

RADIOMETRIC AND PALEOMAGNETIC EVIDENCE FOR THE EMPEROR REVERSED POLARITY EVENT AT 0.46 ± 0.05 M.Y. IN BASALT LAVA FLOWS FROM THE EASTERN SNAKE RIVER PLAIN, IDAHO

Duane E. Champion and G. Brent Dalrymple
U.S. Geological Survey, Menlo Park, CA 94025

Mel A. Kuntz
U.S. Geological Survey, Denver, CO 80225

Abstract. K-Ar and paleomagnetic data from cores through a sequence of basalt flows in the eastern Snake River Plain provide evidence for a brief (0.005 to 0.01 m.y.) reversal of the geomagnetic field 0.46 ± 0.05 m.y. ago. This reversed polarity event has also been found in sea-floor magnetic anomalies and in sediment cores and is probably the Emperor event of Ryan [1972].

Introduction

In the early stages of development, the geomagnetic polarity time scale was divided by Cox et al. [1964] into polarity epochs and polarity events in order to establish a convenient terminology. Polarity epochs were defined as periods of the order of 1 m.y. long when the earth's field was predominantly or entirely of one polarity, while events were defined as much shorter (ca 0.1 to 0.2 m.y. long) periods of opposite polarity within the epochs. Evidence soon suggested, however, the existence of polarity events of very short (ca. 0.01 m.y.) duration [Bonhommet and Babkine, 1967; Heirtzler et al., 1968; Smith and Foster, 1969]. On theoretical grounds, Cox [1968] proposed that the frequency distribution of polarity epochs and events was continuous and that there were numerous undiscovered events with durations shorter than 0.05 m.y. The ages of the principal polarity epoch boundaries for the last 5 m.y. are now well determined, as are the times and durations of the major events [Mankinen and Dalrymple, 1979]. Discovery and confirmation of the very short events, however, has progressed slowly because they are of such short duration that evidence for their existence does not widely occur.

Five short reversed events have been proposed for the Brunhes normal polarity epoch, which began 0.73 m.y. ago and includes the present (Figure 1). All have been found, with varying frequency, in sediment cores, but until now only the Laschamp event has been found in dated subaerial lava flows, and until recently [Wilson and Hey, 1980] none had been reported from marine magnetic anomalies. In this paper we present evidence that the Emperor event of Ryan [1972] and the Ureki event of Zubakov and Kochegura [1976] represent the same global geomagnetic reversed polarity event that was also recorded in a sequence of basalt flows beneath the eastern Snake River Plain.

The eastern Snake River Plain, Idaho is underlain by Neogene basaltic lava flows and interbedded alluvial sediments. In a recent

assessment of the volcanic hazards to the Radioactive Waste Management Complex (RWMC), Idaho National Engineering Laboratory (INEL), we studied five azimuthally unoriented cores from vertical drill holes that reached depths of from 75 to 183 m [Kuntz et al., 1980]. Coring was continuous and penetrated 13 distinct tholeiitic olivine basalt lava flows and six sedimentary interbeds (Figure 2). Maximum distance between the holes is about 1100m. Although the flows are similar in composition there is sufficient petrographic diversity to correlate the flows between cores.

Paleomagnetism

More than 290 mini-cores, 2.5 cm in diameter, were taken from three of the five drill cores (holes 94, 77-1, and 76-6) to determine the polarity and inclination of remanent magnetization in the basalt flows. The mini-cores, drilled on randomly oriented axes at right angles to the vertical axes of the original cores, were cut to specimens 2.2 cm long and measured with a spinner magnetometer. Two specimens from each flow were chosen for progressive alternating field (af) demagnetization in order to determine the field strength required to remove secondary magnetization. The cleaning field strengths were usually 20 mT for specimens with normal thermoremanent magnetization (TRM) polarity and 30 mT for specimens with reversed TRM polarity because of the slightly larger effects of viscous remanent magnetization on the reversed directions.

The TRM inclinations obtained for core 77-1, which penetrated 12 of the 13 flows studied, are shown in Figure 2. The data show that flows 1 through 9 and flows 12 and 13 cooled in a field of normal polarity, while flows 10 and 11 were emplaced while the field was reversed. Within individual flows, the inclinations are reasonably consistent. Exceptions are one specimen from flow 5, one from flow 6, and three from flow 8, all of which probably represent rare, inadvertently overturned segments of the original drill cores. The top few specimens from flows 10 and 12 are of opposite polarity to the other specimens from those flows. We have found that this is due to thermal remagnetization of the upper parts of flow 12 by flow 11, and of flow 10 by flow 9.

The inclinations of the specimens from both flows 10 and 11 become shallower near the flow tops, a result of either incomplete af cleaning or physical disruption of the flow tops after they had acquired their TRM. Inclinations for the lower parts of flows 10 and 11 and the thermally overprinted top of flow 12 cluster

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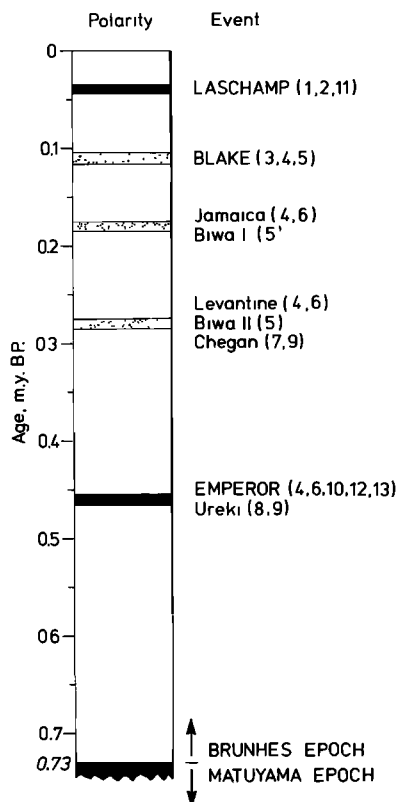


Fig. 1. Postulated reversed polarity events within the Brunhes normal geomagnetic polarity epoch. Events recorded in dated lava flows are shown by solid shading; those found only in sediment cores by stippled patterns. Preferred names are in capital letters. Numbers refer to the following published reports: 1, Bonhommet and Babkine [1967]; 2, Bonhommet and Zahringer [1969]; 3, Smith and Foster [1969]; 4, Wollin et al. [1971]; 5, Kawai et al. [1972]; 6, Ryan [1972]; 7, Zubakov [1974]; 8, Zubakov and Kochegura [1975]; 9, Kochegura and Zubakov [1978]; 10, Champion et al. [1979]; 11, Gillot et al. [1979]; 12, This report; 13, Wilson and Hey [1981].

between -40° and -45° , which probably represents the inclination of the magnetic field at the time of eruption of flows 10 and 11.

The thermal remagnetization in the tops of flows 10 and 12 allowed us to estimate the absolute declinations of the original TRM in flows 10 and 11. We chose specimens from these flows that contain measureable proportions of both the original TRM and the overprinted TRM in different unblocking temperature intervals. Using thermal demagnetization and vector subtraction of the components removed, we then calculated the net angular difference in declination between the original TRM direction and the overprinted partial TRM direction. For specimens that did not contain both components of magnetization in measureable proportions, we were able to reconstruct physically short sections of the original core spanning the zone of transition between overprinting magnetization and original magnetization, and then to calculate the relative magnetic directions of the two components.

The results indicate that the declination of flow 9 relative to the declination of flows 10 and 11 is 216° , while the declination of flows 12 and 13 relative to the declination of flows 10 and 11 is 217° , both in a clockwise sense. If we assume that flows 9, 12, and 13 recorded ambient field directions with absolute declinations of 0° (north), then the absolute declination recorded by flows 10 and 11 is approximately 216° .

Thus the data indicate that the direction of magnetization of flows 10 and 11 is an inclination of -40° to -45° and a declination of about 216° . A reversed axial dipole field at the latitude of the RWMC would have a declination of 180° and an inclination of -62° . These two directions are only about 27° apart, and the magnetization recorded in flows 10 and 11 is thus well within the typical variation of a reversed geomagnetic field [McElhinny and Merrill, 1975]. This result indicates that the reversed magnetization in flows 10 and 11 records a complete geomagnetic field reversal and not an excursion.

Age of the Flows

Nineteen unaltered samples were selected from 10 of the 13 flows for K-Ar dating. None of the

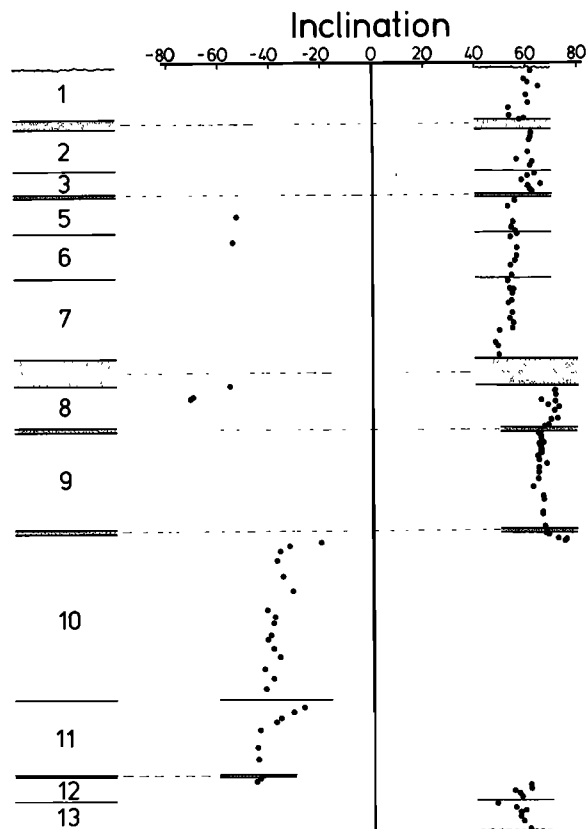


Fig. 2. Paleomagnetic TRM inclinations in core from hole 77-1 at the RWMC/INEL. Depth is to scale (Fig. 2). Dots indicate sign and inclination value for sample taken at what depth in the hole. Positive inclinations are normal polarity, negative inclinations reversed polarity. Basalt flows (numbered) and sedimentary interbeds (stippled) are shown at left. Data from Kuntz et al. [1980].

samples recovered from flows 4, 10, or 11 was suitable for dating because of the presence of opaque glass or slight alteration of the groundmass.

The calculated sample ages and weighted mean flow ages (Table 1) have large analytical uncertainties because of the low percentages of radiogenic ^{40}Ar (<1 to 4.8 %), which results from the low K_2O contents (0.2 to 0.7 wt. %) and youth of the flows. Statistical analysis of the data shows that there is no significant difference between the calculated ages of samples from the same flow at the 95% level of confidence. With only two exceptions, the flow mean ages agree with the known stratigraphic relations in the drill holes. The calculated age of flow 5 is greater than that of flow 6 (but not of flows 7 or 8) at the 95% confidence level. The age of flow 5 is based on data from a single sample for which the duplicate analyses agree well; we have no explanation for the apparent discrepancy. The other apparent anomaly is the calculated age of flow 9, which is numerically greater than the ages of flows 12 and 13, but the difference is not significant at the 95% confidence level.

On the basis of an analysis of the stratigraphy in the drill holes, the changes in paleomagnetic inclinations recorded in the cores, and the K-Ar data, Kuntz et al. [1980] concluded that the basalt flows represent three major episodes of volcanism at approximately 0.050–0.100 m.y. (flows 1–3), 0.225 m.y. (flows 5–8), and 0.450 m.y. (flows 9–13). Although there are no direct age measurements on reversed flows 10 and 11, the ages of these flows are bracketed by the ages of flows 9, 12, and 13. Because there is no statistically significant difference between the ages of these three flows, the weighted mean, 0.465 ± 0.050 m.y. is the best estimate of the age of flows 10 and 11.

Discussion

The paleomagnetic data show that a geomagnetic field reversal is recorded in RWMC core 77-1. The possibility that the change in polarity between flow 9 and flow 10 represents the Brunhes-Matuyama boundary can be ruled out from the dating results. If such were the case, flows 12 and 13 would then have to represent either the Jaramillo (0.90 to 0.97 m.y.) or some even older normal event. This would require that the K-Ar ages for flows 12 and 13 be in error by a factor of two, or nearly nine standard deviations, which is highly unlikely. The results, therefore, clearly show an interval of reversed polarity of the geomagnetic field at 0.45 ± 0.05 m.y.

Reversed polarity at about 0.46 m.y. has also been found in sediment cores and in sea-floor magnetic anomalies. Wollin et al. [1971] presented evidence for five possible brief reversed events in the Brunhes, including one at about 0.4 m.y., in cores from the Caribbean and the North Pacific. The older three of these events were further described and named by Ryan [1972] the Jamaica event at about 0.18 m.y., the Levantine event at 0.26 m.y., and the Emperor event at about 0.45 m.y. On the basis of magnetostratigraphic studies of marine and loess deposits in the Ponto-Caspian region, Zubakov and

TABLE 1. K-Ar ages of basalt flows in drill holes at the RWMC/INEL. Analytical data are given by Kuntz et al. [1980].

Flow No.	Hole	Sample Depth (m)	Calculated Sample Age ^a (m.y.)	Flow Age ^b (m.y.)
1	77-1	9.1	$.095 \pm .050$	$.095 \pm .050$
2	76-6	19.5	$<.240$	
	77-1	24.7	$<.200$	$<.200$
3	76-6	27.4	$<.190$	$<.190$
5	77-1	38.4	$.290 \pm .045$	
	76-6	38.7	$<.240$	$.290 \pm .045$
6	77-1	47.9	$.180 \pm .035$	
	77-1	50.7	$.180 \pm .050$	$.180 \pm .030$
7	94	57.9	$.230 \pm .040$	
	76-6	64.0	$.240 \pm .045$	
	77-1	55.3	$.200 \pm .035$	$.210 \pm .025$
	77-1	64.2	$.155 \pm .055$	
8	76-6	73.4	$.230 \pm .085$	$.230 \pm .085$
9	77-1	91.3	$.550 \pm .060$	
	94	91.3	$.435 \pm .165$	$.515 \pm .085$
	77-1	100.2	$.255 \pm .190$	
12	77-1	173.4	$.435 \pm .075$	
	77-1	174.6	$.310 \pm .125$	$.400 \pm .075$
13	77-1	181.1	$.495 \pm .090$	$.495 \pm .090$

^a Ages calculated using $\lambda_{\epsilon} + \lambda_{\epsilon} = 0.581 \times 10^{-10} \text{ yr}^{-1}$, $\lambda_{\beta} = 4.962 \times 10^{-10} \text{ yr}^{-1}$, and $^{40}\text{K}/\text{K} = 1.167 \times 10^{-4} \text{ mol/mol}$

^b Weighted mean of the sample ages, where weighting is by the inverse of the variance, and estimated standard deviation.

Kochegura [1976] identified a reversed event spanning an age from 0.45 to 0.55 m.y., which they named the Ureki event. Recently, Wilson and Hey [1980, 1981] described a brief reversal at about 0.49 ± 0.05 m.y. recorded in the axial magnetic anomaly over the Galapagos spreading center.

The similarity in age suggests that the Emperor event of Ryan [1972], the Ureki event of Zubakov and Kochegura [1976], the reversal noted by Wilson and Hey [1980, 1981], and the event recorded in the RWMC cores are the same event. Accordingly, we adopt the name Emperor event in conformity with the usual priority given the first naming.

We can estimate the cumulative lengths, Δt , of the reversed events within the Brunhes normal polarity epoch from the density of normal and reversed radiometric-polarity data in the interval from 0 to 0.70 m.y. We chose 0.70 m.y. instead of 0.73 m.y. to avoid including reversed data belonging to the Matuyama reversed polarity epoch. There are 71 normal data, distributed

rather uniformly within this interval [Mankinen and Dalrymple, 1979], to which we must add the two reversed data for the Laschamp and Emperor events. We use two reversed data instead of four because there is a high probability that RWMC flows 10 and 11 are so close in age that they effectively sample the same point in geologic time [Kuntz et al., 1980]. The same reasoning applies to the two Laschamp flows. Thus within the interval $T=0.70$ m.y. there are $N_T=73$ total data. Assuming uniform distribution as a function of time, the number of reversed points we expect to find is simply the fraction of time the polarity is reversed times N_T , or

$$n = \frac{N_T \Delta\zeta}{T} = 104.3 \Delta\zeta$$

which gives $\Delta\delta = 0.019$ m.y. for $n=2$. If $\Delta\zeta$ is the sum of only the Laschamp and Emperor events, then the average length of these events is 0.010 m.y. If the other three events shown in Figure 1 are real, then the estimate of the average length decreases to 0.004 m.y. These estimates are in accord with one of about 0.01 m.y. by Wilson and Hey [1980, 1981] for the Emperor event and explain why reversed events within the Brunhes have been difficult to detect and verify.

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