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Relative geomagnetic paleointensity across the Jaramillo subchron and the Matuyama/Brunhes boundary

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Abstract. Analysis of old paleomagnetic data and new mineral magnetic data from a sediment core from the central equatorial Pacific Ocean indicates that this core can be used for determination of relative geomagnetic paleointensity. These data indicate that during the Jaramillo subchron, there was a gradual decrease in paleointensity from the onset of the subchron to its termination. The data from the subchron also display high-amplitude, fine-scale features that may be coherent over the scale of an ocean basin. Furthermore, there was a rapid rise in paleointensity immediately after the termination of the Matuyama/Brunhes polarity transition. These observations support the hypothesis that an asymmetrical saw-tooth pattern in paleointensity may be a common characteristic of polarity transitions; however, a better understanding of the high-amplitude features is needed before definitive conclusions can be drawn about the overall behavior of the field. The coherence of fine-scale features across such large distances does not support the suggestion that the asymmetrical sawtooth pattern is an artifact of viscous remanent remagnetization.

Introduction

Valet and Meynadier [1993] recently published a paleomagnetic record from cores from the eastern equatorial Pacific Ocean. They claimed that their record represents a history of the relative paleointensity of the geomagnetic field over the past four million years. The most significant feature of this record is the gradual decrease in field intensity prior to most polarity transitions and the rapid rise to high intensity after the transition. Superimposed on this asymmetrical saw-tooth pattern are high-amplitude, finer-scale features.

If these observations are correct, they have profound implications for our understanding of the geomagnetic field. First, they imply that the geomagnetic field can vary systematically on a time scale comparable to the time interval between polarity transitions. This time scale is longer than that expected for coherent geomagnetic field behavior [Merrill and McElhinny, 1983]. Second, the results of Valet and Meynadier [1993] imply that the occurrence of a given polarity transition is determined by the rate of decay of the field and by the intensity to which the field rose immediately after the preceding polarity transition. This conclusion sharply contradicts thirty years of statistical analysis which has demonstrated that polarity intervals conform to a Poisson distribution [Cox, 1968; Tacier et al., 1975; McFadden et al., 1987]. For such a distribution, the transition probability should not be a function of the intensity of the field.

In two subsequent papers, Valet et al. [1994] and Meynadier et al. [1994] compared the record from the eastern equatorial Pacific Ocean with relative paleointensity records from the north Pacific Ocean, the Atlantic Ocean and the Indian Ocean. These records have rates of sedimentation of about 11 mm/kyr while the original record has a sedimentation rate of about 17 mm/kyr. The overall asymmetrical saw-tooth pattern appears to be present in the lower-resolution records, but the pattern is not as well-defined. There are also significant differences in the detailed behavior of the records, suggesting that other factors might be involved. In this paper, we present new results from the central equatorial Pacific Ocean and address the question of the reproducibility and interpretation of the finer-scale features in the record of Valet and Meynadier [1993].

Previous Work

Our data were obtained from a core (K78030) from the central equatorial Pacific Ocean (18.90°N, 160.30°W). This core was collected in 1978 by the *R.V. Kana Keoki* of the Hawaii Institute of Geophysics and Planetology (HIGP) and was first studied by F. Theyer, E. Herrero-Bervera and their colleagues at the HIGP. These workers conducted reconnaissance magnetostratigraphic studies and then carried out a more detailed study of geomagnetic field behavior at the onset and termination of the Jaramillo subchron and across the Matuyama/Brunhes polarity transition [Theyer et al., 1985; Herrero-Bervera and Theyer, 1986]. The cores were sampled with mini-cubes that have an internal dimension of 1 cm. The cubes were arranged in two parallel but offset columns, which resulted in 505 samples from the Jaramillo subchron and the intervals preceding and following it and 370 samples from the vicinity of the Matuyama/Brunhes boundary. Based on the magnetostratigraphy, the average rates of sedimentation are 18 mm/kyr for the Jaramillo subchron, 26 mm/kyr for the upper part of the Matuyama chron, and, because the top of core K78030 is missing, at least 7 mm/kyr for the Brunhes chron.

Pilot demagnetization studies indicated that applied

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alternating fields of 12.5 mT are sufficient to recover the characteristic directions of magnetization, and the data were originally presented in terms of the declination, inclination and logarithm of the intensity of the natural remanent magnetization (NRM) at 12.5 mT [Theyer et al., 1985]. Plotted in this way, the NRM intensities show a broad decrease before and after each transition. Measurements were also made of the anhysteretic remanent magnetization (ARM) acquired by the samples in a peak alternating field of 70 mT with a bias field of 0.05 mT. The NRM/ARM ratio can be used as a measure of relative paleointensity of the geomagnetic field [Johnson et al., 1975; Levi and Banerjee, 1976], and it serves as the basis for the record of Valet and Meynadier [1993]. Because the ARM values from core K78030 show little variation, the curves of the logarithm of NRM/ARM simply reproduce the features of the NRM record [Theyer et al., 1985].

Reanalysis of Old Data

We have recovered the original data from core K78030 and have plotted the NRM/ARM ratios on a linear scale. In Figure 1, we compare the interval that spans the Jaramillo subchron in core K78030 with the corresponding portions of the record of Valet and Meynadier [1993]. For this comparison, we use the sedimentation rate for core K78030 obtained from the ages of the onset and termination of the Jaramillo subchron [Cande and Kent, 1995]. The two records contain several fine-scale features that are similar. For example, the interval between 13.00 m and 12.40 m in Figure 1a and between 1.120 My and 1.080 My in Figure 1b begins with a narrow peak and ends with a broader peak. Within this interval, the ratio of the highest to the lowest intensities is about 1.8 in both cases. Just prior to the onset of the Jaramillo subchron, both records exhibit a pronounced drop which is followed by a sharp rise at the beginning of the subchron. In both cases, there are three peaks of about equal amplitude during the first half of the subchron (between 11.40 m and 12.15 m and between 1.020 My and 1.065 My), and the average value during that period is about 20% higher than it is during the second half of the subchron. The second half of each record is punctuated by a dip (at 11.20 m and 1.007 My), and in both records, the subchron terminates with another pronouced drop. After the termination of the subchron, the records appear to be less similar; however each of them has two distinct peaks (at about 10.40 m and 10.10 m and at 0.980 My and at 0.965 My). In both cases, the second peak is broader and about 10-20% higher than the first peak.

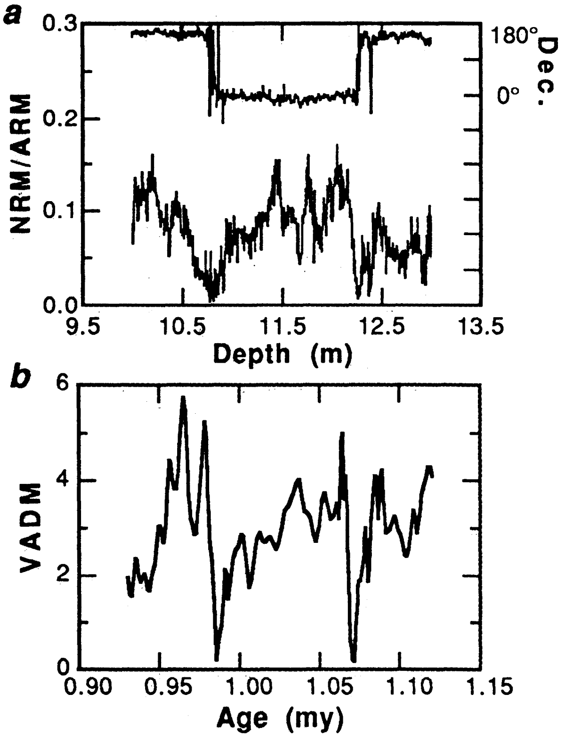

Figure 1 *a*. Relative paleointensity (NRM/ARM) of the geomagnetic field across the Jaramillo subchron from core K78030. Declinations are shown at the top. *b*. Corresponding record of Valet and Meynadier [1993] from the equatorial Pacific Ocean. VADM is the virtual axial dipole moment.

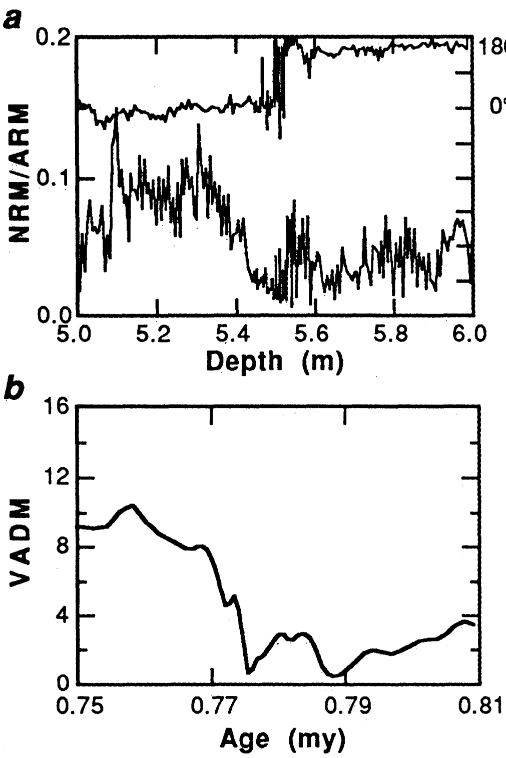

Figure 2 *a*. Relative paleointensity (NRM/ARM) of the geomagnetic field in the vicinity of the Matuyama/Brunhes boundary from core K78030. *b*. Corresponding record of Valet and Meynadier [1993] from the equatorial Pacific Ocean.

In Figure 2, we compare our record from the vicinity of the Matuyama/Brunhes boundary with the corresponding segment of the record of Valet and Meynadier [1993]. Again, the two records contain similar features, most notably a rapid rise in the NRM/ARM ratio across the Matuyama/Brunhes boundary.

Relative Paleointensity Criteria

These results suggest that the high-amplitude, fine-scale features of the record of Valet and Meynadier [1993] may be reproducible on a scale comparable to that of an ocean basin. Although this result is significant, it is equally important to address the question of whether these features represent variations in relative paleointensity of the geomagnetic field. To do this, we must determine whether the sediments of core K78030 fulfill the criteria for relative paleointensity determinations. These criteria require uniformity of grain size, concentration of magnetic grains, and magnetic mineralogy [King et al., 1983; Tauxe, 1993] and the absence of significant correlations between NRM/ARM ratios and other

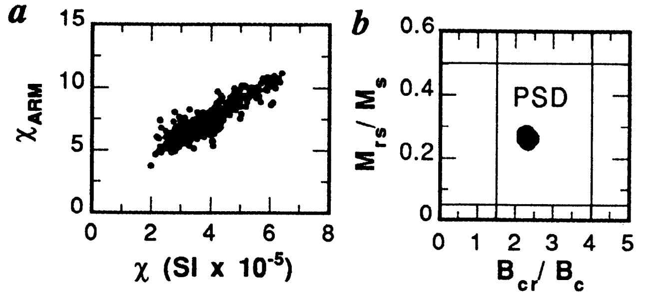

Figure 3 *a*. ARM susceptibility *versus* low-field magnetic susceptibility for samples across the Jaramillo subchron in core K78030. *b*. Hysteresis parameters, M_{rs}/M_s *versus* H_{cr}/H_c, plotted in the manner of Day *et al.* [1977].

magnetic parameters [Tauxe, 1993]. Such correlations would be expected if the NRM/ARM ratios were controlled by climatic factors rather than the geomagnetic field [Amerigian, 1977; Kent, 1982]. In their original paper, Valet and Meynadier [1993] only demonstrated that their sediments have a uniform magnetic grain size. In the subsequent work, Valet et al. [1994] only show that the magnetic susceptibility record from the Atlantic Ocean record is not well-correlated with the corresponding records from the Indian Ocean and the eastern equatorial Pacific Ocean, although the latter two susceptibility records are fairly well-correlated with each other.

According to King et al. [1983], the uniformity of grain size and concentration in a given core can be assessed by plotting ARM susceptibility versus magnetic susceptibility. Our results are shown in Figure 3a, where the linear clustering of points implies that there is little variation in grain size. The fact that the maximum values on each axis are about 3 times larger than the minimum values implies that variations in the concentration of magnetic material are also well within acceptable limits [King et al., 1983; Tauxe, 1993].

To assess the uniformity of the magnetic mineralogy (and the grain size) we analyzed ratios of hysteresis parameters. For every twentieth sample, we determined the saturation remanence (Mrs), the saturation magnetization (Ms), the coercivity (Hc) and the coercivity of remanence (Hcr) using an alternating gradient magnetometer (up to maximum fields of 1T) and then plotted Mrs/Ms versus Hcr/Hc (Figure 3b). The lack of variation in these ratios provides strong evidence for the uniformity of the magnetic grain sizes and mineralogy.

The correlation of the NRM/ARM ratios with mineral magnetic parameters can be determined by coherence function analysis [Tauxe and Wu, 1990], but the lack of correlation can be visually verified by plotting the NRM/ARM ratios and the mineral magnetic parameters separately, as a function of depth (e.g., Roberts et al. [1994]). For the Jaramillo subchron, there are no significant correlations between the NRM/ARM ratios and concentration-dependent mineral magnetic parameters such as ARM (Figure 4). We find a similar lack of correlation for samples that cross the Matuyama/Brunhes boundary. Thus, our results demonstrate that core K78030 is suitable for relative paleointensity determinations.

Additional Mineral Magnetic Studies

There are two additional points that we must address. The first is that the measurements of magnetic susceptibility and hysteresis parameters were made recently while the measurements of NRM and ARM were done ten years ago. The second is that the ARM intensities were not demagnetized at 12.5 mT, the level of demagnetization of the NRM. To determine if either of these circumstances poses a problem, we imparted a new ARM to every twentieth sample and demagnetized that ARM at 12.5 mT. When we compared the intensity of the original ARM with that of the new ARM at 0 mT, we found that the mean value of the ratio of the two intensities was 1.01 with a standard deviation of 0.05. This result provides strong evidence that chemical alteration of the magnetic carriers has been negligible over the past ten years and that mineral magnetic parameters measured at different times can be analyzed together. We also compared the intensity of the new ARM at 0 mT with the intensity of the new ARM at 12.5 mT to determine if the demagnetization reduced the ARM of all samples by the same amount. We found that the mean value of the reduction was 0.87 with a standard deviation of 0.05. This result demonstrates that normalizing the NRM at 12.5 mT with the ARM at 0 mT rather than the ARM at 12.5 mT simply introduces a constant multiplicative factor which does not affect the interpretation of the relative paleointensity record. We conclude that core K78030 provides a credible record of relative paleointensity. This conclusion supports the view that the features seen by Valet and Meynadier [1993] across the Matuyama/Brunhes boundary and at least prior to and during the Jaramillo subchron represent actual geomagnetic field behavior.

Our data do not necessarily prove that Valet and Meynadier [1993] are correct in their interpretation of an asymmetrical saw-tooth pattern in the relative paleointensity record. First, the intervals that we have sampled are too short to provide definitive confirmation of the hypothesis of Valet and Meynadier. Second, the fine-scale features in the record of K78030 can be interpreted in different ways. For example, the data from the Jaramillo subchron (Figure 1) can be interpreted

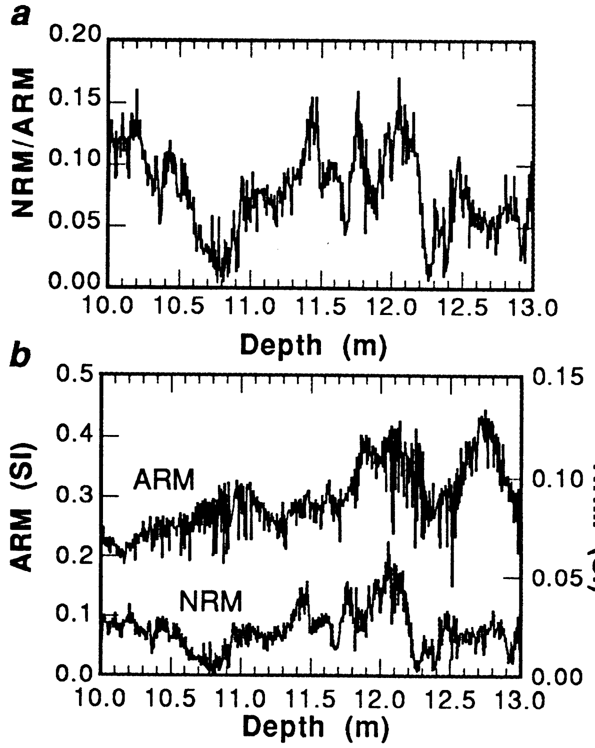

Figure 4 Comparison of (a) the NRM/ARM record across the Jaramillo subchron in core K78030 with (b) the NRM and ARM records. The ARM record is not well-correlated with the NRM/ARM record.

as showing a gradual decrease in mean intensity, as suggested by Valet and Meynadier [1993], but they can also be interpreted as showing that the field oscillated around one value during the first half of the subchron and around a slightly lower value during the second half of the subchron. Both interpretations are possible because the high-amplitude, fine-scale features obscure the longer term behavior of the field. We believe that to test the hypothesis of Valet and Meynadier [1993], we must first understand the high-amplitude features. This could be done by studying the coherence of the high-amplitude features on the scale of an ocean basin.

We also believe that the data from K78030 preclude the possibility that the results of Valet and Meynadier [1993] reflect viscous remanent magnetization (VRM), as suggested by Tauxe [1994]. If VRM is responsible for the overall pattern, it would erase or at least obscure the correlation between the high-amplitude, finer-scale features in Figures 1. In addition, several records of relative paleointensity across the Matuyama/Brunhes boundary [Tauxe, 1993; Kent and Schneider, 1995] contain a brief increase in intensity just before the polarity transition. The feature is seen in the record from core K78030 between 5.50 m and 5.60 m (Figure 2). This feature would not be found so consistently if the records were as strongly smoothed as the VRM hypothesis requires.

Conclusion

The sediments of core K78030 satisfy the criteria for relative paleointensity determinations, and the record from these sediments contain high-amplitude, fine-scale features that are similar to those found in the record of Valet and Meynadier [1993]. However, the record from K78030 is too short to allow us to draw definitive conclusions about the results of Valet and Meynadier [1993]. Our data do show that the high-amplitude features are the key to any test of the ideas of Valet and Meynadier [1993]. The existence of correlatable fine-scale features rules out viscous remanent magnetization as an explanation of the results of Valet and Meynadier [1993].

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