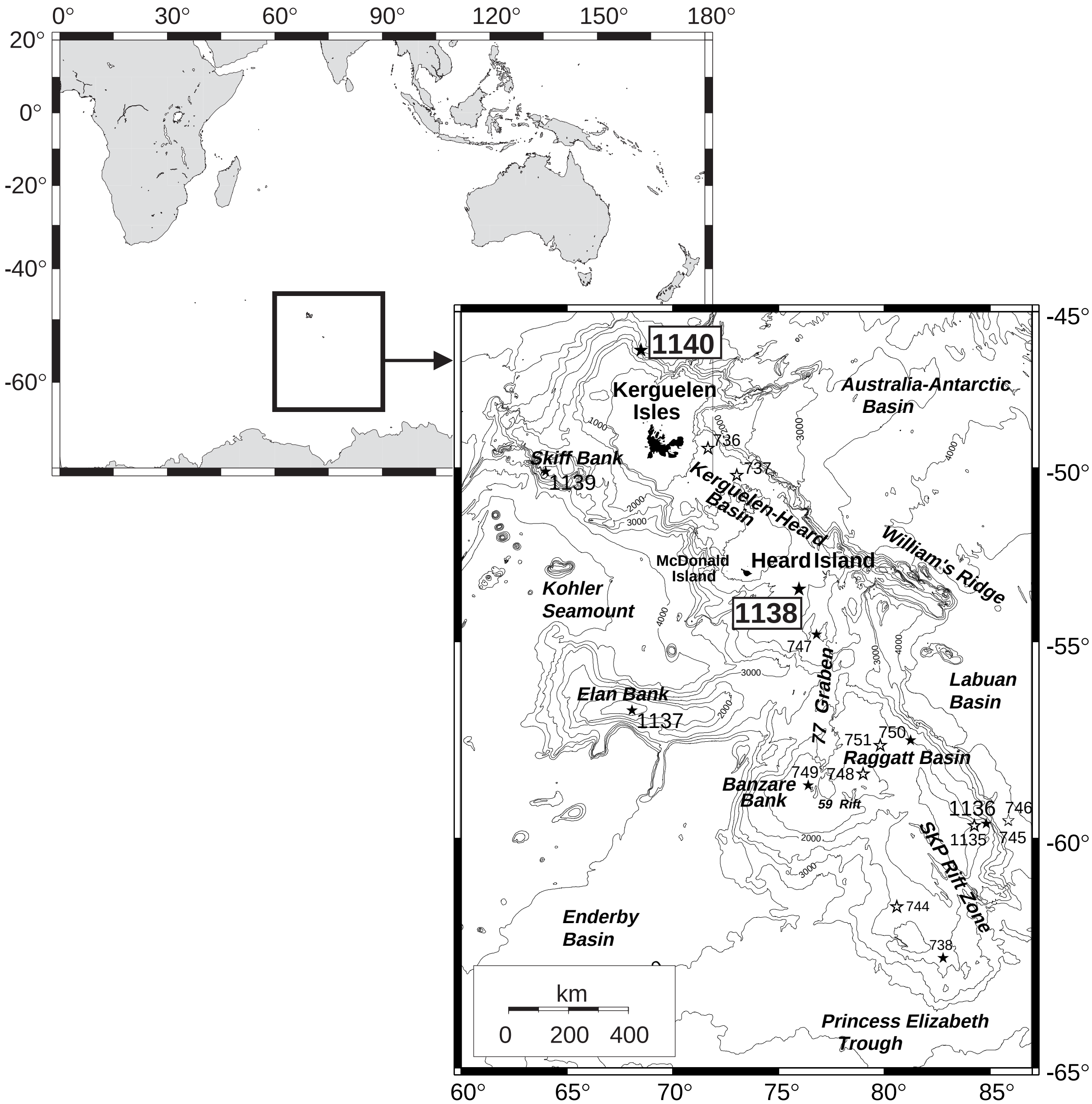


Figure F2. Characteristic behavior of samples from Site 1138 during alternating-field demagnetization. Samples (**A**) 183-1138A-12R-2, 120 cm, (**B**) 183-1138A-43R-5, 112 cm, and (**C**) 183-1138A-37R-6, 90 cm. Open circles = vertical projection of magnetization (V); solid circles = horizontal projection of magnetization (H).

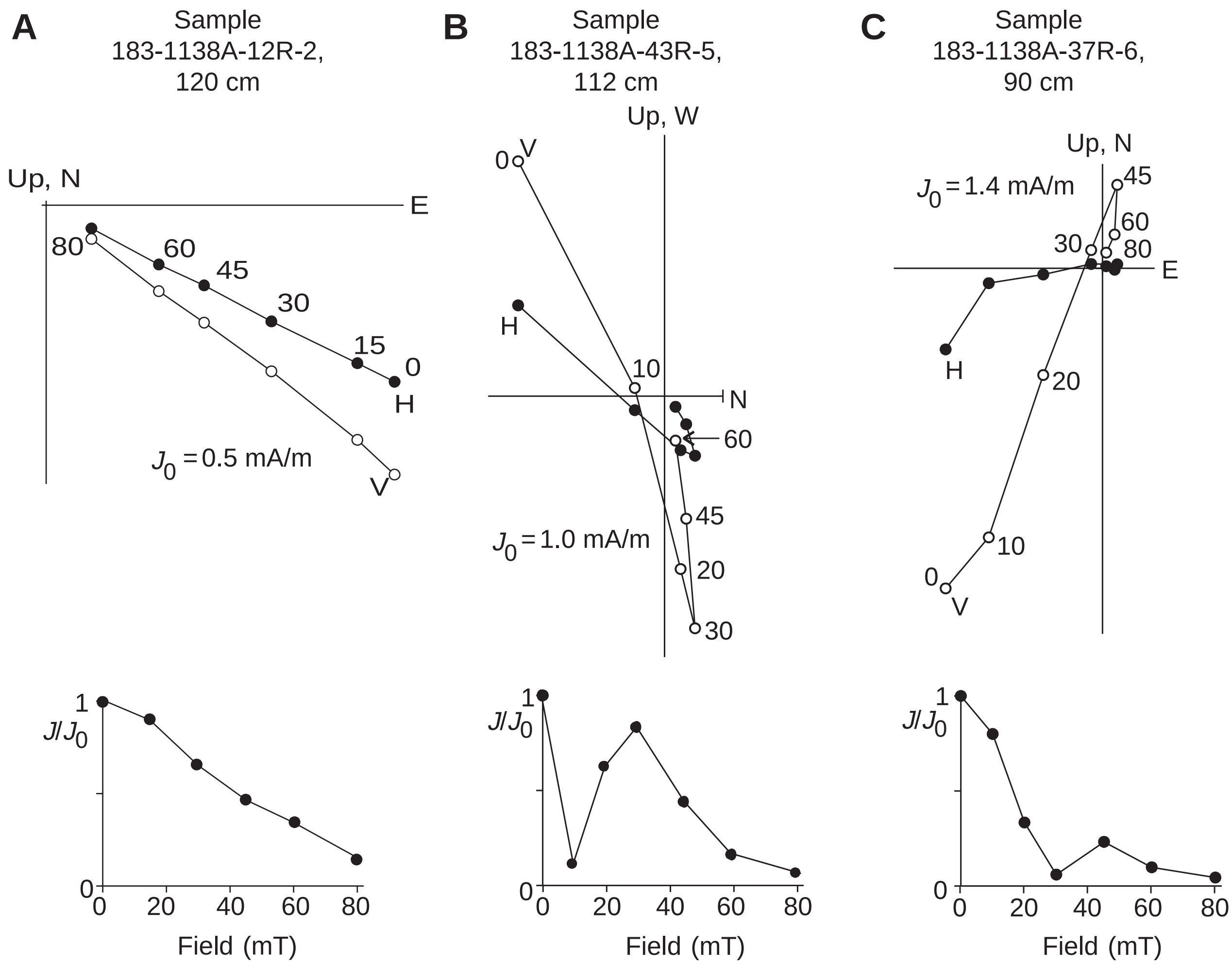
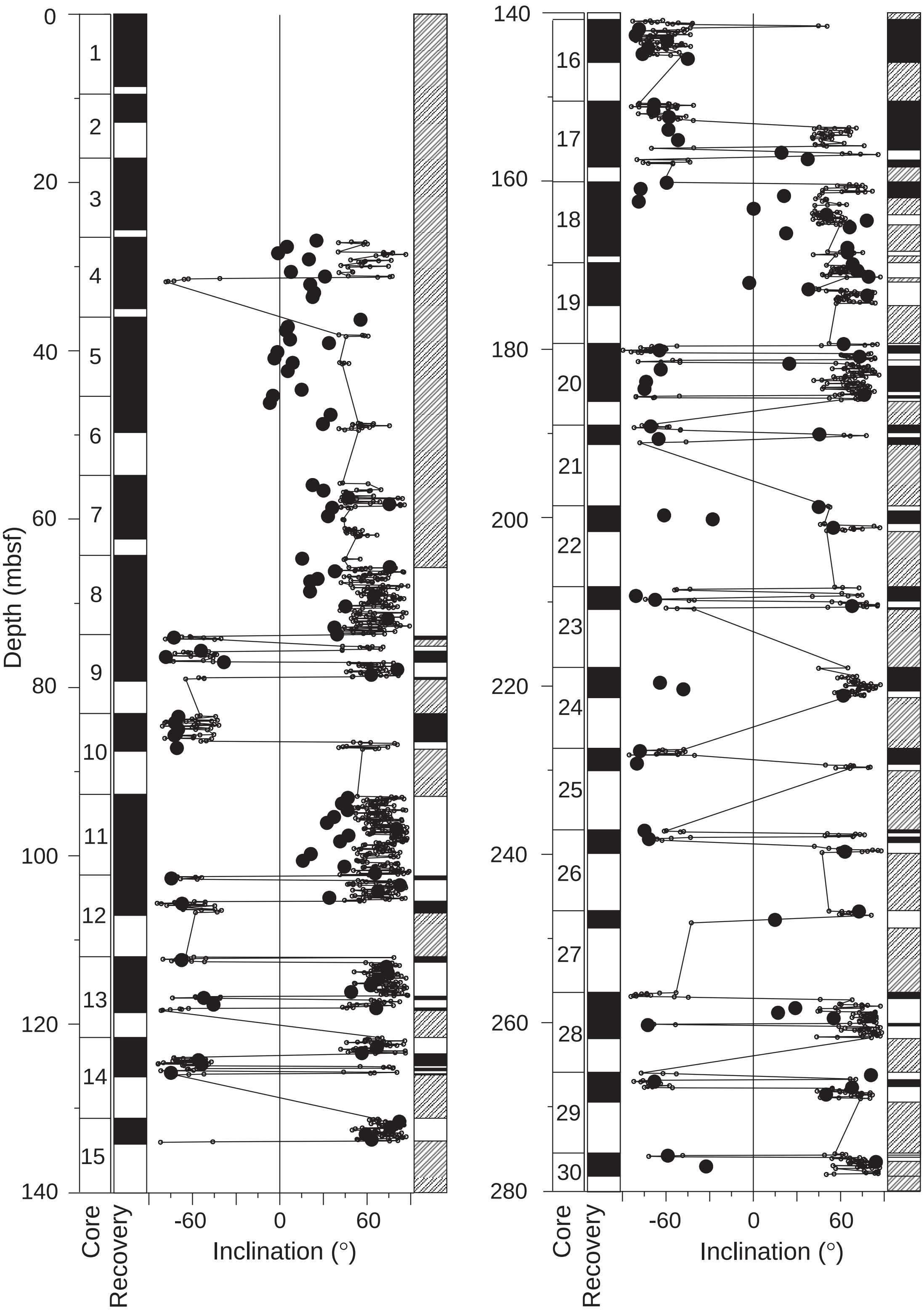


Figure F3. Inclination data for sediments from Site 1138. Small open circles represent shipboard continuous measurements; solid circles represent results from demagnetization of discrete samples. The black and white bars in the right-hand column indicate normal and reversed polarity, respectively. Shaded bars in the right-hand column are zones without recovery or with unreliable inclination data, which have not been interpreted. Data from discrete samples have been used to confirm or to correct the continuous measurements. For example, sections in Cores 183-1138A-51R and 53R had to be corrected. (Continued on next two pages.)



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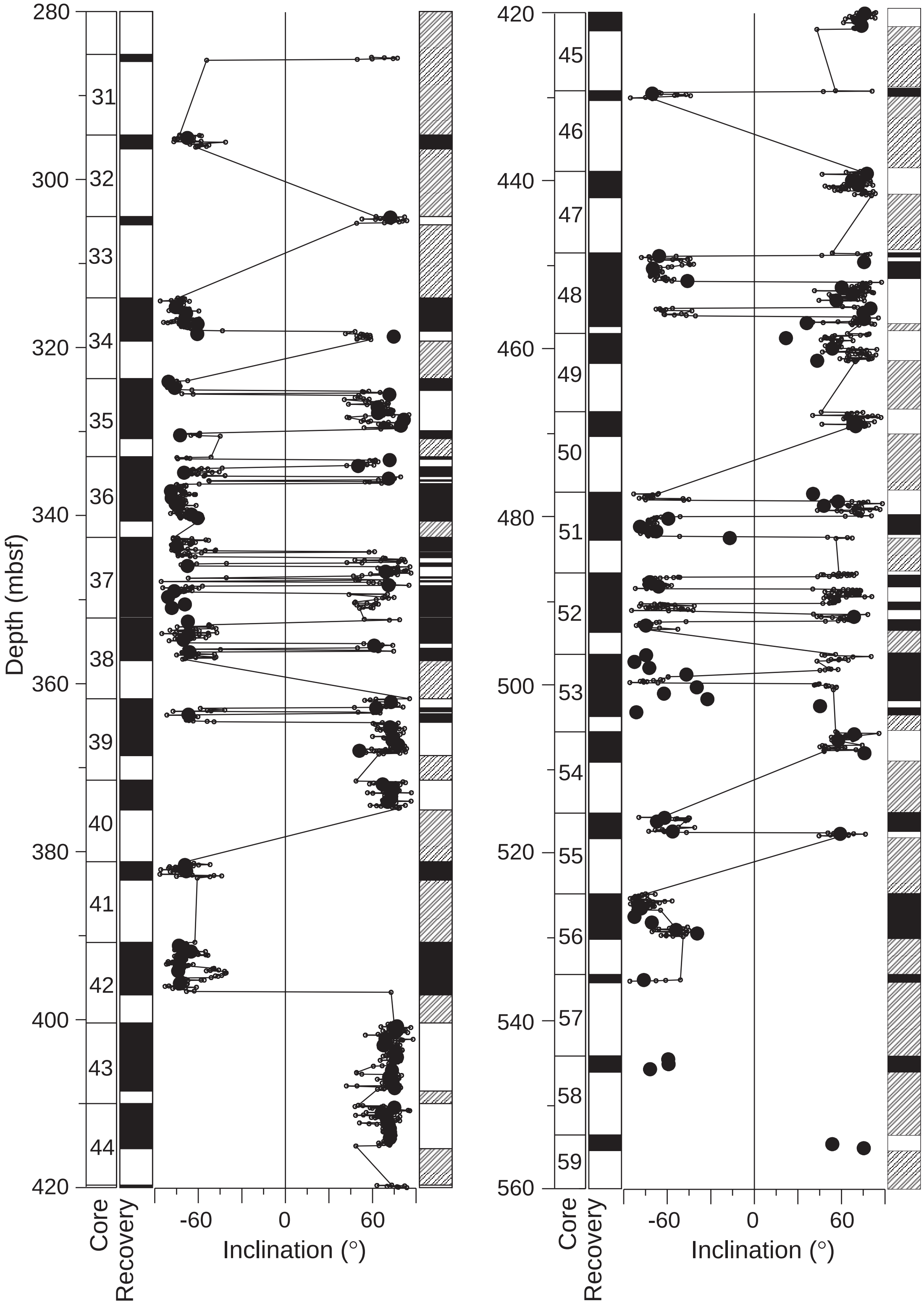

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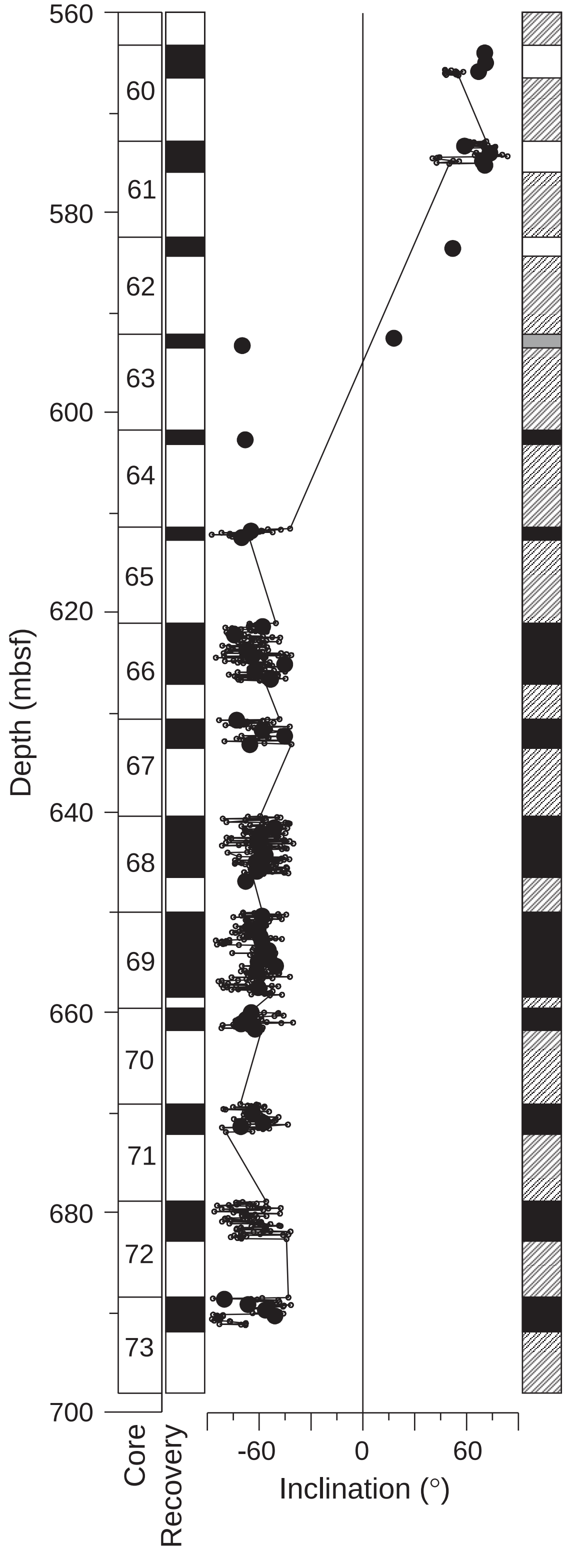

Figure F4. Characteristic behavior of samples from Site 1140 during alternating-field demagnetization. Samples (**A**) 183-1140A-1R-3, 130 cm, (**B**) 183-1140A-21R-4, 73 cm, and (**C**) 183-1140A-19R-4, 32 cm. Open circles = vertical projection of magnetization (V); solid circles = horizontal projection of magnetization (H).

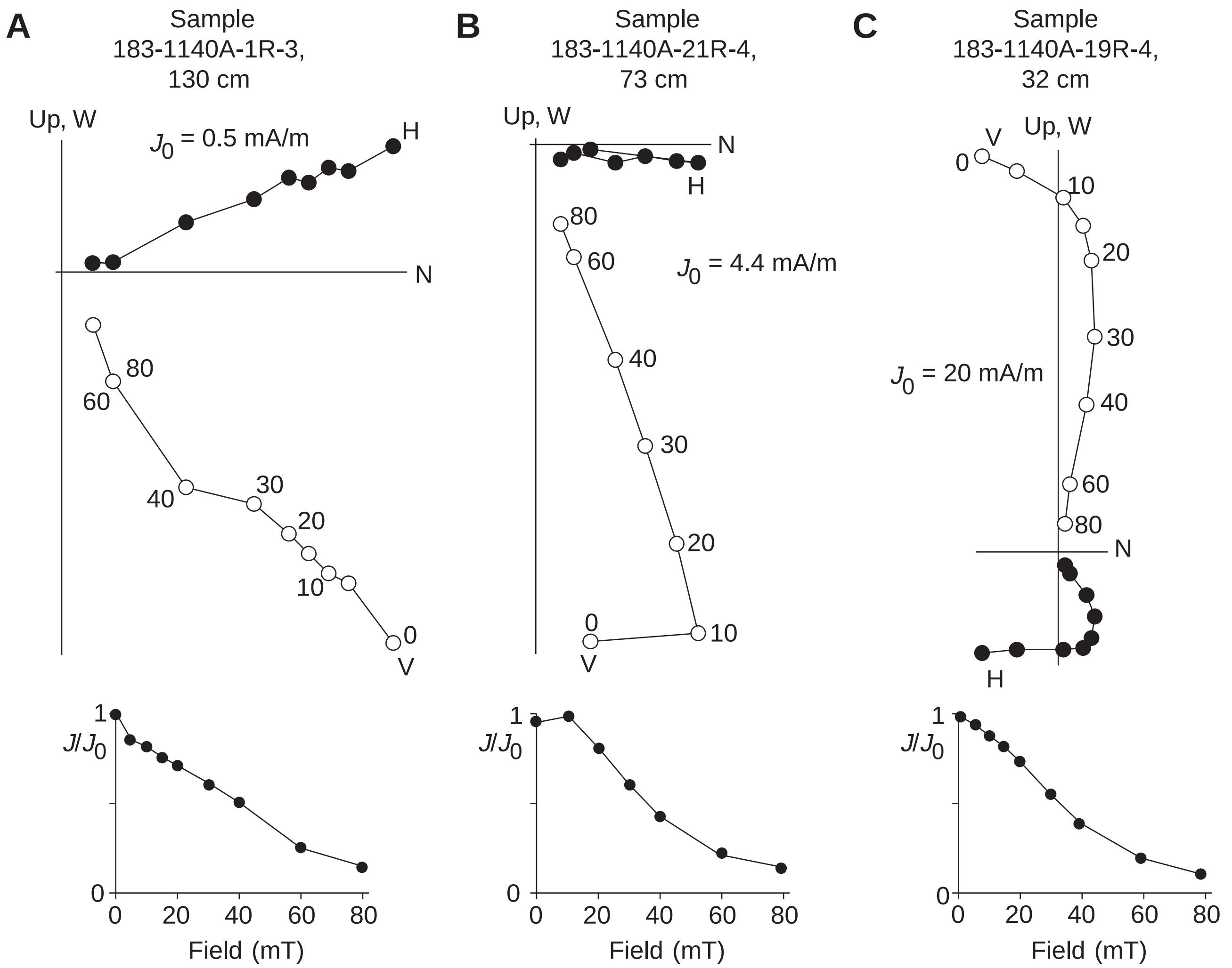

Figure F5. IRM analysis of sediment samples from (**A**) Sites 1138 and (**B**) 1140.

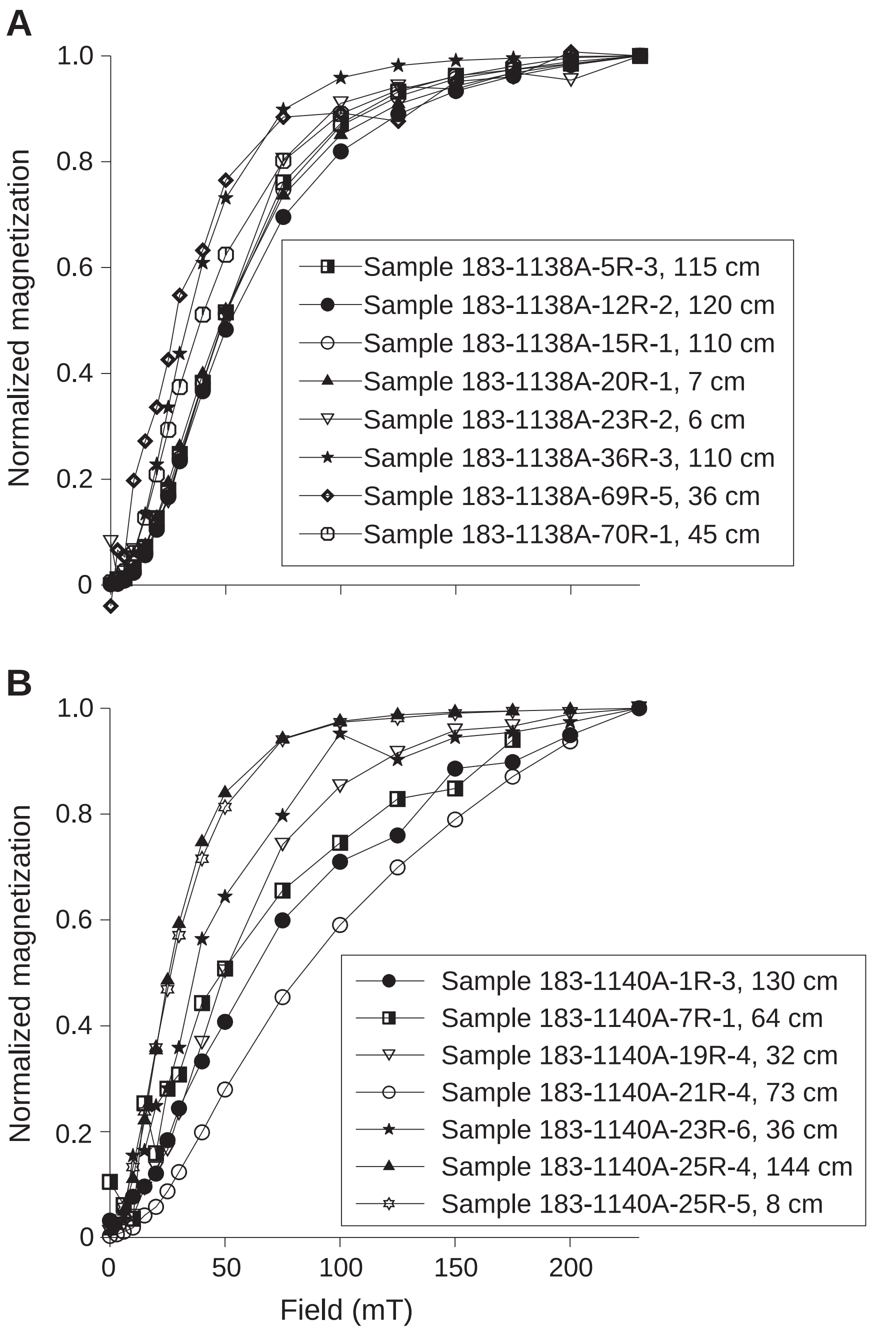

Figure F6. Hysteresis curves from sediments of Sites (**A–D**) 1138 and (**E, F**) 1140. Mag = magnetization.

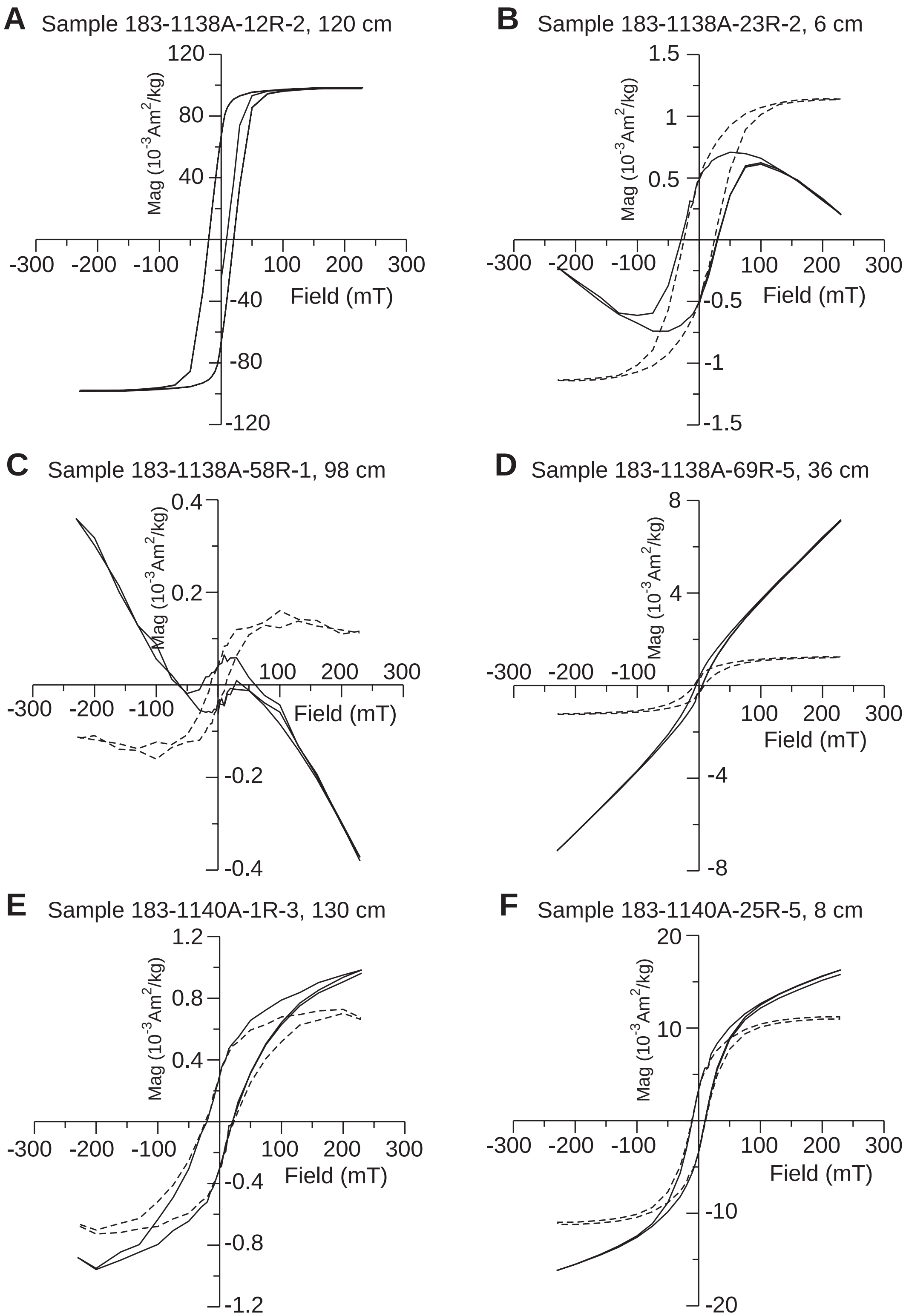

Figure F7. I_{rs}/I_s ratio vs. H_{cr}/H_c after the method of Day et al. (1977). SD = single domain, PSD = pseudo–single domain, MD = multidomain.

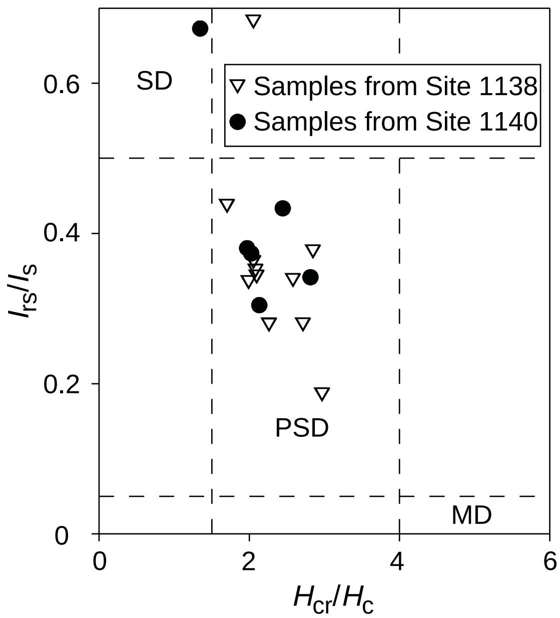

Figure F8. Thermomagnetic measurements on sediments from Sites (**A, B**) 1138 and (**C**) 1140.