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Brunhes–Matuyama polarity transition in three deep-sea sediment cores*

By B. M. Clement†, D. V. Kent† and N. D. Opdyke‡
†*Lamont-Doherty Geological Observatory and Department of Geological Sciences of Columbia University, Palisades, N.Y.* 10964, *U.S.A.*
‡*Department of Geology, University of Florida, Gainesville, Florida* 32611, *U.S.A.*

The Brunhes–Matuyama polarity transition was studied in three deep-sea sediment cores obtained from the mid-northern and equatorial Pacific Ocean. Rates of sedimentation vary from 0.7 to 1.1 cm ka^{-1}. The cores were sampled across the transition in 4 mm slices, and each level was further subdivided into three specimens. Inclinations above and below the transition interval are in close agreement with that of an axial dipole field. Estimates of transition duration based on directional change range from 4900 to 8500 years. The transition can be described by a longitudinally confined portion in each of the v.g.p. paths, but is complicated by broad loops in all three records. While fine-scale sampling reveals considerable detail, the notable increase in within-level dispersion observed in the transition and the apparent differences in v.g.p. paths in nearby cores from the same region indicate that factors other than the geomagnetic field may contribute to these transition records.

Introduction

Although it has been well documented that the Earth's magnetic field has reversed polarity many times, little is understood about the reversal process itself. This is primarily because detailed records of the field during a polarity transition are rare, and records of the same reversal from more than one site are even more rare. This scarcity of data has made attempts at modelling transition field behaviour difficult, although the additional records of polarity transitions that are becoming available have allowed some basic models to be developed (see, for example, Fuller *et al.* 1979; Hoffman 1977, 1979).

The successful determination of magnetic reversal stratigraphy from deep-sea sediments suggests that, in principle, detailed records of polarity transitions should be preserved. Because deep-sea cores are available from all the world's oceans, the potential exists to map transitional field behaviour on a global scale. Although sedimentation is considered to be fairly continuous in the deep sea, the accumulation rates are often low. It is therefore apparent that sampling on an extremely fine scale is required to obtain the desired resolution to address this problem.

Highly sensitive superconducting magnetometers permit the measurement of smaller and more weakly magnetized samples than was possible before. As a result several deep-sea sediment piston cores that span the Brunhes–Matuyama transition could be studied on a scale that was previously not feasible. The data are of interest because they provide constraints on the ability to obtain detailed records of geomagnetic field behaviour in sediments of slow deposition rate and contribute further information pertinent to current models of transitional field behaviour.

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METHODS

The cores used in this investigation were taken in the Pacific Ocean basin. Two of the cores (V20–107 and V20–108), from mid-northern latitudes, were taken less than 200 km apart and should therefore show similar transition records if the transitional field was dominated by dipole or low-order non-dipole terms. A core from the equatorial Pacific (RC15–21) provides an opportunity for comparison of transition behaviour with nearby cores studied by Freed (1977), as well as allowing the comparison of the site latitude dependence predicted in some reversal models (Williams & Fuller 1981).

In each of the cores, one of the split sections containing the transition was sampled continuously by cutting 4 mm slices with a jeweller's saw. Each slice of sediment was then cut into thirds, providing three specimens for measurement at each stratigraphic level. The resulting specimens measured approximately 8 mm × 8 mm × 4 mm. The specimens were weighed and then glued in a known orientation into plastic boxes.

The direction and intensity of the natural remanent magnetization (n.r.m.) of each specimen was measured in a two-axis cryogenic magnetometer (Goree & Fuller 1976). Progressive alternating field (a.f.) demagnetization was done at increments of 25 or 50 mT on six to ten pilot samples from each core. Analysis of the a.f. demagnetization results was used to determine an appropriate field in which to demagnetize the remaining samples in each core.

RESULTS

The results of the progressive a.f. demagnetization of the pilot samples were plotted in orthogonal vector endpoint diagrams (Zijderveld 1967), examples of which are shown in figure 1. In most cases it was found that after treatment at 10.0–15.0 mT a low-coercivity component was successfully removed, isolating a stable, characteristic magnetization. This characteristic component was identified by a linear trajectory decaying towards the origin. These same linear trajectories demonstrate that in spite of the smallness of each specimen, stable magnetizations can be readily measured and isolated by using a cryogenic magnetometer. The remaining specimens from each core were demagnetized with a field determined by the behaviour of the pilot samples during demagnetization. The inclination at each level is derived from the Fisher mean of the measured directions of the three individual specimens, while the intensity value represents the arithmetic mean of the three measured intensities normalized by specimen mass.

Although the cores were only internally oriented when taken, it was possible to construct a v.g.p. path by making a deliberate adjustment to the data. This was done by determining the mean declination for each core above and below the polarity transition. The mean declinations were assumed to represent an actual value of 360° or 180° depending upon the polarity, and the entire core segment was uniformly reoriented. It is believed that this adjustment is justified because the observed mean inclinations are in good agreement with the axial dipole field inclination at each site.

An important feature of a sediment record is that it allows an estimate of the duration of the transition to be made given that a sedimentation rate is available. For an accurate estimate to be made, the stratigraphic interval of the transition must be carefully identified. In this study, the transition as determined by the directional change is defined as beginning when the v.g.p.

path crosses 60° S and ending when it crosses 60° N and reaches a stable position near the north geographic pole. A more qualitative judgement is made about the interval over which a corresponding change of intensity occurs, as described for the individual cores.

The record from core V20–108 (see figure 2*a*) is characterized by inclinations that before and after the transition fall very close to the inclination of 64° predicted by an axial dipole field.

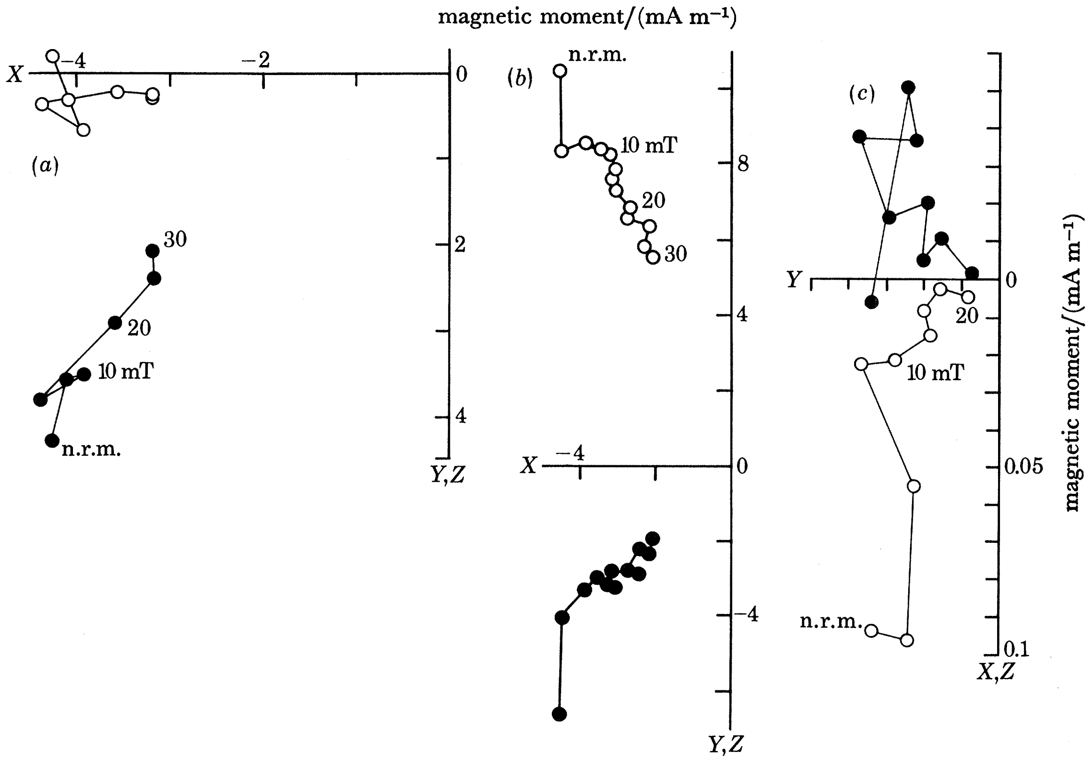

FIGURE 1. Examples of orthogonal vector endpoint diagrams obtained from progressive a.f. demagnetization of samples from (*a*) V20–108, (*b*) V20–107 and (*c*) RC15–21. Solid dots represent projections onto horizontal plane, and open circles onto vertical plane.

The transitional field appears to be recorded in a 7.0 cm section of core, beginning at 800.0 cm and continuing to 793.0 cm. The intensity from the same core shows a decrease that reaches a minimum between 708.7 and 795.1 cm and then begins to increase in value, the minimum is approximately 2 % of the maximum value observed in this section of the core.

The v.g.p. path constructed from the data from V20–108 (figure 3*a*) exhibits a transitional path that appears to be longitudinally constrained initially, being centred about 240° E Long. The older half of the transition record is characterized by a broad loop that crosses the equator at 85° E Long., approximately 180° of longitude away from the younger part of the path.

In core V20–107, intermediate directions are observed through 6.1 cm of sediment, from 532.3 to 526.2 cm, while the mean inclinations on either side of the transition are again in agreement with that predicted for an axial dipole field (see figure 2*c*). The accompanying intensity fluctuation occurs between 524 and 534 cm, reaching a minimum at 529 cm. Through this 10 cm section the intensity drops to 5 % of the maximum value.

The v.g.p. path across the transition consists of two parts. The early part is a wide loop that is

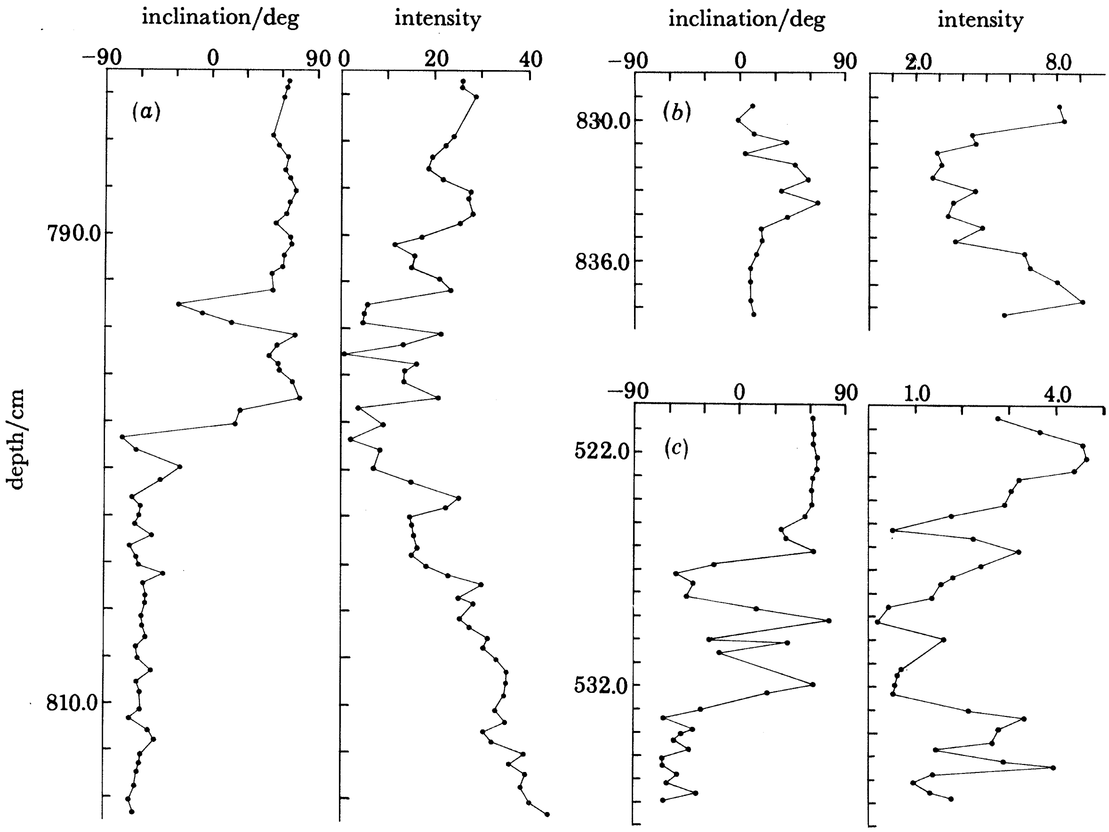

FIGURE 2. Mean inclination and intensity values for each stratigraphic level plotted against core depth for (*a*) V20–108, (*b*) RC15–21 and (*c*) V20–107. Intensity units are 1.0×10^{-2} for V20–108 and V20–107 and in 1.0×10^{-4} for RC15–21 (SI units normalized by sample mass).

roughly centred around 130° E Long., followed by a return to high southerly latitudes. The later part consists of a longitudinally confined path along 270° E Long. to high northerly latitudes. The total path consists of ten intermediate v.g.ps (see figure 3*b*).

The transition record obtained from the equatorial core, RC15–21, is characterized by a downward steepening in inclination from 835.8 to 833.5 cm followed by a shallowing of directions from 833.5 to 830.0 cm. The total direction change occurs across 5.5 cm of sediment. This change is accompanied by a decrease of intensity between 837 and 830 cm to about 30% of the maximum intensity measured (see figure 2*b*).

The v.g.p. path calculated from this record is plotted in figure 3*c*. This path consists of seven intermediate v.g.p. positions that define a northward longitudinally confined movement followed by two large concentric loops.

DISCUSSION

The primary goal of studying polarity transitions is to obtain information about the behaviour of the geomagnetic field during a reversal. Therefore when examining sediment records on a detailed scale it is critical to determine whether the directions observed are indeed a record of the geomagnetic field, or if they are in part a product of sedimentary processes capable of affecting the remanence acquisition process.

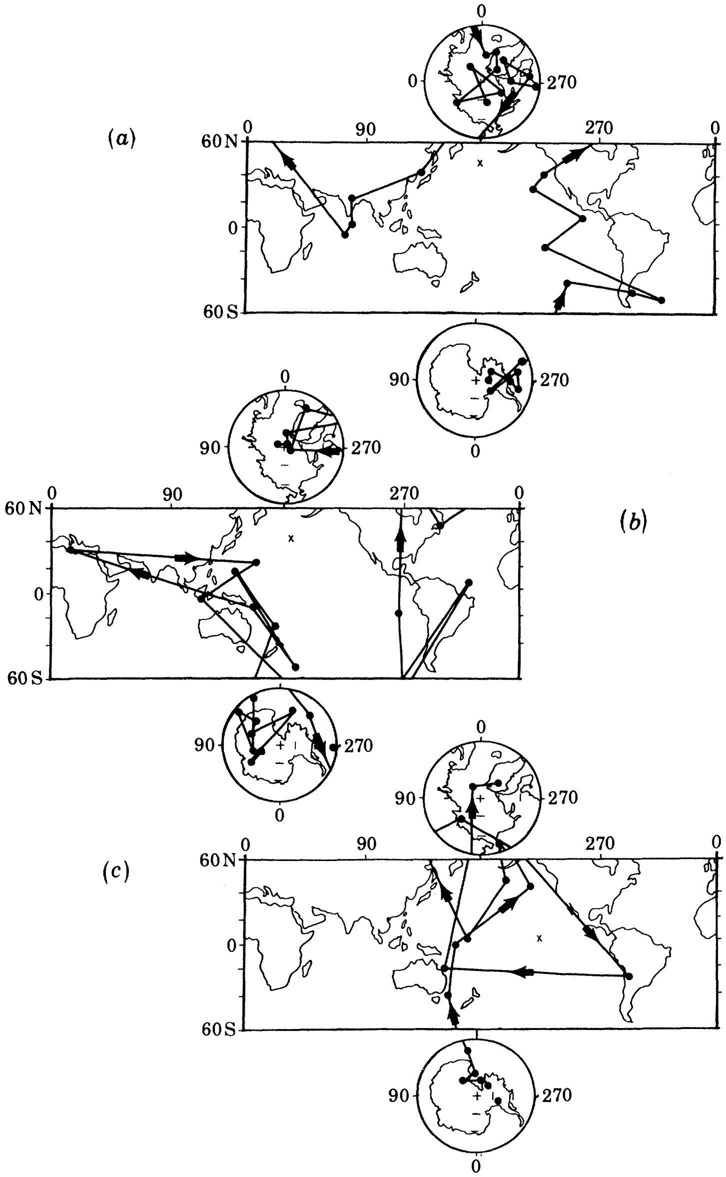

FIGURE 3. Transitional v.g.p. paths calculated for cores (*a*) V20–108, (*b*) V20–107 and (*c*) RC15–21. Each point represents the v.g.p. calculated from the mean direction determined at each stratigraphic level.

It should be noted that despite the smallness of the samples used in this study, the results demonstrate that the magnetizations could be readily measured. The most weakly magnetized specimens were encountered in core RC15–21, which exhibited a minimum total magnetic moment of 0.2 mA m^{-1} about an order of magnitude above the instrumental noise level. Furthermore, the internal consistency of the data and the recovery of inclination directions above and below the transition, in close agreement with expected dipole field values, demonstrates that the sediment magnetizations are homogenous on this sample scale, and as a whole can be interpreted as a record of the geomagnetic field.

As noted, a valuable characteristic of transition records obtained from sediments is that the duration of the reversal can be estimated, provided a sedimentation rate is known. Table 1 provides a summary of the sedimentation rates for these cores as well as the resolution (in terms of time represented by each sample) that sampling on a 4 mm scale provides. An estimate of the length of time it took for the field to reverse can then be obtained by dividing the core interval containing the transition by the sedimentation rate. The mean estimate of the duration of the transition is 6600 years.

Table 1

core	position		core length	length of Brunhes	sedimentation rate	time represented by each sample	length of transition	estimated duration of transition
			cm	cm	cm/ka	year	cm	year
V20–108	45° 27′ N	179° 14′ W	1671	792	1.1	360	7.0	6400
V20–107	43° 24′ N	178° 52′ W	1282	525	0.7	550	6.1	8500
RC15–21	01° 33′ N	132° 58′ W	2106	830	1.1	357	5.5	4900

This estimate is well within the range of transition durations discussed by Fuller *et al.* (1979). Most of the other estimates were also based on sediment records and were derived from sediments with varying accumulation rates. It is interesting to note for example, that the estimate of 4600 years by Opdyke *et al.* (1973) for the Lower Jaramillo is similar to that presented here for the Brunhes–Matuyama transition despite an order of magnitude difference in sedimentation rates. This agreement suggests that a reliable record of the first-order features of the transitional field has been obtained in our more slowly deposited sediments.

There are some indications in these data, however, that the detailed record during the transition may not be simply related to the geomagnetic field: for example, the v.g.p. paths for cores V20–108 and V20–107 do not exactly coincide as might be expected considering their geographic proximity. Only if the preceding and following loops are ignored are their v.g.p. paths similar, being constrained longitudinally to lie between 230° E and 270° E. In addition, the v.g.p. path for RC15–21 is not coincident with those obtained by Freed from nearby cores in the East Pacific (reported in Fuller *et al.* 1979).

The dissimilarities in v.g.p. paths from nearby cores can be explained either as noise in the record or as a result of incomplete records. With V20–108 and V20–107, however, it is apparent that both sections must be incomplete for the latter explanation because the loops occur in different parts of the transition. It was also observed in these three cores that a greater dispersion in directions exists among specimens from levels within the transition interval than in sampling levels outside the transition. The increased dispersion may result from unresolved multicomponent magnetizations or may be an indication that these sediments do not accurately record a geomagnetic field of apparent low intensity.

These observations indicate the possible influence of sedimentological factors, such as the effects of burrowing organisms, variations in remanence lock-in depth and small hiatuses, which can distort the magnetization record at the same fine scale at which details in transitional field behaviour are expected to be observed. Investigation of higher deposition rate cores, where the scale of sedimentary disturbances may encompass shorter time intervals, will be necessary to assess fully the reliability of observations of transitional field behaviour in sedimentary records.

Despite these uncertainties, and bearing in mind that most previous records of transitional field have been similarly obtained from sediments, some general comments regarding proposed models for the reversal process can be made based on the data presented here.

The three transitional v.g.p. paths (as previously defined) presented here are each characterized by a portion in which the v.g.p. position moves from high southerly latitudes to high northerly latitudes along a longitudinally confined path, lying no more than 90° in longitude away from the site. Thus the paths tend to be near-sided (Hoffman 1977), but not markedly so. In addition each path contains one or more loops which either precede the longitudinal path (V20–107) or follow it (V20–108 and RC15–21). The loops, which in all of these paths are generally clockwise, show a movement of the v.g.p. from high latitudes to very shallow ones with wide swings in longitude (of at least 90°) followed by a return to the geographic pole.

In general the longitudinal constraint observed in the portions of these paths in which the v.g.p. moves from high southerly latitudes to high northern latitudes supports models by Hoffman (1977), Fuller *et al.* (1979) and William & Fuller (1981) of an axisymmetric transitional field. It should also be noted that the inclination data from RC15–21 agrees with that predicted for an equatorial site by William & Fuller (1981) in that it is characterized by high (up to 79°) positive inclinations.

Williams & Fuller's model predicts transitional inclination patterns that are dependent upon site latitude. Their model also suggests that the duration of directional change might be a function of site latitude. With the three cores discussed here it is not possible to determine if the length of the observed transitional record is a function of geomagnetic field behaviour (as the Williams–Fuller model suggests) or a result of sedimentary processes affecting the remanence acquisition process. From table 1 it can be seen that the estimated duration of the reversal obtained from each core is not a function only of sedimentation rate or only of latitude. At this point there appears to be no way of isolating either of these two effects in these records.

Given the amount of complication in the available records and the number of parameters necessary in field behaviour models, it is understandable that workers at this point are forced to try to find similar characteristics in transitional records. Nevertheless, the potential significance of loops and other features, which are reported from several of the other available records (Fuller *et al.* 1979), and which do not fit into models assuming a purely zonal transitional field, should not be ignored. These complicated features of transition fields may be a result of noise in the record, but they may just as easily reflect more detailed records than those in which they do not appear.

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REFERENCES (Clement *et al.*)

Freed, W. K. 1977 *Trans. Am. geophys. Un.* **58**, 380.
Fuller, M., Williams, I. & Hoffman, K. A. 1979 *Revs. Geophys. Space Phys.* **17**, 179–203.
Goree, W. S. & Fuller, M. 1976 *Rev. Geophys. Space Phys.* **14**, 591.
Hillhouse, J. & Cox, A. 1976 *Earth planet. Sci. Lett.* **29**, 51–64.
Hoffman, K. 1977 *Science, Wash.* **196**, 1329–1332.
Hoffman, K. A. 1979 *Earth planet. Sci. Lett.* **44**, 7–17.
Ninkovitch, D., Opdyke, N. D., Heezen, B. C. & Foster, J. H. 1966 *Earth planet. Sci. Lett.* **1**, 476–492.
Opdyke, N. D., Kent, D. V. & Lowrie, W. 1973 *Earth planet. Sci. Lett.* **20**, 315–324.
Williams, I. & Fuller, M. 1981 *J. geophys. Res.* **86**, 11,657–11,665.
Zijderveld, J. D. A. 1967 In *Methods in paleomagnetism* (ed. D. W. Collinsen *et al.*), pp. 254–286. Amsterdam: Elsevier.