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5. MAGNETIC FABRIC STUDIES OF ONTONG JAVA PLATEAU BASALTS FROM ODP LEG 192[1]

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ABSTRACT

Magnetic measurements of samples from Ocean Drilling Program Leg 192 cores were made to characterize the magnetic fabric of oceanic basalts from the Ontong Java Plateau. Results of anisotropy of magnetic susceptibility measurements from both pillowed and more massive units indicate broad similarities in their general properties but several important differences in the orientation of their anisotropy axes. Few samples studied show evidence of strong anisotropy but many of those that do are associated with the same changes in characteristic remanent magnetization inclination that have been used to identify inclination groups. Such groups are thought to represent a record of the Earth's magnetic field over periods too short to average secular variation. The more strongly anisotropic samples are therefore interpreted to be located near major boundaries between discrete cooling units.

The orientation of maximum magnetic susceptibility is dominantly subhorizontal and provides an estimate of local flow conditions. Azimuths of the maximum anisotropy axis of individual samples at each site have been used to identify a preferred azimuth that may reflect a sustained flow direction. These azimuths differ from site to site, suggesting that flow directions record local rather than regional conditions. Sites 1186 and 1187 exhibit the same strong directional bias along N155°, which is parallel to local bathymetric patterns. Site 1185 has a predominantly east–west preferred azimuth that is interpreted to represent the dominant flow direction near the eastern edge of the plateau. Site 1183 lies closest to the crest of the plateau but displays a weakly developed azimuthal bias along two orthogonal directions—one along

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N120°/300° and one along N30°/210°. This ambiguity reflects the difficulty in reliably defining a dominant flow direction in weakly anisotropic samples.

More detailed sampling and analysis are required to reliably identify individual flow units and to map changes in the flow regime across the plateau.

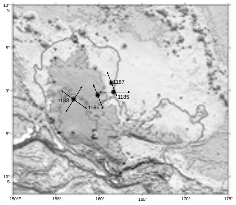
INTRODUCTION

Reviews of the application of magnetic fabric analysis to various rock types including igneous rocks have been provided by Tarling and Hrouda (1993), Jackson and Tauxe (1991), and Rochette et al. (1992). Magnetic fabric studies of various kinds of igneous bodies have been used extensively to examine their structure and emplacement history. Examples of fabric studies of igneous bodies include those involving dikes (e.g., Knight and Walker, 1988; Archanjo et al., 2002), sills (e.g., Ferré et al., 2002; Liss et al., 2002), plutonic complexes (Lopez-de-Luchi et al., 2002; Steenken et al., 2000; Talbot et al., 2000), and lava flows (e.g., Herrero-Bervera et al., 2002; Morris, 2000). Although there are many magnetic fabric studies of igneous bodies, those involving oceanic basalts are much less numerous, in part because of their complex extrusion and cooling histories (Ellwood, 1975, 1978; Ellwood and Watkins, 1976).

The primary purpose of these studies has been to improve our understanding of emplacement mechanisms for igneous bodies. Magnetic fabrics have been used to provide important constraints on the flow regimes associated with the formation of these bodies, especially dikes (Callot et al., 2001; Aifa and Lefort, 2001) and flows (Glen et al., 1997; Canon-Tapia et al., 1995). Recent work on the magnetic anisotropy of lava flows has focused more attention on their internal structure and the character of the boundaries between successive flows (e.g., Canon-Tapia et al., 1997; Canon-Tapia and Coe, 2002). These studies have examined individual flows in considerable detail to identify and characterize within-flow variations that can be interpreted in terms of their spatial position and cooling history.

In this study we present the results of magnetic fabric measurements on basalts from four sites drilled during Ocean Drilling Program Leg 192. Magnetic properties of both pillowed and more massive units obtained at Sites 1183, 1185, 1186, and 1187 on the Ontong Java Plateau (Fig. F1) are examined in an attempt to characterize systematic differences. Our sampling of the basalt cores is not sufficient to allow us to identify and characterize small-scale (approximately a few centimeters) within-flow variations for the Ontong Java Plateau. However, several of the within-flow characteristic features reported by Canon-Tapia and Coe (2002) in their study of the Birkett lava flow are apparent, if not well documented, in our results. To obtain a rough measure of within-unit variations in magnetic fabric, we made a detailed study of a single 1.3-m-thick complete pillow basalt from Site 1187. Although it is not known how typical this pillow may be and therefore whether other pillows would display similar variability, its overall dimensions and level of alteration are directly comparable to many others drilled during Leg 192, suggesting that it may be used to illustrate the variability present in many other pillows.

F1. Predicted bathymetry of the Ontong Java Plateau, p. 13.



A directional analysis of the anisotropy of magnetic susceptibility axes was also carried out for samples from each site in order to determine whether a preferred azimuth attributable to flow is present and also to examine differences in this azimuth between individual sites that might reflect the local rather than regional nature of the flow.

MEASUREMENTS

Magnetic susceptibility (κ) anisotropy of magnetic susceptibility (AMS), natural remanent magnetization (NRM), and the direction of characteristic remanent magnetization (ChRM) were measured for 277 basalt samples from Sites 1183, 1185, 1186, and 1187. A total of 166 samples were taken from pillowed sections; the remaining 111 were obtained from the more massive units. Pillowed units are characterized by the presence of glassy margins, groundmass grain-size variations, and vesicle-rich bands. More massive units are those that do not display any of these characteristics over core lengths >2 m. The lack of complete recovery, however, means that some massive units may be part of a pillowed sequence. In some cases, therefore, massive units may simply represent somewhat thicker pillows, whereas in other cases they may be part of a flow. The pillow and massive unit samples are not evenly distributed between the four sites because Sites 1183 and 1187 are dominated by pillows, whereas Sites 1185 and 1186 are characterized by more massive units. Although samples were obtained on average every 1 to 2 m, the stratigraphic sampling interval at each site is very irregular. Some intervals were intensively sampled (<20 cm), and others were sparsely sampled (>5 m). There are also several large gaps involving >10-m intervals where sampling was not possible due to poor core recovery or the fragmented nature of the core. One complete pillow from Site 1187 was sampled at 10-to 15-cm intervals from the top through the interior to the base of the pillow. Of the >160 samples obtained from pillows, only four samples were collected from regions known to be near their glassy rims. More than 90% of the pillow samples were obtained from points >10 cm from the nearest identifiable margin.

The magnetic measurements were made at three different laboratories: University of California at Santa Cruz, University of Houston, and University of Munich. The susceptibility measurements were made using either a Kappabridge KLY-3 (University of California at Santa Cruz and University of Munich) or an SI-2 by Sapphire Instruments (University of Houston). In all cases the basalts are strongly magnetic and therefore produced reliable estimates of both bulk susceptibility and AMS. Repeat measurements on the same instrument carried out on a number of Site 1185 samples demonstrated remarkable consistency, confirming the reliability of the measurements. Although no individual sample was measured at more than one laboratory, comparison of the results from each laboratory with those obtained on board the *JOIDES Resolution* demonstrated consistent results, indicating that the individual measurements are directly comparable. Details regarding the measurement of NRM intensities and ChRM directions are provided in Riisager et al. (2003).

Anhysteretic remanent magnetization (ARM) measurements were carried out on 20 samples (10 each from Sites 1183 and 1187). Samples were placed in a steady 0.2-mT field and then demagnetized using a maximum alternating field (AF) of 70 mT. Results of the AF demagnetization of NRM indicate most samples have median destructive fields <25 mT and that <10% of the remanence is carried by minerals with coercivities >70 mT.

RESULTS

General Properties

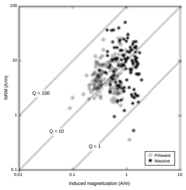
Site mean values of the mean susceptibility,

$$(\kappa_1 + \kappa_2 + \kappa_3)/3,$$

and NRM intensity for both pillowed and massive units are given in Table **T1.** Although the mean susceptibility of individual samples varies from 0.003 to 0.06 SI units, most samples have values in a much narrower range (i.e., 0.01–0.03 SI units). In contrast, NRM intensities vary over two orders of magnitude (Fig. **F2**). There is a tendency for the more massive units to have somewhat higher susceptibilities and NRM intensities, but differences with pillowed units are relatively minor and do not appear to be pervasive. For example, samples from the massive units at Site 1187 have lower NRM intensities than the pillow samples (Table **T1**). Site to site comparison, however, is limited by the uneven sample distribution between pillowed and massive units at the individual sites. For example, 90% of the samples at Site 1187 are from pillowed units. A majority of samples have high Koenigsberger ratios (*Q*), reflecting the well-known dominance of remanent magnetization in oceanic basalts (Fig. **F2**). Basaltic material obtained at Site 1185 was divided into upper and lower groups based on significant geochemical differences (Shipboard Scientific Party, 2001). These differences are also reflected in magnetic properties, particularly the mean susceptibility values, which are notably larger for the lower group.

T1. Magnetic properties of basalts, p. 20.

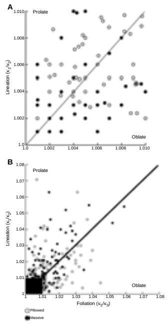
F2. NRM vs. induced magnetization, p. 14.



Fabric

Magnetic fabric parameters (lineation, *L,* foliation, *F,* and shape factor, *T*) show considerable variation within individual sites. However, a majority of samples from all sites have low lineation ($1.0 < L < 1.01$) and foliation ($1.0 < F < 1.01$) values, indicating that most samples have low anisotropy with neither strongly oblate nor strongly prolate character (Fig. **F3A**). Figure **F3B** shows that for those samples that exhibit larger lineation and foliation values there is a minor tendency for the more massive units to have higher lineation values and therefore to be more prolate. Of the massive unit samples, 57% have prolate and 43% have oblate shapes, whereas pillow samples are almost equally distributed between prolate (49.4%) and oblate (50.6%) shapes.

F3. Lineation vs. foliation, p. 15.



The degree of anisotropy (*A*),

$$100 \times [1 - (\kappa_2/2\kappa_1) - (\kappa_3/2\kappa_1)]$$

(Canon-Tapia, 1992, 1994), of Leg 192 basalts also shows considerable variability, but a majority of samples have low values ($A < 2$). Although approximately one-third of the samples (92/277) have values of $A > 2$, only 13 (~5%) have values of $A > 5$. The massive units are characterized by slightly larger values of *A,* but several pillowed units have values of $A > 5$, indicating that differences between massive and pillowed units are again relatively minor. Large values (i.e., $A > 5$) have been linked to the anisotropy produced during rapid cooling in high-stress environments such as those found at the boundaries of flows or pillows (Canon-Tapia and Pinkerton, 2000). As such, large values of *A* may be used to define flow boundaries. Some samples with large *A* values are close to such boundaries identified while drilling during Leg 192, but many are not.

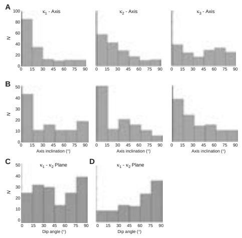
Directional Analysis

The directions of maximum, intermediate, and minimum susceptibility (i.e., κ_1, κ_2, and κ_3) axes were examined in order to detect the presence of any preferred orientation of key fabric features such as lineation and foliation. Directions in the vertical (i.e., inclination) and horizontal (i.e., azimuth) planes were examined separately because the cores were not azimuthally oriented when drilled and their absolute orientation in the horizontal plane is therefore more uncertain than that in the vertical plane.

Inclinations

Figure **F4** shows histograms of the inclination of the κ_1, κ_2, and κ_3 axes for pillowed and massive units for all sites. Both pillowed (Fig. **F4A**) and massive (Fig. **F4B**) units show a tendency to shallow inclination (<20°) for the κ_1 axis. Shallow κ_1 inclinations are observed in both oblate and prolate samples and in those with small and large degrees of anisotropy, *A*. Similarly, in many cases the κ_2 axis is also shallow. In the case of pillowed units, the κ_3 axis appears to be almost randomly oriented in the vertical plane with just a minor suggestion of a bimodal distribution of shallow (<15°) and steep (~70°) inclinations. In the case of the massive units, the κ_3 axis shows a definite bias toward shallow angles. In addition, several massive samples have steep κ_1 axes—a feature less prevalent in the pillowed samples.

F4. Inclination of the κ_1, κ_2, and κ_3 axes, p. 16.



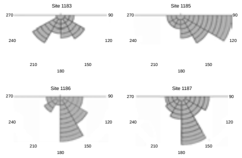
The dip of the κ_1–κ_2 plane was calculated and is shown in histogram form for both pillowed (Fig. **F4C**) and massive (Fig. **F4D**) samples. Clearly, the more massive units are dominated by steeply dipping κ_1–κ_2 planes with almost one-half (50/111) having dips >70°. Samples from the massive units with steeply dipping κ_1–κ_2 planes and shallowly inclined κ_3 axes (Fig. **F4B, F4D**) have a mostly prolate fabric. Thus, for many of the massive units the κ_1–κ_3 or the κ_2–κ_3 plane is nearly horizontal and is thought to represent the flow plane. In contrast, dips of the κ_1–κ_2 plane for pillowed samples show a bimodal distribution with both shallow (<30°) and steep (>60°) dips (Fig. **F4C**). For many of the pillowed samples the κ_1–κ_2 plane is subhorizontal, which together with the dominance of shallow κ_1 axis (Fig. **F4A**) suggests that for many pillowed samples it is the κ_1–κ_2 plane that is the flow plane.

Azimuths

Rotary drilling during Leg 192 produced cored pieces of basalt that were not azimuthally oriented. To obtain information regarding any preferred azimuthal direction that may be associated with their flow, the basalts must first be oriented with respect to a fixed common direction. This was done using the ChRM to define magnetic north at the time of basalt eruption. The ChRM direction for most samples has been well defined using standard alternating-field and thermal demagnetization techniques (Riisager et al., 2003). However, the directions for individual samples also reflect the influence of secular variation and, as such, do not provide a single fixed direction but rather give an approximate direction to magnetic north defined by an axial dipole. The range of magnetic declination is thought to be small (<15°) and is not therefore further accounted for in the directional analysis. However some of the variation in flow directions described below may be attributable to secular variation.

Preferred azimuths were initially determined for both pillowed and more massive units using the κ_1 direction. For samples with shallowly inclined (<15°) κ_1 directions, the preferred direction was selected as the κ_1 azimuth. For samples with steep κ_1 inclinations—dominantly those associated with samples from the massive units—the κ_2 direction was chosen as the preferred azimuth. In those cases where the κ_1 and κ_2 axes have intermediate inclinations but lie in an almost vertical plane (i.e., where the $\kappa_1 - \kappa_2$ azimuthal difference is 180° ± 20°), the strike of the vertical plane (i.e., a line perpendicular to the κ_3 azimuth) was chosen as the preferred azimuth. In samples where the κ_1 axis was neither shallow (<15°) nor steep (>75°) and the κ_1–κ_2 plane was not near vertical, no preferred azimuth was assigned. Approximately 50% of the samples from each site met these criteria and were used to determine a preferred azimuth. Because the κ_1 (or κ_2) axes of these samples are all shallow (<15°), it is difficult to unambiguously determine which of the two possible antipodal directions is correct. Accordingly, all of the individual azimuths have been rotated into the either the southeast or the southwest quadrant and displayed as Rose diagrams (Fig. **F5**). The mean preferred direction for each site was determined using a simple Gaussian distribution for all azimuth data and a Fisher distribution for the inclinations and declinations of the κ_1 (or κ_2) axes (Table **T2**).

F5. Distribution of AMS azimuths, p. 17.

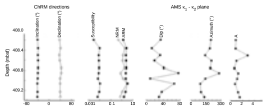


T2. Preferred AMS azimuths, p. 21.

Single Pillow Study

Ten samples obtained from a single 1.3-m-thick pillow basalt at Site 1187 were analyzed in detail. The remarkably uniform ChRM directions (<2° variation in inclination and ~5° variation in declination) (Fig. **F6**) are consistent with the jigsawlike fit of the individual pieces, indicating that the pillow is more or less intact. This consistency in the ChRM directions suggests that there has been no significant internal disruption of the pillow since it acquired its magnetization, although the entire pillow may have been tilted subsequent to magnetization. The uniformity in the paleomagnetic results also suggests that sampling pillows at points anywhere in their interiors will likely produce representative and reliable ChRM directions. The NRM intensity, mean susceptibility, and ARM intensity are relatively uniform, with minor decreases in those samples near the top and bottom reflecting changes in grain size. As shown by Figure **F6,** samples >15 cm from either the top or the bottom have very uniform properties. This is also true for many of the magnetic fabric parameters (e.g., lineation, foliation, and degree of anisotropy), which exhibit relatively uniform values throughout the pillow. The AMS fabric *directions*, on the other hand, are more variable, with substantial changes in the orientation of the κ_1–κ_2 plane toward the pillow center. In the upper 50 cm and lower 15 cm, the κ_1 axis is consistently <25° and the κ_1–κ_2 plane has a subhorizontal (<30°) attitude. Although the κ_1 axis remains shallowly inclined throughout, the dip of κ_1–κ_2 plane changes substantially in the central portion to almost vertical (Fig. **F6**). In this same depth interval, between 60 and 90 cm from the top of the pillow, the dip direction (i.e., azimuth) of the plane undergoes a roughly 90° counterclockwise rotation. As shown in Figure **F6,**

F6. Magnetic properties of a single pillow, p. 18.



these changes in magnetic fabric directions appear to have no measurable influence on the ChRM.

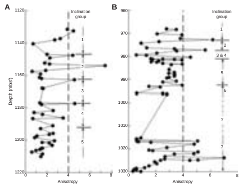
DISCUSSION

Previous magnetic fabric analyses of oceanic basalts by Ellwood (1975) and Ellwood and Watkins (1976) focused attention on the nature of their emplacement. Ellwood (1975) presented a parameter, the *F*-factor, the value of which could be used to distinguish between intrusive and extrusive igneous bodies. We have calculated values of this parameter for our samples which show that ~10% (i.e., 29 samples) have *F*-factor values indicative of intrusive rocks. This is consistent with the extrusive nature of practically all of our samples. Based upon the standard parameters used to describe their magnetic fabric, it appears that the majority of our samples exhibit weak anisotropy. Ellwood (1978) reports similar low anisotropy values for the basaltic bodies he examined. In general this is true for both the pillowed units and massive units, although the massive units show a minor tendency to greater anisotropy. Differences between pillowed and massive units, however, are mostly small, and similarities in their magnetic properties are more pronounced. The broad similarity between the pillowed and massive units may in part be attributed to difficulties in discriminating between those massive units that are part of basaltic flows from those that are simply thicker pillows. There are some differences in the magnetic fabric that may be discerned in the orientations of the anisotropy ellipsoid. The subhorizontal plane of the ellipsoid (which is assumed to represent the flow plane) is somewhat different for pillowed samples than the massive samples. For many massive units the κ_3 axis is nearly horizontal with either the κ_1–κ_3 or κ_2–κ_3 plane, forming a subhorizontal flow plane, whereas for many of the pillowed samples it is the κ_1–κ_2 plane that is nearly horizontal. These differences are not pervasive, however, and there are examples of both steep κ_1–κ_2 planes for pillowed samples and shallow κ_1–κ_2 planes for massive units.

Laboratory experiments by Canon-Tapia and Pinkerton (2000) on simulated lava flows suggest that high values of the degree of anisotropy, A, may be associated with environments where the rocks are deformed close to their eruption temperatures and then cooled rapidly, reflecting conditions near the boundary or edge of an individual flow. Conversely, low values of A appear to be associated with more gradual cooling, suggestive of interior portions of flows (Canon-Tapia and Pinkerton, 2000). In principle, therefore, values of A together with other changes may be used to identify boundaries between individual cooling units. In the experiments of Canon-Tapia and Pinkerton (2000), the distinction between high and low values of A is not sharply defined, but generally values of $A < 3$ are considered low and values of $A > 4$ are considered high. As noted above, most of the pillowed samples in our study were obtained from portions of the pillow away from the chilled, glassy margins and, consequently, their low A values are consistent with their interior locations and presumably more gradual cooling conditions.

In their work on the Birkett flow, Canon-Tapia and Coe (2002) identify individual flow units based upon changes in both magnetic fabric parameters, especially A, and dominant AMS directions. Their results suggest individual flow units have variable thicknesses but are generally between 0.2 and 1.9 m thick. Unfortunately, sampling of the massive units in our study is generally too coarse to identify and document individual flow units with such thicknesses. Several samples have high *A* values, but we have insufficient samples between these to characterize individual flow units. The various pillow and massive units have been subdivided into inclination groups on the basis of their ChRM directions. Boundaries between inclination groups have been chosen on the basis of the ChRM inclination values and their variability. As such, the inclination groups are in some intervals well defined and elsewhere poorly defined. An examination of *A* values at or near the boundaries between inclination groups at all four sites shows that in many cases the transition is associated with higher *A* values (i.e., $A > 4$). For example, at Site 1183, values of *A* are generally <2, but for those samples at the transitions between inclination groups 1 and 2, 2 and 3, and 3 and 4, $A > 4$ (Fig. **F7A**). However, samples near the transition from groups 4 to 5 do not have large *A* values. Furthermore, within inclination group 2 there is a sample with high value ($A > 7$). Similar correlations of high *A* values with boundaries between inclination groups can be made at each of the other three sites. At Site 1186, boundaries between inclination groups 1 and 2, 2 and 3, 4 and 5, and 5 and 6 are all associated with spikes in *A* values that are 4 or greater (Fig. **F7B**). But there are a number of intervals within the presently defined inclination groups at each site where *A* is high but no substantial change in the ChRM inclination is recorded. Individual inclination groups often span several stratigraphically successive samples even though they are clearly from several separate pillows or flows. In a succession of flows or pillows that form during a short time interval, there may be several individual bodies that have boundaries where rapid cooling takes place. Such a succession is expected to have the same magnetic field directions and therefore would be part of the same inclination group. High values of *A* in the middle of an inclination group are therefore not unexpected. High values of *A* associated with boundaries for the Birkett flow are observed over 10- to 20-cm intervals, and it is therefore entirely possible that such boundaries have been missed by our coarse sampling.

F7. Variation in the degree of anisotropy, p. 19.



Studies of magma flow directions derived from oceanic pillow basalts are very limited. Ellwood (1978) examined the anisotropy ellipsoid of samples from two pillows and found preferred azimuths but was unable to relate these to geographic coordinates. Thus, although there are broad similarities between our results and those reported by Ellwood (1978), the limited number of samples from this latter study make detailed comparisons difficult. Preferred azimuths for the magnetic fabric have been identified at each site, although the standard deviations and α-95 angles are large, making it possible to only define the quadrant with any reliability. Estimates of the secular variation at ~120 Ma for a paleolatitude of ~25° (corresponding to the Ontong Java Plateau) suggest changes in the magnetic pole position of ±18° (McFadden et al., 1991). Secular variation may therefore contribute in a significant way to the large standard deviations. For two sites (i.e., 1186 and 1187) there is a strong directional bias; for Site 1185 there is a modest directional bias, and for Site 1183 there are two more or less orthogonal directions for which there is a minor directional preference (Fig. **F5**). To relate these directions to the overall geometry of the Ontong Java Plateau it is necessary to reorient the directions so that they are referenced to the location of the paleomagnetic north pole at the time of basalt eruption at ~120 Ma. Unfortunately, the Apparent Polar Wander Path for the Pacific plate for the Early Cretaceous is not well determined, and, consequently, the direction to magnetic north is not well defined. In a recent study based upon results from Leg 192, Riisager et al. (2004) estimated a pole for the time of eruption of the Ontong Java Plateau basalts. This pole, located at 63.0°N, 10.1°E, lies ~15° counterclockwise of geographic north with respect to the sites. To account for this difference, the preferred azimuths for each site given in Table **T2** and shown in Figure **F5** have been rotated counterclockwise by 15° in Figure **F1.** Sites 1186 and 1187, which are located >200 km apart, have essentially the same strong preferred azimuth along ~N155° (or N335°). The similarity in the preferred azimuths at Sites 1186 and 1187 is somewhat surprising because the value for Site 1187 is based mostly on pillow data, whereas the Site 1186 direction comes mostly from massive samples. The N155° direction is almost perpendicular to a line from these sites toward the present-day shallowest part of the plateau (Fig. **F1**). It is therefore not clear whether the directional bias relates to the flow direction or a direction perpendicular to flow. Although some studies have indicated that the κ_1 axis may be perpendicular to flow (e.g., Ellwood, 1978), many more studies have indicated that flow is generally parallel to this axis. An alternative explanation is that the directions represent local flow patterns. Site 1185, with a somewhat smaller azimuthal bias, has a preferred azimuth along ~N90°/270°—a direction that points approximately toward the present-day crest of the plateau. Site 1185 also lies near the edge of the plateau (Fig. **F1**), and the preferred azimuth is almost orthogonal to this boundary. Site 1183, which lies closer to the plateau crest than the other sites, has two rather poorly defined preferred azimuths: N120° and N210°—both of which can be interpreted as flow directions away from the crest. Because the two directions are orthogonal to one another, it is also possible that only one represents the flow direction but, if so, it is not known which direction is the flow direction.

The results for Sites 1183 and 1185 are broadly consistent with a flow direction away from the shallowest part of the plateau. The common direction at Sites 1186 and 1187 is more problematic because it is roughly parallel to the general bathymetric trend near these sites. A more detailed fabric analysis is needed to resolve whether the N155° azimuth represents the flow direction at these sites or some other attribute of emplacement.

SUMMARY

Drilling on the Ontong Java Plateau during Leg 192 provided an opportunity to examine the magnetic properties of oceanic basalts produced during eruption of the world's largest igneous province. We examined the magnetic fabric of basalt cores for evidence of anisotropy related to their style of emplacement and cooling history. Broadly similar AMS characteristics involving only minor anisotropy are observed for most samples from both pillowed and more massive flow units. Only a few samples display higher degrees of anisotropy, but many of these are associated with changes in ChRM inclination and are thought to reflect major boundaries between successive cooling units.

The axis of maximum magnetic susceptibility of individual samples is dominantly subhorizontal and is believed to provide a reliable estimate of local flow conditions. The azimuths of the maximum anisotropy axis for each site were used to identify any preferred azimuth that may reflect a sustained flow direction. Differences in the preferred azimuth at each of the four sites suggest that the flow directions may reflect local rather than regional conditions. Although Sites 1186 and

1187 exhibit the same strong directional bias along N155°, the other sites display different azimuths. Site 1185 has a predominantly east–west preferred azimuth that is interpreted to represent the dominant flow direction near the eastern edge of the plateau. Site 1183, which lies closest to the crest of the plateau, has only a weakly developed azimuthal bias along two orthogonal directions—one along N120°/300° and one along N30°/210°.

More detailed sampling and analysis are required to reliably identify individual flow units and to map changes in the flow regime across the plateau.

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Figure F1. Predicted bathymetry of the Ontong Java Plateau showing locations of Sites 1183, 1185, 1186, and 1187 and the mean preferred azimuths at each site.

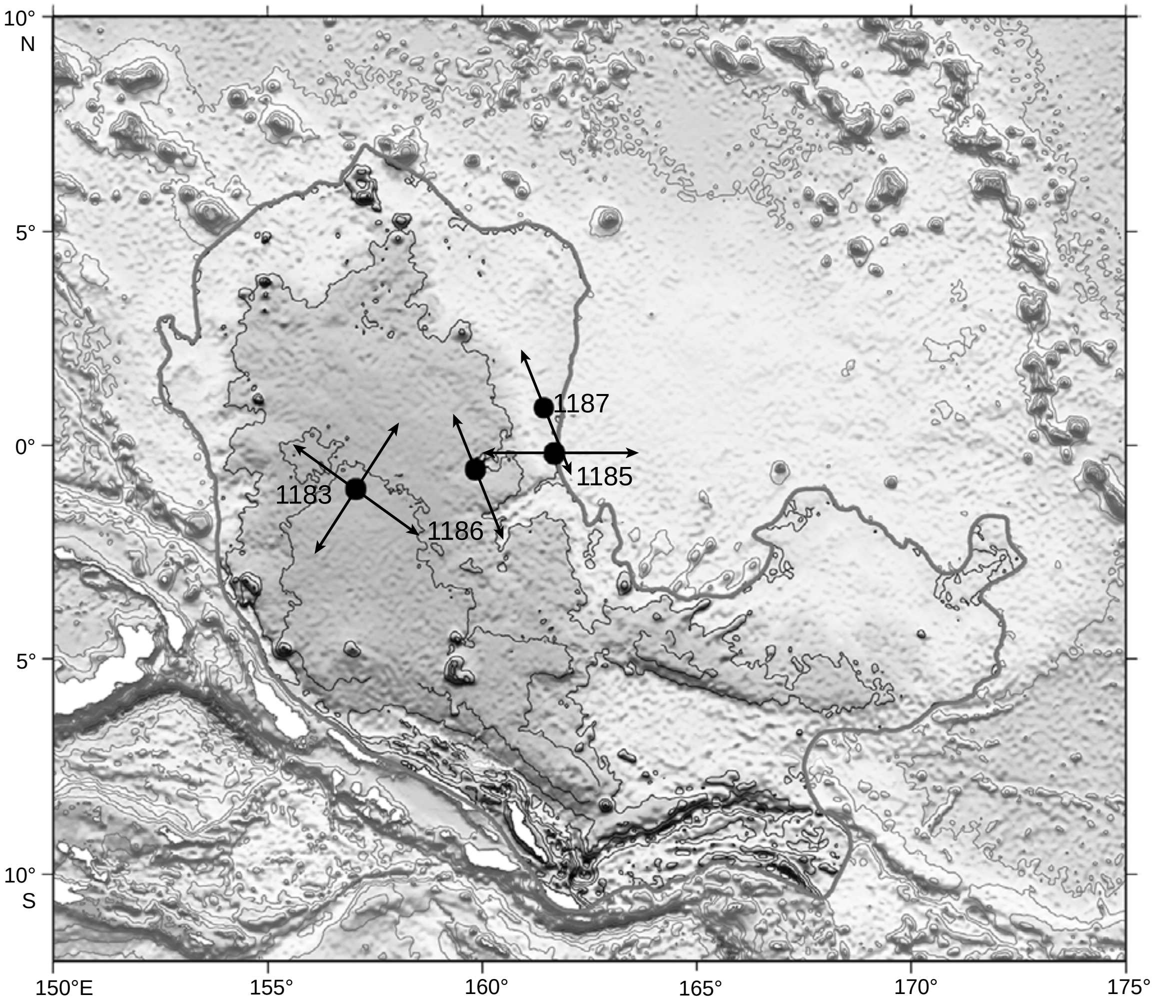

Figure F2. Plot of natural remanent magnetization (NRM) intensity (A/m) vs. induced magnetization (A/m) for samples from all sites. Open circles = samples from pillowed units, solid circles = samples from massive units. Induced magnetization represents mean susceptibility multiplied by 30 A/m. Q = Koenigsberger ratio.

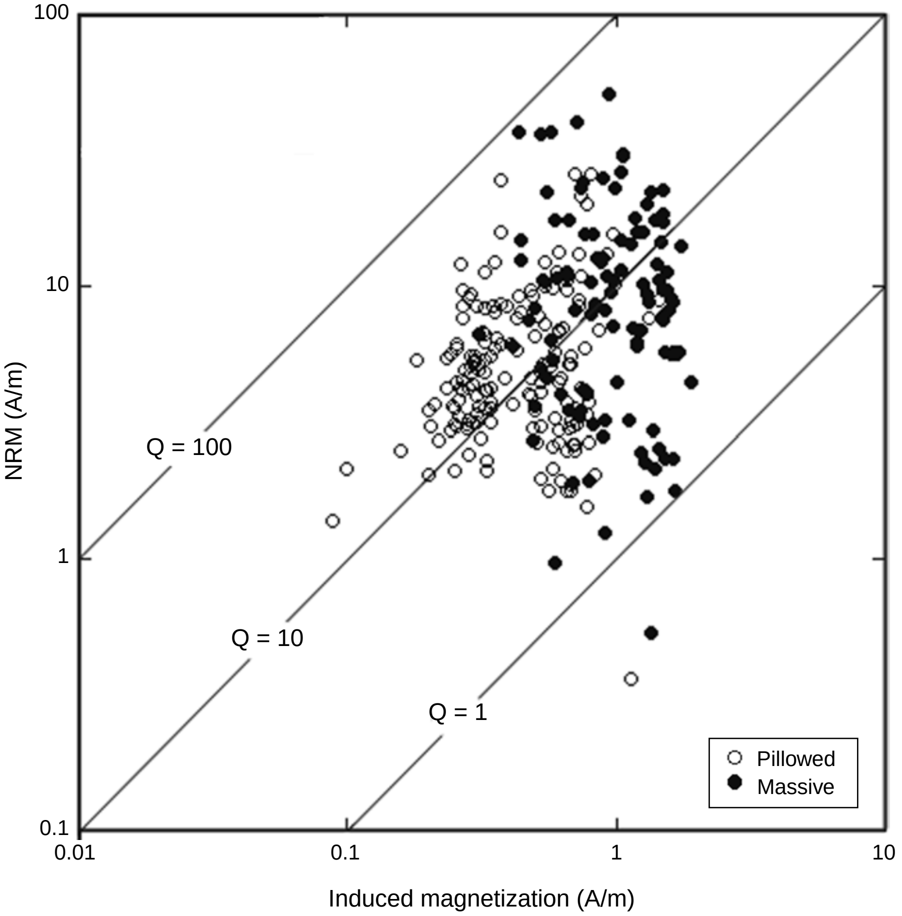

Figure F3. Plot of lineation (κ_1/κ_2) vs. foliation (κ_2/κ_3) for samples from all sites. Open circles = samples from pillowed units, solid circles = samples from massive units. **A.** Samples with lineation and foliation values <1.01. **B.** Samples with lineation and/or foliation values >1.01

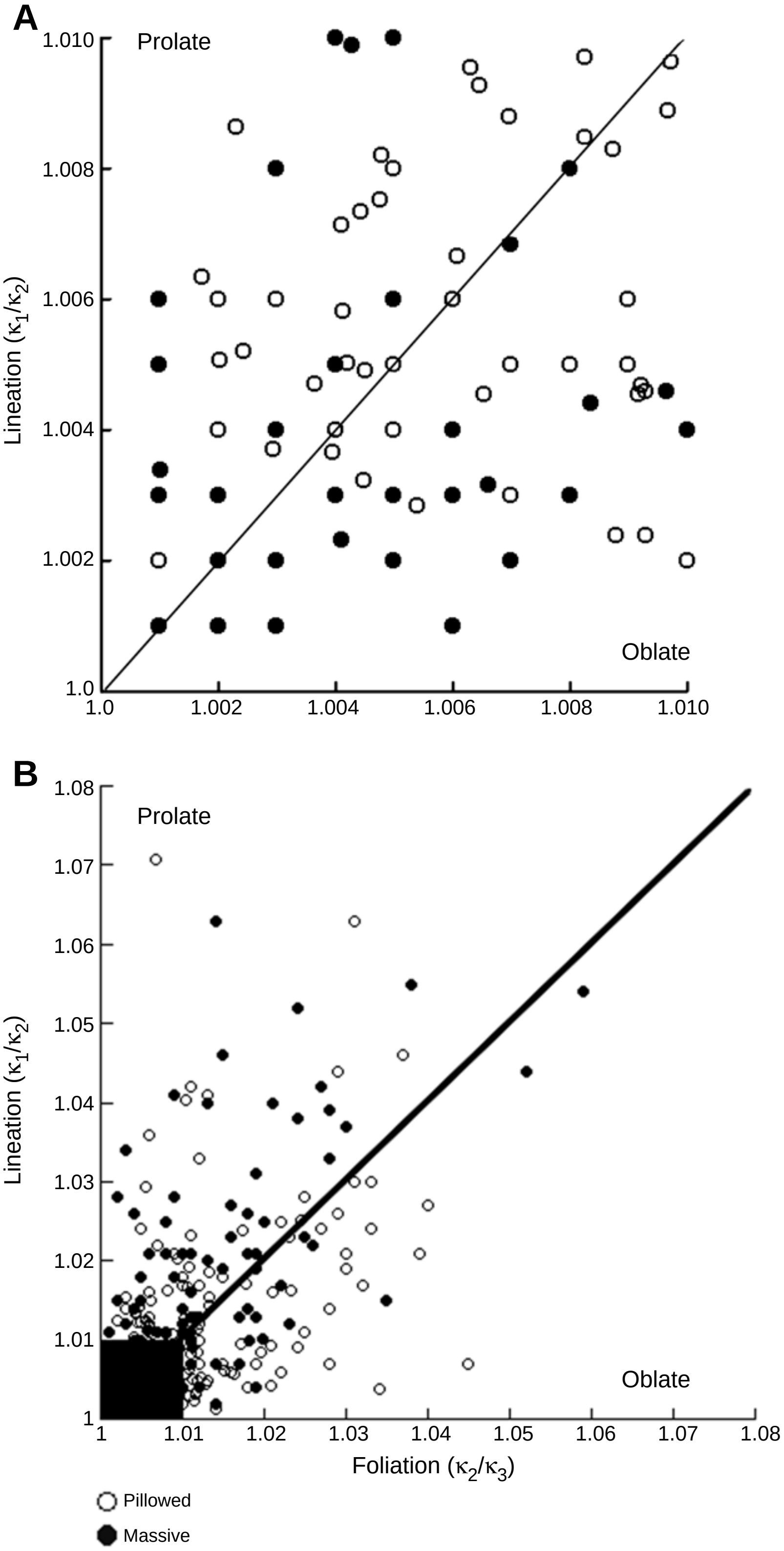

Figure F4. Histograms of the inclination of the κ$_1$, κ$_2$, and κ$_3$ axes for (**A**) pillowed units and (**B**) massive units. Histograms of the dip of the κ$_1$–κ$_2$ plane for (**C**) pillowed units and (**D**) massive units.

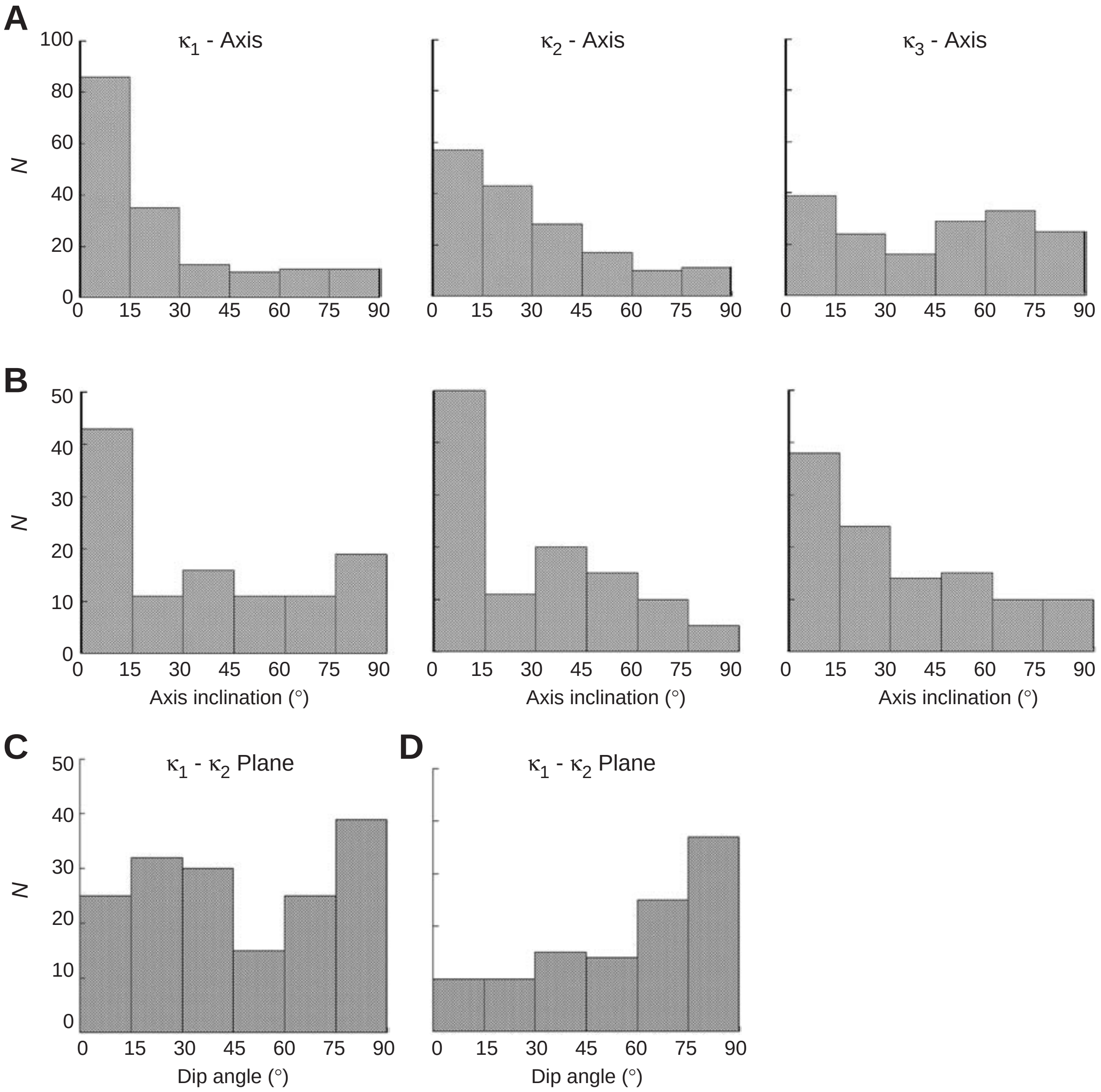

Figure F5. Rose diagrams showing the distribution of AMS azimuths for each site rotated into the southeast and southwest quadrants.

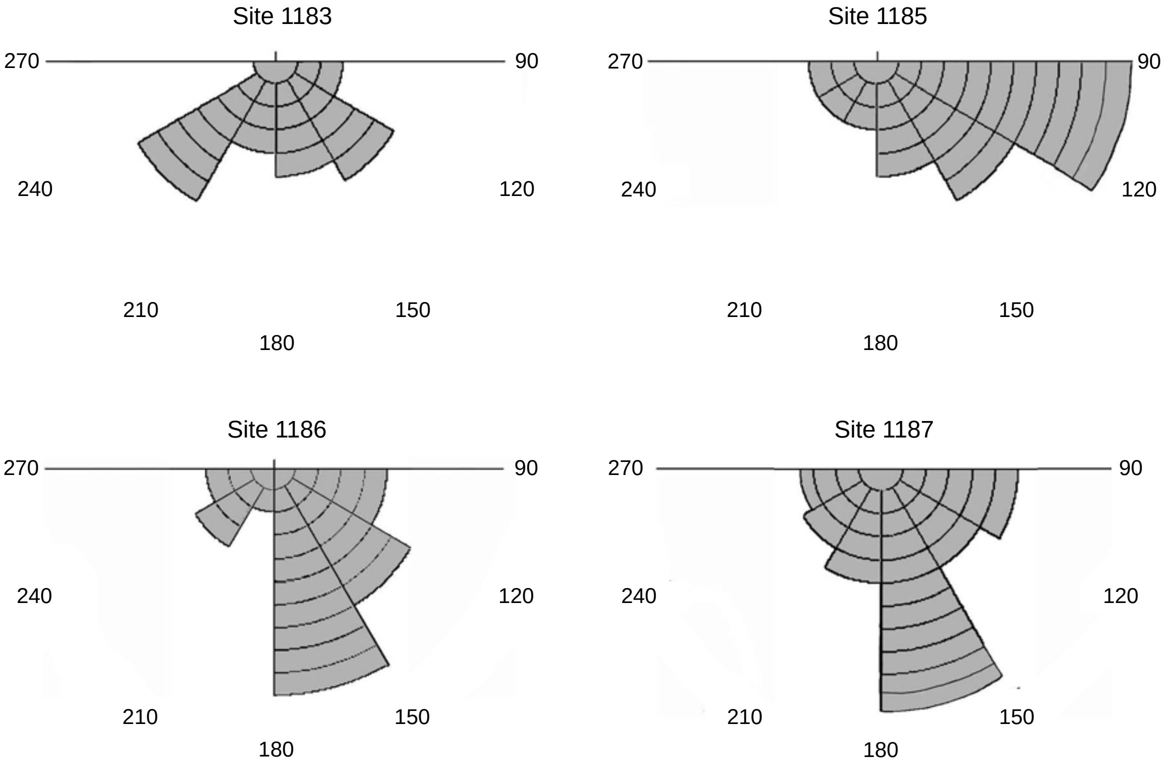

Figure F6. Magnetic properties of a single pillow from Site 1187 showing depth variations in characteristic remanent magnetization (ChRM) inclination and declination, mean susceptibility (in SI units), natural remanent magnetization (NRM) intensity (in Am²/kg × 10^{-3}), anhysteretic remanent magnetization (ARM) (in A/m), dip and dip azimuth of the κ_1–κ_2 anisotropy of magnetic susceptibility (AMS) plane, and the degree of anisotropy (A).

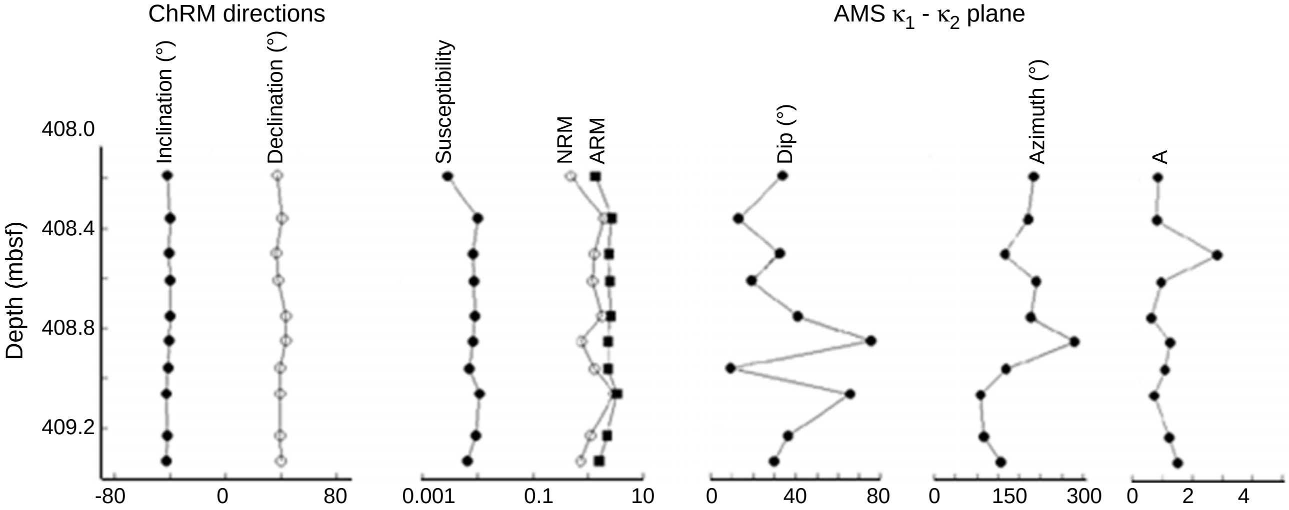

Figure F7. Variation in the degree of anisotropy, *A*, with depth for (**A**) Site 1183 and (**B**) Site 1186. Characteristic remanent magnetization inclination group boundaries from Riisager et al. (2003) are also shown.

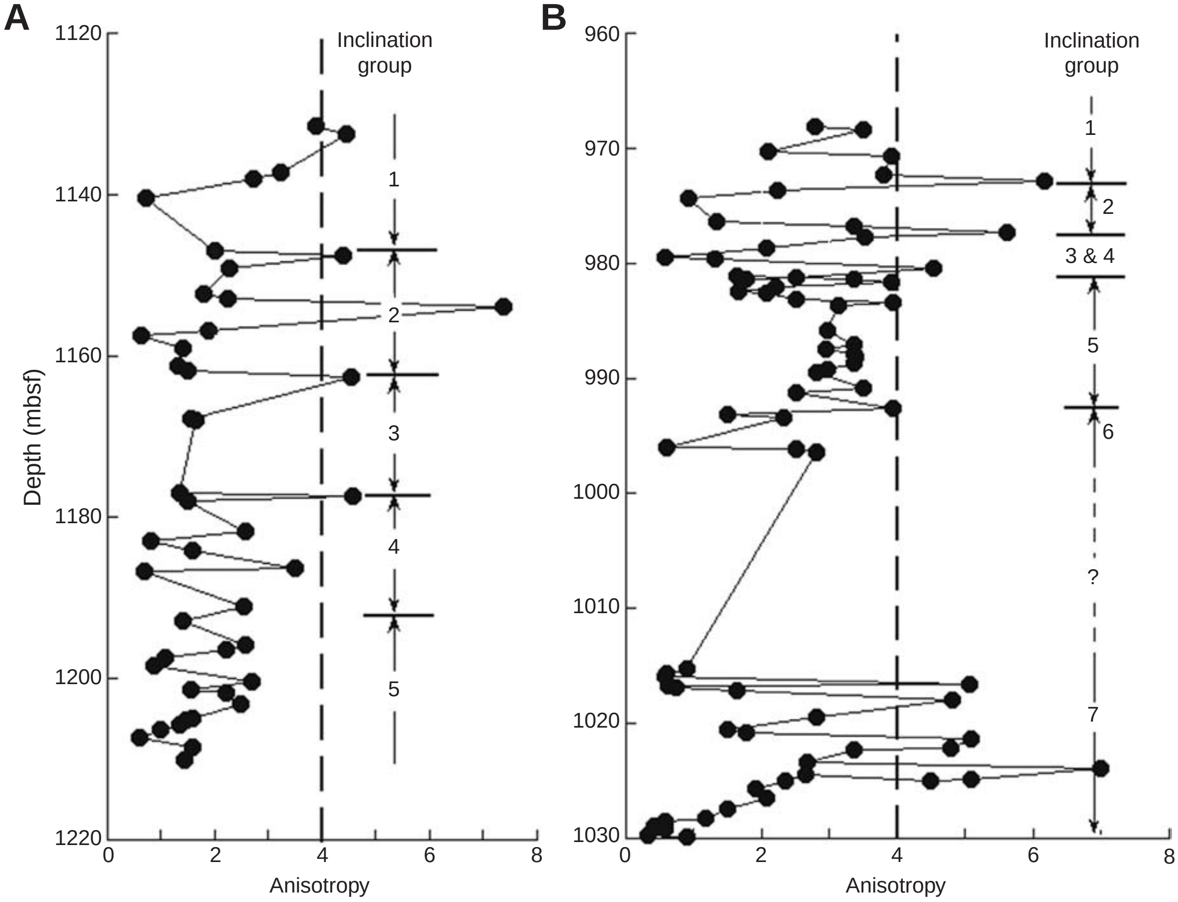

Table T1. Magnetic properties of basalts.

Site	Structure	*N*	Mean susceptibility (SI units)	Mean NRM intensity ($Am^2/kg \times 10^{-3}$)
1183	Pillows	34	0.022 ± 0.003	1.25 ± 0.55
	Massive	10	0.022 ± 0.004	2.07 ± 1.25
1185	Pillows	15	0.018 ± 0.010	3.26 ± 1.13
	Massive	45	0.034 ± 0.013	4.78 ± 3.86
1186	Pillows	27	0.023 ± 0.008	3.53 ± 2.49
	Massive	43	0.041 ± 0.011	4.21 ± 3.08
1187	Pillows	90	0.011 ± 0.004	1.86 ± 1.08
	Massive	11	0.022 ± 0.006	1.51 ± 0.63
All	Pillows	166	0.016 ± 0.008	2.13 ± 1.55
	Massive	111	0.035 ± 0.013	3.98 ± 3.34

Notes: *N* = number of analyses, NRM = natural remanent magnetization.

Table T2. Preferred AMS azimuths.

	Gaussian Distribution			Fisher Distribution			
Site	Preferred azimuth (°)	*N*	SD (°)	Preferred azimuth (°)	*N*	α-95 (°)	κ
1183	135 or 225	26	—	—	—	—	—
1185	107/287	32	46	109/289	29	16	3.6
1186	167/347	31	47	160/340	21	20	3.5
1187	171/351	68	45	170/350	66	11	3.6

Notes: The preferred azimuth is given with respect to magnetic north as defined by the characteristic remanent magnetization. *N* = number of analyses. SD = standard deviation.