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APPENDIX: MAGNETICS EXPERIMENT[1]

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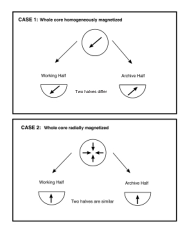
BACKGROUND

Paleomagnetists have found that the natural remanent magnetization (NRM) measured in advanced piston coring (APC) sediments is commonly oriented parallel to the +X direction in the Ocean Drilling Program (ODP) coordinate scheme, which is defined to be parallel to the scribed double line on the core liner (i.e., 0° declination) (e.g., Curry, Shackleton, Richter, et al., 1995). Because the core liner is oriented arbitrarily with respect to Earth's magnetic field, this must be an artifact. In very weakly magnetized rocks, a machine error may cause the observed declinations, although no clear explanation has been presented. In more strongly magnetized rocks, the declination anomaly can arise from a radially inward magnetization, as illustrated in Figure **F1.** The magnetization in discrete samples taken from the cores has also been determined, and the horizontal component has been found to be oriented radially inward (Curry, Shackleton, Richter, et al., 1995; Herr et al., 1998). The degree of remagnetization has been shown to decrease from the margin of the core inward (Stokking et al., 1993; Curry, Shackleton, Richter, et al., 1995).

A natural explanation for the magnetic contamination observed in APC cores is that the magnetic fields of the various components used in the coring process have given rise to magnetic fields in which remagnetization has taken place. Numerous investigations of the magnetic fields of the various components used in coring have indeed demonstrated that APC barrels and shoes can have relatively strong magnetic fields, as much as two to three orders greater than the geomagnetic field, and that there can be very strong local fields in the bits and in the pipe (e.g., Stokking et al., 1993; Fuller et al., 1998). Another possibility is that in the process of coring, particles are mechanically realigned. Sediment deformation during coring with a circular cutting shoe could give such a realignment a radial symmetry, as required to explain the

F1. The explanation of the 0° declination observation, **p. 10.**



[1]**Examples of how to reference the whole or part of this volume.**
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radially inward moments. To test these models and to investigate possible mitigation of the observed contamination, a program of coring with experimental nonmagnetic barrels and cutting shoes was performed during this leg and during Leg 174B (Shipboard Scientific Party, in press).

A comparison between the paleomagnetic records of cores obtained with nonmagnetic APC barrels and standard barrels was conducted during Leg 174B (Fuller and Garrett, 1998). The nonmagnetic barrels were made with 15-15-LC steel, which is a nonmagnetic material commonly used in the petroleum industry. This did not solve the 0° declination problem. However, additional experiments demonstrated that the magnetization acquired as the core travels up the drill string was predominantly vertically downward and magnetically soft and could be removed by alternating field (AF) demagnetization. The experiments also demonstrated that relatively hard magnetization can be acquired by the core as the APC barrel comes to rest in the sediment. However, the problem of the 0° declination remained.

The use of half cores for the measurement in the magnetometer may contribute to the 0° declination problem because of the off-centered position of the sample in the pick-up coil array; studies are under way to investigate this effect (J. Gee, pers. comm., 1998). However, it seems unlikely that measuring off center should introduce major error. If a radial moment is generated by the coring process, then measuring the whole core should eliminate the integration effect discussed above. We therefore compared whole-core and half-core measurements of cores taken with standard and nonmagnetic APC assemblies and shoes.

The analysis of the data generated during Leg 182 is under way, and only preliminary results are available. Here we describe the results from Site 1128, the first site at which experimental coring was performed, and from Site 1131, the first site at which the comparisons of whole-core and half-core measurements were made in conjunction with coring using the experimental nonmagnetic cutting shoe.

METHODS

During Leg 182, a large amount of data were collected to compare the paleomagnetic records of cores obtained using the experimental nonmagnetic assembly and shoe with cores obtained using standard APC assemblies. The nonmagnetic shoe, including the flapper valve, was made of 15-15-LC steel. The magnetic fields of the nonmagnetic shoe and assembly were first compared with a standard assembly.

During coring, the effect of the whole nonmagnetic assembly, consisting of the shoe and two nonmagnetic barrels, was first compared with standard assemblies. Then comparisons were made between the effect of the nonmagnetic shoe and the whole nonmagnetic assembly. Finally, numerous comparisons were made between the shoe and standard assemblies. When possible, the comparisons were made in two ways: (1) the paleomagnetic records in alternate cores in a single hole were compared and (2) cores from equivalent depths in the A and B holes were compared. In the single-hole studies, the effects in cores immediately above and below the core taken with the nonmagnetic tool provide controls. When studying different holes at the same site, the effects in material at identical depths were compared.

The principal means of comparison used in this study is the departure of the observed horizontal component of magnetization declination from the fiducial line on the core liner. This 0° declination was the expression of the radial moment that originally drew attention to the phenomenon, but it is an imperfect measure of the effect because the core could be shot so that the fiducial line is near geomagnetic north. We therefore need an independent determination of the orientation of the field with respect to the core liner to compare how well the geomagnetic field is recorded in the cores obtained with standard and nonmagnetic assemblies, or shoes.

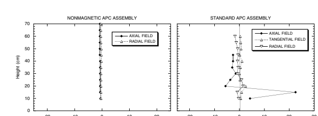
In principle, the tensor tool should give the necessary information, but there is a history of difficulties with this observation and uncertainties remain in the interpretation of the tensor tool data. A second possible method of orientation is provided by the magnetization of discrete samples taken from near the center of the core. These have been found to be much less susceptible to the radial moment than the half cores and, therefore, provide a means of orienting the core for comparisons with the tensor tool. Eventually, both methods will be used, but the discrete sample measurements must largely await shore-based work because many of these samples are so weakly magnetized that they cannot be measured with the shipboard magnetometer. They should, however, be measurable in the University of Hawaii magnetometer, which has similar direct-current superconducting quantum interference devices, but has a smaller pick-up coil volume, providing higher sensitivity for discrete samples.

The nature of the comparison and, consequently, the assessment of the effect and the possibility of improving the quality of the record are clearly not straightforward. Given this situation, final interpretations must await shore-based work. However, for a preliminary discussion the departure from the fiducial line of the observed magnetization is useful. In addition, we know the geomagnetic axial dipole (GAD) field inclination at the sites and we have some discrete sample measurements.

MEASUREMENT OF FIELDS OF STANDARD APC AND EXPERIMENTAL NONMAGNETIC ASSEMBLIES

The nonmagnetic assembly consisted of a cutting shoe, flapper valve and spacer (in place of the 10-finger core catcher), and two 3.3-m nonmagnetic APC barrels. Before coring, this experimental assembly and a standard assembly were placed in chucks and the magnetic fields within the shoes measured. The measurements were made using the Walker Scientific Inc. MG5D Hall probe used in previous experiments (Fuller and Garrett, 1998). Field measurements were made immediately below the cutting shoe, in the assembly beyond the cutting shoe, and into the lowermost APC barrel. The results are shown in Figure F2. The strongest field was observed at the cutting surface of the standard cutting shoe, which reached 2 mT. Other fields in the standard shoe and all the fields of the nonmagnetic shoe were close to the background field in the region below the chucks.

F2. Magnetic surveys of nonmagnetic and standard APC assemblies, p. 11.



CORING WITH EXPERIMENTAL NONMAGNETIC APC ASSEMBLY

The nonmagnetic cutting shoe had a nonmagnetic flapper valve, but a nonmagnetic spacer was used initially in place of the usual 10-finger catcher. The spacer was later replaced with a standard 10-finger core catcher. The nonmagnetic tool was used for alternate cores starting at 3H and ending when the lithology precluded further use. Experiments were performed to investigate the effect of the nonmagnetic cutting shoe used with the experimental nonmagnetic barrels and with standard APC barrels.

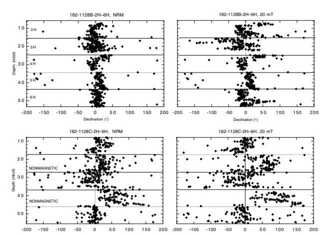
Site 1128

The sediments sampled during the experimental coring are within Unit I of the sedimentary section and consist of nannofossil oozes with numerous small pelagic foraminiferal turbidites. A zone of debrites has been defined in Cores 7H and 8H in both Holes 1128B and 1128C. Beneath this are two more cores of nannofossil ooze that complete Unit I. Unit II consists of olive-green clay from which Cores 11H–14H of Holes 1128B and 1128C were taken.

The APC coring in Hole 1128B was performed using standard barrels and permits a comparison between sediments cored using these standard barrels and cores from the same depth recovered from Hole 1128C using nonmagnetic assemblies. The analysis here focuses upon the declination, although there are minor differences in inclination between control cores and those cored using the nonmagnetic assembly. The intensities are similar whether the cores are taken with nonmagnetic or standard APC assemblies. The interpretation of the effect of the nonmagnetic corer at this site is complicated because the section contains a sequence of reversals.

The declinations before and after 20 mT demagnetization for Cores 182-1128B-2H through 6H are shown in the top panels of Figure F3. The declinations of all cores are similar, with tightly grouped distributions with means close to zero. The means and standard errors are –0.8, 1.7 for Core 182-1128B-2H; 0.2, 2.3 for Core 3H; 3.0, 3.3 for Core 4H; 9.7, 4.3 for Core 5H; and 5.8,1.1 for Core 6H. This is the classic expression of the 0° declination phenomenon.

F3. Declination for Cores 182-1128B-2H through 6H and 182-1128C-2H through 6H, p. 12.



After AF demagnetization, the pattern in declination remains, but the means are not as close to the fiducial line on the core liners as in the NRM case. The means and standard errors after demagnetization are 11.6, 3.1 for Core 182-1128B-2H; –24.8, 33.3 for Core 3H; 8.3, 4.0 for Core 4H; 8.9, 4.6 for Core 5H; and 0.4, 2.0 for Core 6H.

The lower panels of Figure F3 show the declinations observed in Cores 182-1128C-2H through 6H. There is a systematic difference in declination of the NRM between the even cores, which were taken with standard assemblies, and the odd cores, which were taken with the nonmagnetic assembly. The former have declinations close to 0° with means of 7.7, –14.7, and 1.4, with standard errors of 3.5, 4.6, and 4.6, whereas the cores taken with the nonmagnetic assembly have means of 21.3 and 52.3, with standard errors of 4.0 and 4.3. There is no comparable systematic difference in inclination or in intensity.

The pattern observed in the NRM declination is again seen in the declination after 20 mT demagnetization, but with a larger systematic difference between the declinations of cores taken with the magnetic and nonmagnetic assemblies. Thus the means and standard errors of the declinations of cores taken with the standard assemblies were –5.0, 4.0 for Core 182-1128C-2H; –15.0, 5.1 for Core 4H; and –6.2, 6.4 for Core 6H; whereas with the nonmagnetic assemblies, the means and standard errors of the declinations were 39.0, 4.7 for Core 3H; and 87.3, 6.2 for Core 5H.

Anomalously steep inclinations are more evident in Cores 182-1128C-4H and 6H taken with the standard assemblies, but the means are close to the GAD inclination for the site, which is 52°. Core 182-1128C-3H has a slightly lower intensity compared with the neighboring Cores 2H and 4H. This intensity is also lower than that of Core 182-1128B-3H, which suggests that subtle differences in intensity may be induced by the different coring assemblies, with the cores obtained with the nonmagnetic assembly consistently having slightly lower intensities. However, it is the declination that shows the most distinctive pattern.

As we noted above, it is important to check this estimation of the effect of the coring on the magnetization against an independent determination of the orientation of the field that the sediments should be recording. Taken at face value, the results of the tensor tool are again consistent with a reduction of coring contamination and better recording of the geomagnetic field in Cores 182-1128C-3H and 5H compared with Cores 2H, 4H, and 6H. Thus, Core 182-1128C-3H gives an estimate of the field direction of ~70°, whereas the tensor tool gives 95°. Core 182-1128C-5H gives 95° where the tensor tool gives 197°. Although these can hardly be regarded as in good agreement, the agreement is better than for Cores 182-1128C-4H and 6H, which disagree with the tensor tool by 178° and 166°, approaching the maximum possible disagreement of 180°.

The NRM of Hole 1128C presents a similar picture in which Cores 182-1128C-3H and 5H depart from the 0° direction in the appropriate sense as defined by the tensor tool, whereas the magnetization of Cores 182-1128C-2H, 4H, and 6H is closely aligned parallel to the fiducial line. The controls from Hole 1128B yield results aligned with the fiducial line again, as do the 20 mT values, with the exception of Core 182-1128B-5H, which departs in the correct sense and gives a result in agreement within 60° of the tensor tool.

Unfortunately, Hole 1128C was not sampled on the ship, so checking the tensor tool results by the magnetization of discrete samples must await analysis on shore. However, samples taken from Section 182-1128C-3H-2 yielded inconsistent declinations close to zero. Core 182-1128C-3H has remanence oriented close to zero and therefore should give 0° declinations in the ODP core axis convention, which it does before demagnetization. However, neither the demagnetized remanence nor the tensor tool orientation gives this direction. Two results from Core 182-1128B-4H gave declinations of 45° and 75°. The tensor tool gave 105°, but the half-core NRM direction was 6.7°, and after demagnetization to 20 mT it remained essentially unchanged at 8.3°. In this case, the tensor tool and the discrete sample results are in some degree of agreement and the values suggest that the half core is again giving a false near-zero declination. These results show the possibility of using discrete samples as another check of core orientation and tensor tool performance, but much more work is required on shore.

To summarize the results from this first sequence of cores, it is evident that the nonmagnetic APC assembly has significantly decreased the tendency for the direction of the magnetization of the half cores to be aligned with the fiducial line, or double-line scribed on the core liner. This implies a reduction of the radially inward moment discussed above. In both Cores 182-1128C-3H and 5H, the field appears to be recorded better by these cores and one type of systematic noise has been reduced. Curiously, there appears to be increased scatter of the NRM declination in all of the cores from Hole 1128C compared with those from Hole 1128B. This pattern is also maintained after AF demagnetization.

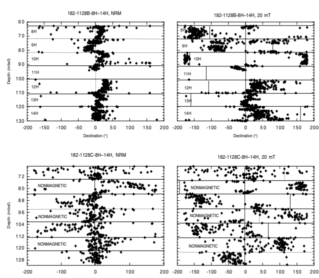
Cores 182-1128B-7H and 182-1128C-7H

The disturbed zone in Cores 182-1128B-7H and 182-1128C-7H was not used in the analysis because of the difficulty in interpreting the magnetization in this zone. However, the declinations were strongly dispersed in Core 182-1128C-7H, which was cored with the nonmagnetic assembly, whereas Core 182-1128B-7H, taken using the standard assembly, again gave declinations near 0°.

Cores 182-1128B-8H through 14H and 182-1128C-8H through 14H

Beneath the disturbed zone, Cores 182-1128C-9H, 11H, and 13H were again taken with the nonmagnetic assembly, whereas the even numbered cores were taken with a standard assembly. Plots of declination from the equivalent cores from Hole 1128B, which again act as controls, are shown in Figure F4 in the top panels, with NRM on the left and the 20 mT value on the right. The NRM declination is close to 0°, but after demagnetization, the declination of Cores 182-1128B-8H through 10H all move substantially away from zero, whereas Cores 182-1128B-12H through 14H move much less.

F4. Declination for Cores 182-1128B-8H through 14H and Cores 182-1128C-8H through 14H, p. 13.



The declination for the NRM and 20 mT demagnetization value for Cores 182-1128C-8H through 14H are shown in Figure F4 in the lower panels. The NRM in the top row again shows the directions clustered around 0° declination, with the possible exception of Core 182-1128C-9H. Inclinations are, for the most part, steeply downward. The intensity of magnetization falls to a minimum at depths of 90 meters below seafloor. With demagnetization to 20 mT, the declination and inclination patterns change radically, but the intensity changes less and becomes almost uniform throughout the sequence.

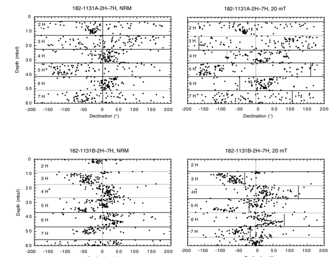
The results from this second group of cores are not as dramatic as in the shallower cores, but again those cored with the nonmagnetic assembly move away from the 0° declination and are in broad agreement with the tensor tool results. However, Core 182-1128C-10H gives an excellent paleomagnetic record in agreement with the tensor tool, but was collected with the standard assembly. As in the shallower cores, the overall scatter in declination is greater in Hole 1128C than in Hole 1128B.

CORING WITH EXPERIMENTAL NONMAGNETIC SHOE AT SITE 1131

In Holes 1131A and 1131B, the nonmagnetic cutting shoe was used with standard APC barrels for Cores 182-1131A-3H through 7H and 182-1131B-3H through 7H. The nonmagnetic cutting shoe had a nonmagnetic flapper valve. A standard 10-finger core catcher was incorporated because of earlier core loss. Sections 182-1131B-3H-3 and 3H-4 and 182-1131B-4H-3 and 4H-4 were measured both as whole cores and as archive halves.

Plots of declination are given in Figure F5 for Cores 182-1131A-2H through 7H for NRM and after 20 mT demagnetization. In the even-numbered cores, which were cored with the standard shoe, the declination is close to zero, whereas in the odd-numbered cores, which were cored with the nonmagnetic shoe, the direction of magnetization departs from 0°. Agreement with the tensor tool is not very good for any of the cores.

F5. Declination for Cores 1131A-2H through 7H and Cores 1131B-2H through 7H, p. 14.

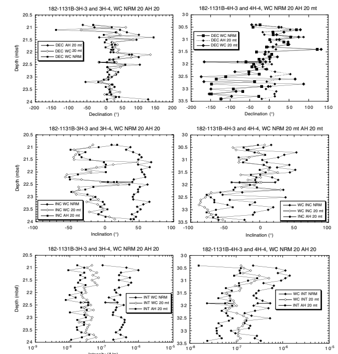


The lower panels of Figure F5 show the results for Hole 1131B. Scatter in the data is less than for Hole 1131A, and the distinction between the results for cores taken with the nonmagnetic shoe and those taken with the standard shoe is also less. The agreement between tensor tool and remanence for the cores taken with the nonmagnetic shoe is better for Hole 1131B than for Hole 1131A.

Tensor tool measurements were available for Cores 182-1131A-3H through 7H and for Cores 182-1131B-3H through 7H. The agreement between the direction of magnetization of the cores and the tensor tools was poor. The tensor tool orientations for the cores taken with the nonmagnetic corer in Hole 1131B were 329°, 336°, and 335°. One would expect tensor tool orientations to be very randomly between 0° and 360°; therefore, these orientations are suspect.

Figure F6 shows the comparison between the whole-core and archive measurements for Sections 182-1131B-3H-3 and 3H-4, and 182-1131B-4H-3 and 4H-4. In the top row of panels, declination, inclination, and intensity are shown for Sections 182-1131B-3H-3 and 3H-4, and below are the corresponding plots for Sections 182-1131B-4H-3 and 4H-4. In each plot, the values for the whole-core NRM, the whole core after 20 mT demagnetization, and the archive core are shown. There is no NRM plot for the archive-half core because it was already demagnetized as part of the whole core. The declination values after all three measurements are very similar for Sections 182-1131B-3H-3 and 3H-4, as are the demagnetized values for both the inclination and intensity. The pattern is a little different in Sections 182-1131B-4H-3 and 4H-4 in that the declination, inclination, and intensity of the archive half of Section 182-1131B-4H-4 differ significantly from the whole-core measurements. This is consistent with a larger radial moment in the cores taken with the standard corer but needs to be checked by discrete measurements from the cores to assess the radial moments present.

F6. Comparison of Site 1131 whole-core and archive half-core measurements, p. 15.



At Site 1131 as at Site 1128, there is a general tendency for cores taken with the standard cutting shoe to show declinations that are more closely aligned with 0° declination than are the declinations in the cores taken with the nonmagnetic shoe. The comparison between half-core and whole-core measurements revealed greater differences in the cores taken with the standard cutting shoe than with the nonmagnetic shoe, which is consistent with a greater radial moment in cores taken with the standard cutting shoe.

DISCUSSION

This preliminary analysis of the experimental coring on Leg 182 clearly shows that the nonmagnetic assembly consisting of cutting shoe, flapper valve, spacer for 10-finger core catcher, and APC barrel does reduce the 0° declination phenomenon in some cores. However, this is not a simple invariable result. There are occasions when it appears to have no effect. There are even occasions when cores taken with the standard assemblies give better results than similar cores obtained using the nonmagnetic assembly. Two disadvantages of the nonmagnetic barrel assembly are (1) an anomalous field at the joint between the nonmagnetic barrels with the standard barrel (i.e., this assembly is not entirely nonmagnetic) and (2) the failure of nonmagnetic barrels in general to shield the sediment from stray fields as do standard barrels during passage through the bottom-hole assembly (BHA) and up the drill string. The effect of the nonmagnetic shoe alone appears to be similar to that of the whole nonmagnetic assembly, although additional relevant data remain to be analyzed. The variability of the effects of the nonmagnetic cutting shoe and assembly is a major puzzle. Moreover, to understand this variability in the effect is a major part of the study because the phenomenon of coring contamination itself is so variable. If the observed effects are a combination of magnetic field plus sediment deformation during piston coring, then it is natural to think that the physical properties of the sediments may be a key factor. It was in the region of partial lithification and increased vane strength in Hole 1128C that the effect of the nonmagnetic cutting shoe appears to decrease and excellent paleomagnetic records are obtained whether the nonmagnetic or the standard shoe is used.

These experiments have also drawn attention to the between-hole variability at a single site. We have found repeatedly that the quality of the paleomagnetic record is different in two holes from a single site, although nothing has changed in the BHA or in the APC barrel assembly.

The study will be continued on shore with measurement of the magnetization of discrete samples and U-channel samples as a means of orienting the cores and of investigating the distribution of the coring contamination as a function of position in the cross section of the core.

As a result of these preliminary results, it is recommended that further trials of the nonmagnetic shoe and APC assembly be planned. The results from this leg were of considerable interest, but it was far from ideal as a test of the nonmagnetic cutting shoe and APC assembly because the signal was in many cases so weak that comparisons between nonmagnetic and standard elements were compromised. It remains possible that the nonmagnetic shoe alone may provide a relatively cheap and quick fix for a significant part of the 0° declination problem.

The explanation of the declination effect remains elusive. A particularly puzzling feature, noted since the early work of Jean-Pierre Valet and David A. Schneider on Leg 154 (Curry, Shackleton, Richter, et al., 1995), is its intermittent occurrence. The experiments conducted during Leg 182 demonstrate that the declination effect can sometimes be mitigated by the use of a nonmagnetic cutting shoe and also suggest that the deformation of the sediment during coring plays a role in the effect.

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Figure F1. The explanation of the 0° declination observation by a radially inward horizontal component of magnetization.

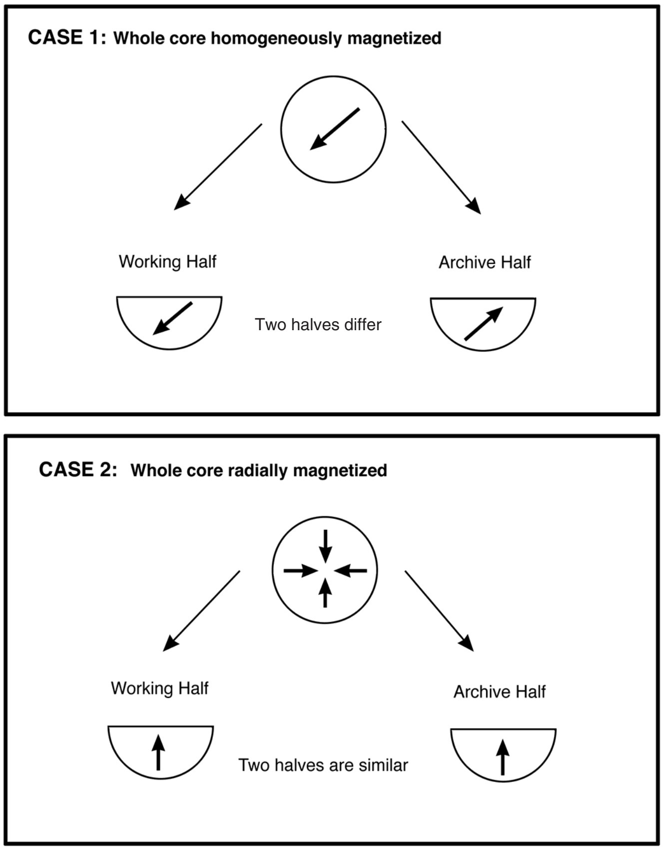

Figure F2. Magnetic surveys of nonmagnetic and standard advanced hydraulic piston coring (APC) assemblies. The cutting surface of the shoes was at 20 cm from the origin of the ordinate scale. Radial, tangential, and axial fields were all measured along a vertical line at ~5 mm from the inner wall of the shoes.

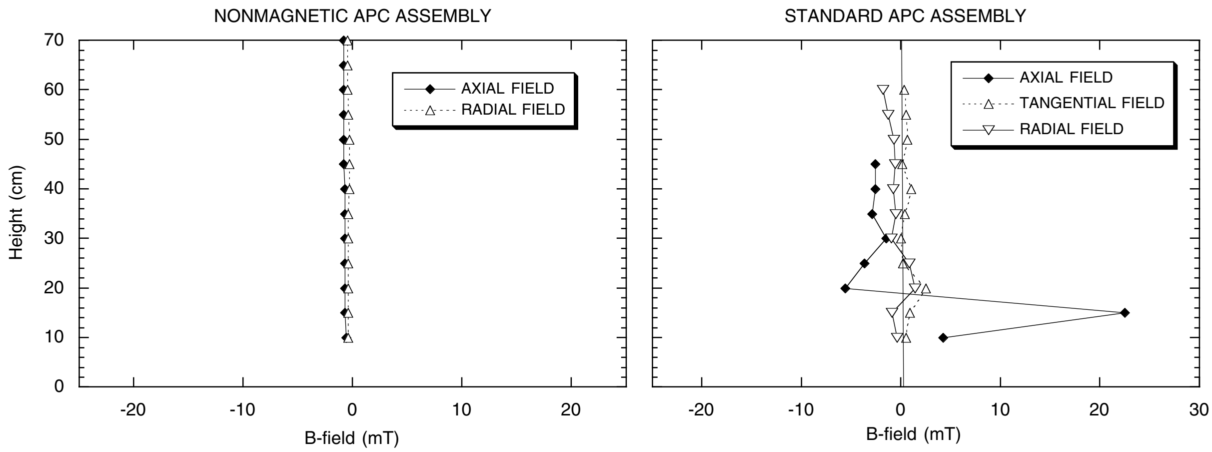

Figure F3. Declination for Cores 182-1128B-2H through 6H and 182-1128C-2H through 6H. This angle represents the departure of the horizontal component of magnetization from the fiducial line on the core liner. The horizontal lines represent core boundaries. The vertical lines within cores are the tensor tool orientations, (i.e., magnetic north as measured by the tensor tool). NRM = natural remanent magnetization.

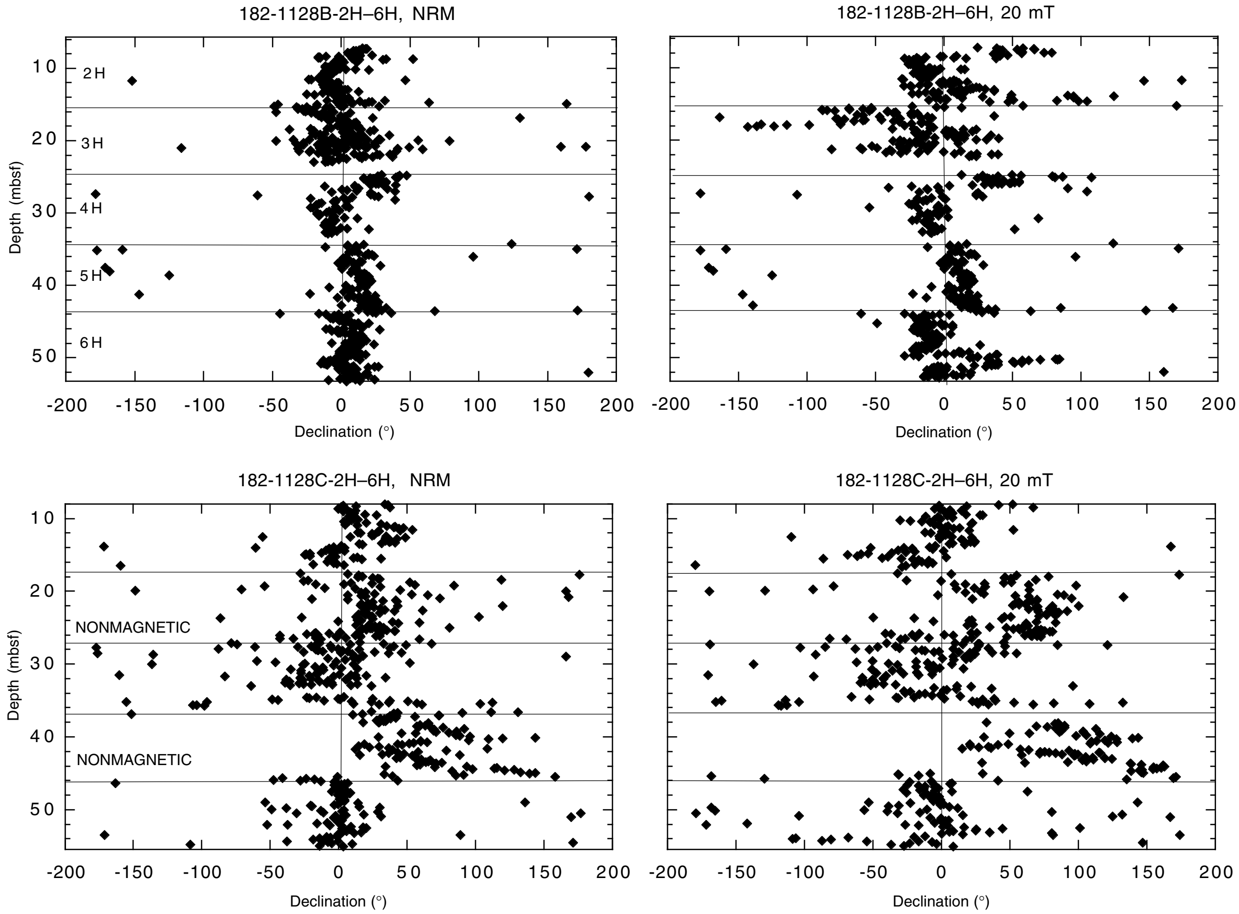

Figure F4. Declination for Cores 182-1128B-8H-14H and Cores 182-1128C-8H through 14H. This angle represents the departure of the horizontal component of magnetization from the fiducial line on the core liner. The horizontal lines represent core boundaries. The vertical lines within cores are the tensor tool orientations, (i.e., magnetic north as measured by the tensor tool). NRM = natural remanent magnetization.

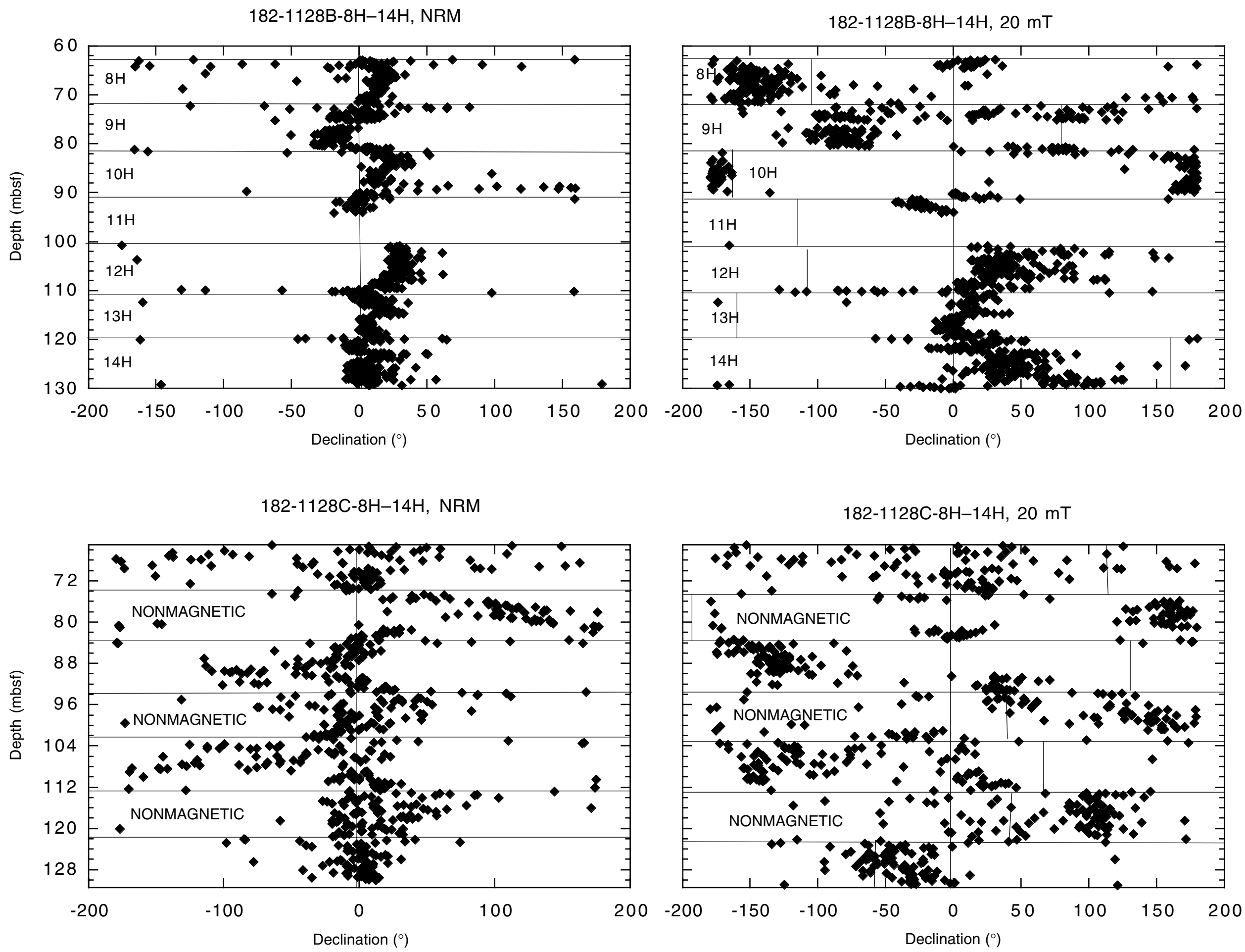

Figure F5. Declination for Cores 182-1131A-2H through 7H and Cores 182-1131B-2H through 7H. This angle represents the departure of the horizontal component of magnetization from the fiducial line on the core liner. The horizontal lines represent core boundaries. The vertical lines within cores are the tensor tool orientations, (i.e., magnetic north as measured by the tensor tool). NRM = natural remanent magnetization.

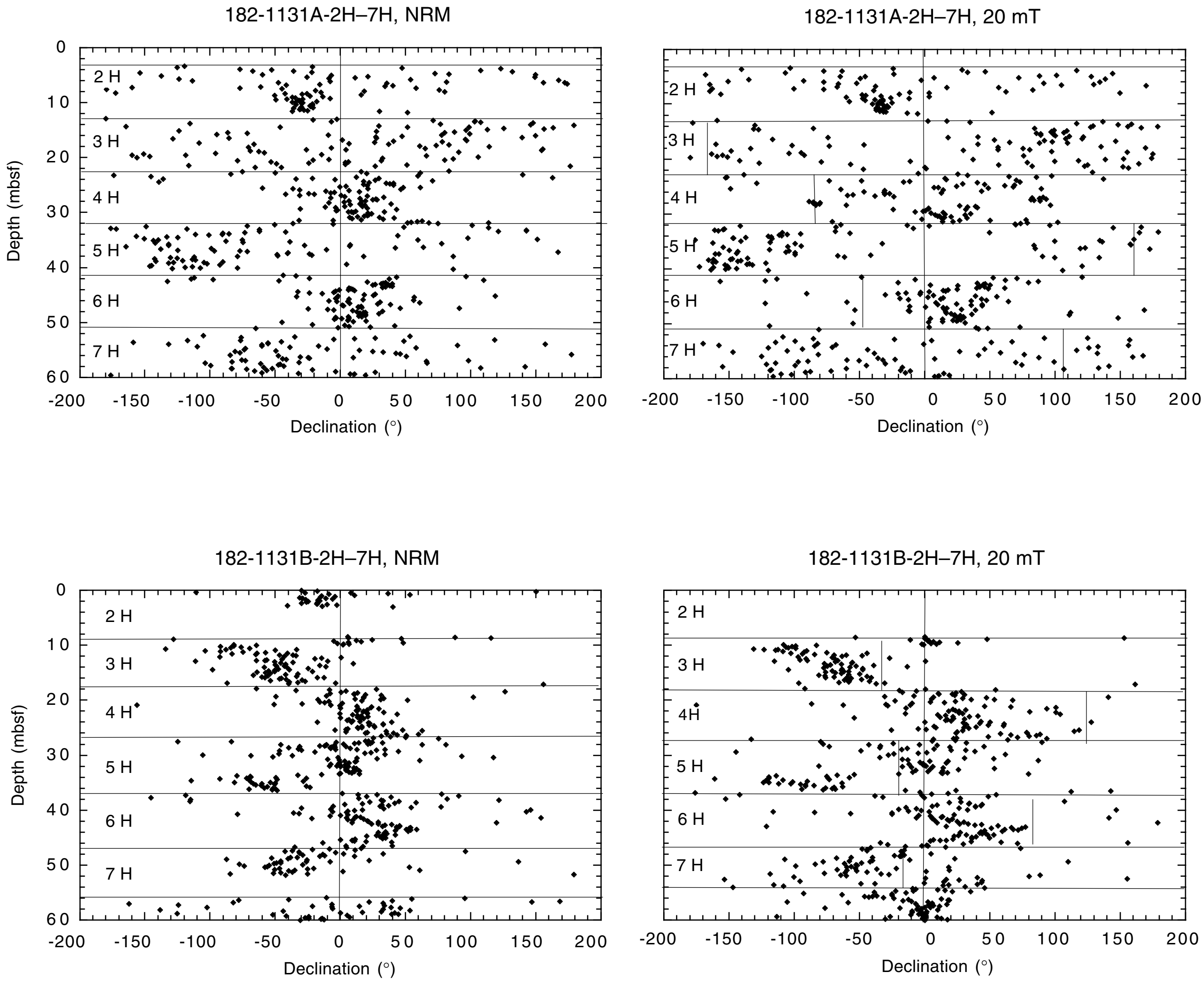

Figure F6. Comparison of whole-core (WC) and archive half-core (AH) measurements for Sections 182-1131B-3H-3 and 3H-4 and 182-1131B-4H-3 and 4H-4. Declination, inclination, and intensity are shown for the whole core natural remanent magnetization (NRM) and 20 mT demagnetization and for the archive half core after 20 mT demagnetization. DEC = declination, INC = inclination, INT = intensity.