MANTLE-HELD MAGNETIC FLUX EVIDENCED BY 21MA R-N REVERSAL RECORDED IN AUTRALIAN LAVAS

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Abstract

The basalts of Quamby Falls, Queensland, Australia record a 21 Ma geomagnetic field reversal from reverse to normal polarity. The reversal path exhibits clusters of virtual geomagnetic poles (VGPs) southwest of Australia and in Siberia. The location of these VGPs is remarkably similar to modern-day features of the non-axial dipole (NAD) field as well as to previously proposed locations of preferential VGP clustering. The VGP clusters also lie directly above seismically cold areas of the lowermost mantle. These correlations suggest that fluid core motions are strongly affected by these thermal heterogeneities in the mantle. Thus, the data from Quamby Falls suggests that core-mantle coupling has had a recurring influence on the geometries of transitional fields since at least the early Miocene.

Introduction

Polarity reversals of the Earth's magnetic field have been enigmas of geophysics since their discovery, and the nature of reversal processes remains at the forefront of paleomagnetic research. The effects of the mantle on the geomagnetic-field-producing outer core are an important factor in the field reversal process, and it has been hypothesized but not agreed upon that they are a controlling factor of reversal morphologies (Bloxham and Gubbins, 1987; Jacobs, 1994; Hoffman et al, 2005). In addition, the consistency of deep-earth processes over geologic time is not easily assessed. The intraplate hotspot volcanics of Eastern Australia and New Zealand span the Cenozoic and have little weathering and exceptional magnetic mineralogy; they provide an excellent opportunity to study core-mantle coupling by examining reversal morphologies.

Results from Quamby Falls

The basalt flows of Quamby Falls, New South Wales, Australia (28.2 S, 153.2 E), are approximately 21 million years old and untilted; titanomagnetite is the primary recorder of remanent magnetism in the unaltered specimens (Hoffman et al, 2005). Approximately 180 cores were drilled over ~150m of continuous vertical section, traversing about 30 flows within Quamby Creek in January and September 2004.

We identified the chemical remanent magnetization (ChRM) with stepwise demagnetization using alternating fields with amplitudes up to 45mT. Fisherian statistics are generally acceptable with κ values ranging from 34.9 – 2128.3 and only six flows with $\alpha_{95} > 5°$, the largest at 10.8°. Plots of inclination (I) and declination (D) suggest a single R→N polarity reversal is recorded (Figure 1).

The oldest flows included in this study, flows QF8 and QF9, reveal ChRM and VGPs (Fig. 1, Fig. 2) typical of a reverse geomagnetic field (D_m = 199.5, I_m = 71.9). Flows QF10 through QF15 record ChRMs with D_m ranging from 241.5 – 253.9° and I_m ranging from 68.6 – 70.9° (Figure 1), ranges associated with transitional VGPs (Figure 2). These intermediate directions form an apparent VGP cluster centered at approximately 35S, 110E off the west coast of Australia. QF16 and QF17 record two isolated transitional directions just west of New Zealand. The next youngest flows, QF18 through QF26, record ChRMs with D_m ranging from 351.0 – 358.2° and I_m ranging from -20.7 – -28.1° ranges associated with transitional VGPs. These directions form an apparent VGP cluster centered at approximately 68N, 135E in Siberia (Figure 2). The youngest flows, QF27 through QF30, record ChRMs with D_m ranging from 8.6 – 18.2° and I_m ranging from -44.4 – -62.4°, ranges associated with VGPs typical of a normal geomagnetic field orientation (Figure 2).

Evidence for Core-Mantle Interactions

The lower mantle's influence on the geomagnetic field is a much-debated topic, and several researchers have used the NAD field to make inferences about the core-mantle relationship. Because fluid motions in the core are the driving force of the dynamo, it has been suggested that anomalous convective currents can produce anomalous patches of magnetic flux. Several models for core-mantle coupling have been proposed, including thermal coupling, topographic coupling, and electromagnetic coupling (Bloxham and Gubbins, 1985; Bloxham and Gubbins, 1987; Hoffman, 1992; Hoffman and Singer, 2004). These models allow the convective currents in the outer core to be controlled by heterogeneities in the lower mantle.

According to Bloxham and Gubbins (1987), it is improbable that proposed topographic variations significantly affect core circulation. Also, Bloxham and Gubbins (1987) illustrate that electromagnetic coupling can produce movement in the core, but there is no reason why it should be correlated with thermal variations as seismic data suggests. Thus, thermal interactions are illuminated as the strongest coupling model. (Bloxham and Gubbins, 1987).

Several passive seismic studies examined the velocity structure of the lower mantle. Analyzing normal-mode data, Dziewonski and Woodhouse (1987) showed areas of anomalously fast P-wave velocities at the core-mantle boundary. Li and Romanowicz (1996) had similar findings using shear wave tomography. These seismically fast areas correspond to heterogeneities that indicate cool areas in the mantle and may influence fluid motions in the core (Hoffman and Singer, 2004).

As shown in Figure 3, seismically fast areas (shaded) correlate to present-day observed non-dipole flux patches (dots) described by Hoffman (1992) and Bloxham and Gubbins (1987). This tight geographic relationship suggests that magnetic flux is related to heterogeneities represented by the seismic data.

Because the intensity of the axial dipole tends to wane during polarity reversals (Jacobs, 1994), transitional field records provide information about non-dipole components of the geomagnetic field throughout geologic time (Hoffman and Singer, 2004). Transitional VGP clusters, such as those resolved in this study, have been documented from 580 Ka through 2.9 Ma (see Hoffman and Singer, 2004). Notably, these VGP clusters reside above the aforementioned seismically fast areas (Figure 3), suggesting the occurrence of core-mantle interactions from the Holocene through the Pliocene (Hoffman and Singer, 2004). The Quamby Falls data presented here appear to extend this time period by 19 My into the early Miocene.

Interpretation and Conclusion

The directional data from Quamby Falls provide exceptional support not only for VGP clustering, but also for the occurrence of preferred cluster localities over at least the past 21 Myr. If a transitional field configuration is at all dominated by regions of mantle-held flux concentrations, then paleomagnetic data from sites in the region directly above them are likely most affected. The fact that the clusters revealed from Quamby Falls samples as well as from regionally recorded reversals documented by Laj et al (1991), Hoffman (1992), and others (see Hoffman and Singer, 2004) lie in similar geographic regions as historic and present-day vertical field features of the NAD field (Figure 4) strongly supports the assertion that these flux patches regionally dominate the geomagnetic field during polarity reversals.

The proximity of VGP clusters at Quamby Falls to seismically fast areas suggests that transitional field geometries and reversal processes are heavily influenced and may even be dependent on thermodynamic interactions between the lowermost mantle and the fluid, dynamo-producing outer core. Magnetic field lines entrained in a conducting fluid will concentrate at areas of downwelling (K. Hoffman, personal communication, 2004). This strengthens existing hypotheses about core-mantle coupling as suggested by Bloxham and Gubbins (1987), Hoffman (1992), and Hoffman and Singer (2004). This correlation, along with the age of the Quamby Falls basalt, also suggests that quasi-stationary thermal coupling of the core and mantle has had a dominating influence on field structure during reversals for at least the last 21 Myr. The origin of these thermal perturbations is a rising question, and more detailed sampling of the paleomagnetic record has yet to show whether they are constant or sporadic.

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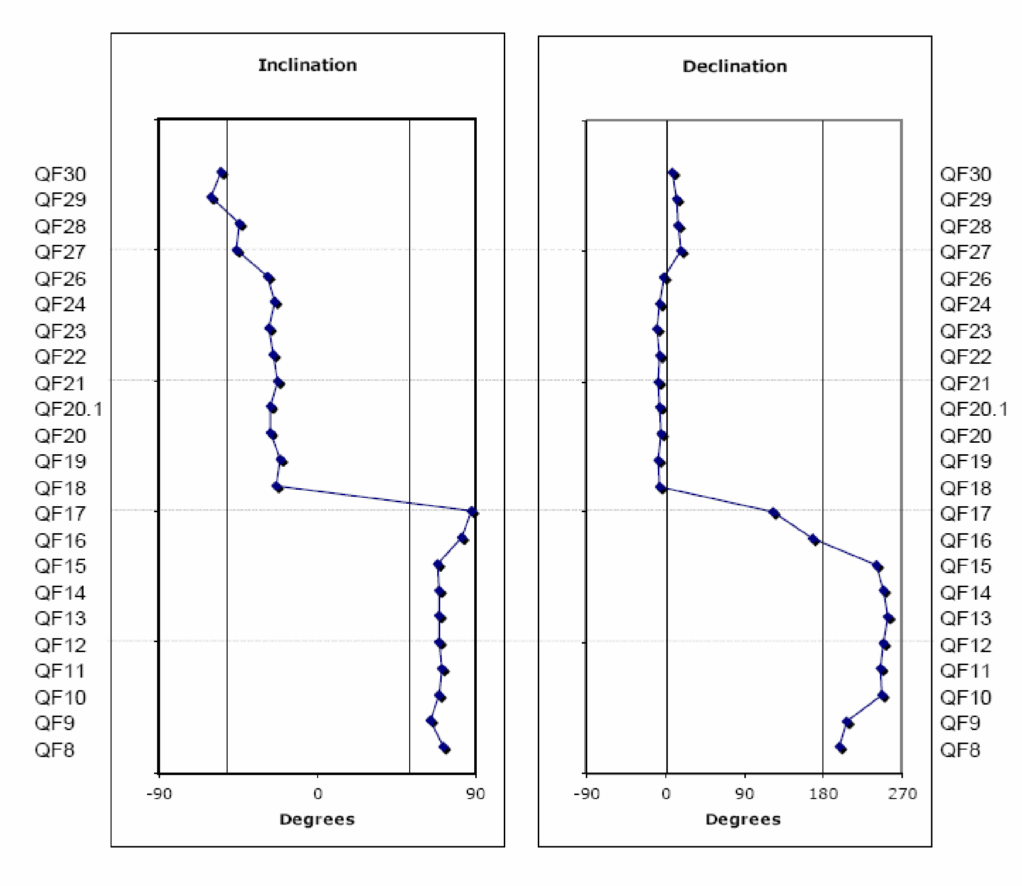
Inclination
Declination
QF30
QF29
QF28
QF27
QF26
QF24
QF23
QF22
QF21
QF20.1
QF20
QF19
QF18
QF17
QF16
QF15
QF14
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QF12
QF11
QF10
QF9
QF8
-90
0
90
180
270
Degrees

Figure 1

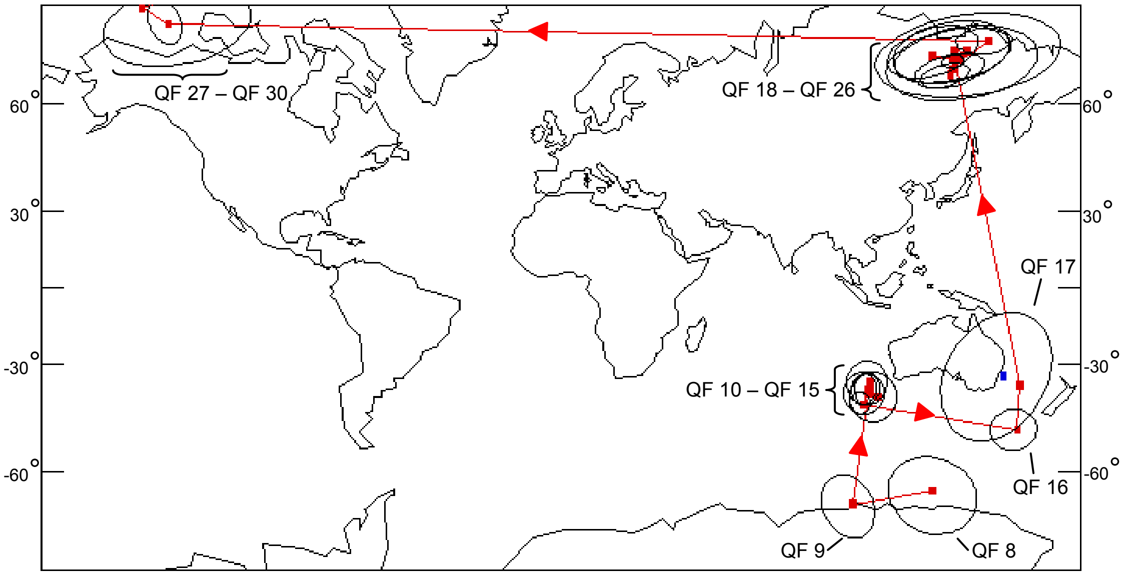
60°
30°
-30°
-60°
60°
30°
-30°
-60°
QF 27 – QF 30
QF 18 – QF 26
QF 17
QF 10 – QF 15
QF 16
QF 9
QF 8

Figure 2

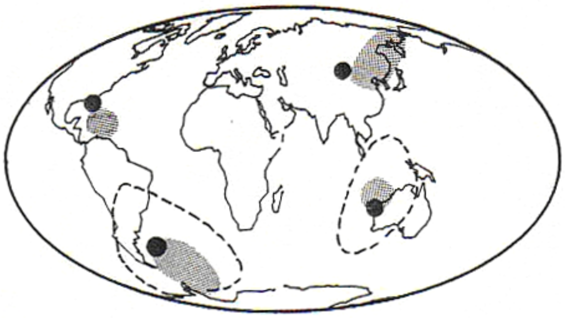

Figure 3

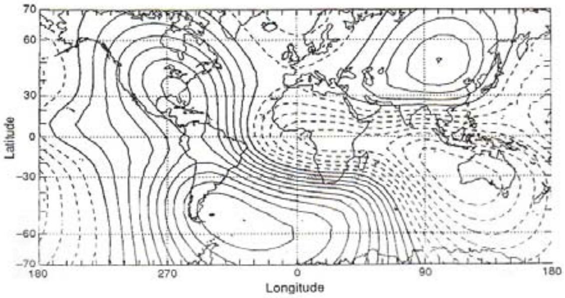

Figure 4

Figure 1. Plots of mean inclination and declination of flows sampled at Quamby Falls. Flows are in stratigraphic order with the oldest flows on the bottom. Vertical lines denote approximate values for non-transitional directions.

Figure 2. The Quamby Falls reversal path. VGPs associated with studied flows are marked by red squares. The effects of continental drift were accounted for by amending the site latitude by six degrees. The modified site location is marked by a blue square. Ellipses denote α_{95} confidence intervals. Of note are the distinct VGP clusters, one SW of Australia and one in Siberia.

Figure 3. Regions of fastest P-wave propagation in the lower mantle (shaded), localities of near-radial flux centers associated with today's surface field stripped of its axial dipole (large dots), and the transitional field VGP cluster patches derived from lavas (from Hoffman, 1992).

Figure 4. Contours of the vertical component of the 1975 International Geomagnetic Reference Field at the Earth's surface for the case in which the axial dipole term is removed. Downwardly directed and upwardly directed fields are denoted by solid and dashed contour lines, respectively (from Hoffman, 1992).

Application Information

Mantle-held magnetic flux evidenced by 21Ma R-N reversal recorded in Australian lavas.

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I learned of the awards program through AGU’s publication, EOS.