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A Negative Test of Orbital Control of Geomagnetic Reversals and Excursions

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Abstract. A ~41 Kyr periodic component has been reported in some sedimentary paleointensity records, allowing speculation that there may be some component of orbital control of geomagnetic field generation such as by obliquity modulation. However, no discernable tendency is found for astronomically-dated geomagnetic reversals in the Plio-Pleistocene (0 to 5.3 Ma) or excursions in the Brunhes (0 to 0.78 Ma) to occur at a consistent amplitude or phase of obliquity cyclicity, nor of orbital eccentricity. An implication is that paleointensity lows which are characteristically associated with these features are not distributed in a systematic way relative to obliquity and eccentricity, supporting the idea that orbital forcing does not power the geodynamo.

Introduction

The main geomagnetic field originates from dynamo action in the fluid outer core. Principal energy sources include compositional and thermal convection due to growth of the inner core [*Cardin and Olson*, 1992; *Jacobs*, 1995]. A contribution from precessional forces is also possible [*Malkus*, 1963, 1968] which has led to some speculation that the geodynamo might somehow be modulated by the 41 Kyr orbital obliquity cycle [*Kent and Opdyke*, 1977]. A recent high resolution study of sedimentary records from North Atlantic ODP Sites 983 and 984 revived interest in the possible existence of a 41 Kyr periodic component of paleointensity variation [*Channell et al.*, 1998]. Age control for the Site 983 and 984 sections was based on oxygen isotope records which revealed Milankovitch cyclicity in the familiar eccentricity (~100 Kyr), obliquity (41 Kyr) and precessional (~20 Kyr) wavebands. Rock magnetic parameters used to normalize the natural remanent magnetization (NRM) for fluctuating magnetic carriers were found to be coherent with the 100 Kyr and 20 Kyr cycles, cautioning that some spectral components of normalized NRM may be contaminated by climatically induced lithological change. However, because rock magnetic proxies of lithology seemed to be independent of the 41 Kyr cycle, the variation in normalized NRM in the obliquity waveband may represent actual geomagnetic intensity change.

The reality of a 41 Kyr paleointensity component nevertheless remains in doubt. For example, a renewed wavelet analysis suggests that the Site 983 paleointensity signal in the obliquity waveband may in fact also be contaminated by lithologic variations [*Guyodo et al.*, 2000]. Moreover, no stable periodicity was found in a composite profile of sedimentary relative paleointensity records for the past 800 Kyr [*Guyodo and Valet*, 1999] although the lack of periodicities could be due to uncertainties in chronology of some of the records incorporated in the stack and the smoothing imposed by the stacking process.

The determination of precise astronomical dating of the geomagnetic polarity time scale over the Plio-Pleistocene [*Shackleton et al.*, 1990; *Hilgen*, 1991] allows the possibility of evaluating obliquity modulation of the geomagnetic field with a different albeit indirect approach. All 21 well established polarity reversals over the past 5.3 Ma (Chron C1n to Chron C3r.4n; [*Cande and Kent*, 1995] have been placed in an astronomical context, that is, within the calculated precession, obliquity and eccentricity variations as most recently evaluated by *Lourens et al.* [1996] (Table 1). Geomagnetic polarity reversals have long been known to be associated with reductions in paleointensity by about an order of magnitude e.g.,[*Ninkovich et al.*, 1966; *Opdyke et al.*, 1973; *Clement and Kent*, 1984; *Prevot et al.*, 1985;

Table 1. Earth orbital parameters corresponding to astronomical ages of geomagnetic polarity reversals for 0 to 5.5 Ma. Age of each geomagnetic polarity reversal Chron *Cande and Kent* [1995] is from *Lourens et al.* [1996] using astronomical solutions of *Laskar* [1990] which were also used to obtain values of obliquity (Obliq.), eccentricity (Eccen.) and precession index (Prec.) corresponding to the reversal ages with AnalySeries software *Paillard et al.* [1996].

Chron	Age (ka)	Obliq.	Eccen.	Prec.
C1n base	780	23.557	0.020507	0.016165
C1r.1n top	990	23.796	0.047712	0.047533
C1r.1n base	1070	23.879	0.055236	-0.036798
C2n top	1785	23.184	0.017272	-0.016970
C2n base	1942	23.885	0.035966	0.007651
C2r.1n top	2129	22.647	0.043885	0.043633
C2r.1n base	2149	24.165	0.029245	0.019976
C3An.1n top	2582	23.519	0.034301	0.032302
C3An.1n base	3032	23.274	0.048092	0.040875
C3An.2n top	3116	23.453	0.022899	-0.003408
C3An.2n base	3207	23.481	0.004045	0.004029
C3An.3n top	3380	23.387	0.006652	0.003728
C3An.3n base	3596	22.704	0.014014	-0.012901
C3n.1n top	4188	23.410	0.030960	0.021239
C3n.1n base	4300	22.940	0.030844	-0.002156
C3n.2n top	4493	23.048	0.026533	-0.013309
C3n.2n base	4632	22.946	0.031013	-0.007230
C3n.3n top	4799	23.771	0.009510	0.009419
C3n.3n base	4896	23.037	0.010484	-0.004800
C3n.4n top	4998	23.425	0.027625	0.016661
C3n.4n base	5236	22.692	0.015152	-0.000919

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Table 2. Earth orbital parameters corresponding to astronomical ages of geomagnetic excursions in the Brunhes (C1n), 0 – 0.78 Ma. See Table 1 for explanation.

Excursion	Age (ka)	Obliq.	Eccen.	Prec.
Laschamp	43	24.062	0.013635	0.008569
Blake	115	22.445	0.043842	0.041416
Jamaica/Pringle CR0	210	24.389	0.049318	0.047638
Calabrian Ridge1 CR1	320	22.948	0.035319	0.015743
Calabrian Ridge2 CR2	520	22.750	0.021132	0.014570
Emperor/Big Lost CR3	565	23.056	0.034049	0.028300

Constable and Tauxe, 1996]. Geomagnetic excursions are enigmatic features that signal field instabilities characterized by marked decreases in paleointensity [*Gubbins*, 1999; *Carlut et al.*, 1999b; *Guyodo and Valet*, 1999] and for the Brunhes (Chron C1n), have also been recently catalogued and dated astronomically by *Langereis et al.* [1997] (Table 2). The astronomical timing makes it possible to gauge any tendency for geomagnetic reversals or excursions, and the inferred or demonstrated decreases in paleointensity associated with them, to occur at a consistent amplitude or phase of the obliquity (as well as the eccentricity or precession) cyclicity.

Test of orbital phase of reversals and excursions

The astronomical ages of geomagnetic polarity reversals determined by *Lourens et al.* [1996] for the Plio-Pleistocene are plotted in Figure 1 with respect to obliquity variations over the past 5.5 Myr based on the same astronomical solutions of *Laskar* [1990]. The values of obliquity predicted from the astronomical ages of these 21 geomagnetic reversals do not show any obvious preference: 8 reversals occurred when obliquity was less than the mean obliquity (23.3°) and 13 occurred when obliquity was higher the long-term mean (Fig. 2a). Moreover, the mean of the 21 reversal obliquity values of 23.34° is hardly different from the long-term mean obliquity of 23.26°.

The obliquity oscillations are actually quite complex and in particular, there is an appreciable fluctuation in the amplitude of the envelope of obliquity variations with a period around 1 m.y. To recheck if the reversals might occur at a preferred phase of the obliquity cycles, we normalized the portion of each obliquity cycle that contains a reversal to a half-sinusoid of unit amplitude as a first-order approximation of the local obliquity variation. The distribution of normalized reversal values again shows that 8 reversals occur at obliquities less than the normalized mean and 13 reversals occur at obliquities greater than the normalized mean (Fig. 2b). In addition, the normalized reversal values are distributed throughout the whole spectrum of a sinusoidal distribution and do not occur at any particular phase of the obliquity cycle (such as extrema), suggesting they are not distinguishable from a random population of 21 points drawn from a sinusoid. Although the small number of data poses limitations on statistical tests, a simple χ^2 test made using the 10 intervals of Figure 2b yields a value of 6.36, implying that 70% of randomly picked populations of 21 points derived from a sinusoid distribution would give a higher mismatch with a sinusoid.

Parenthetically, there also does not appear to be an anomalous preference for reversals to occur with respect to the distribution of eccentricities (Fig. 2c) although there is a hint of extra occurrences at positive values of the precession index (Fig. 2d).

A similar analysis was conducted of arguably the 6 best-established geomagnetic excursions in the Brunhes as determined by *Langereis et al.* [1997] (Table 2). The number of well-documented occurrences are too few to draw strong conclusions but the observation that the excursion obliquity values range widely from 22.45° to 24.39° (Fig. 3a), or over a broad range of normalized positive and negative values

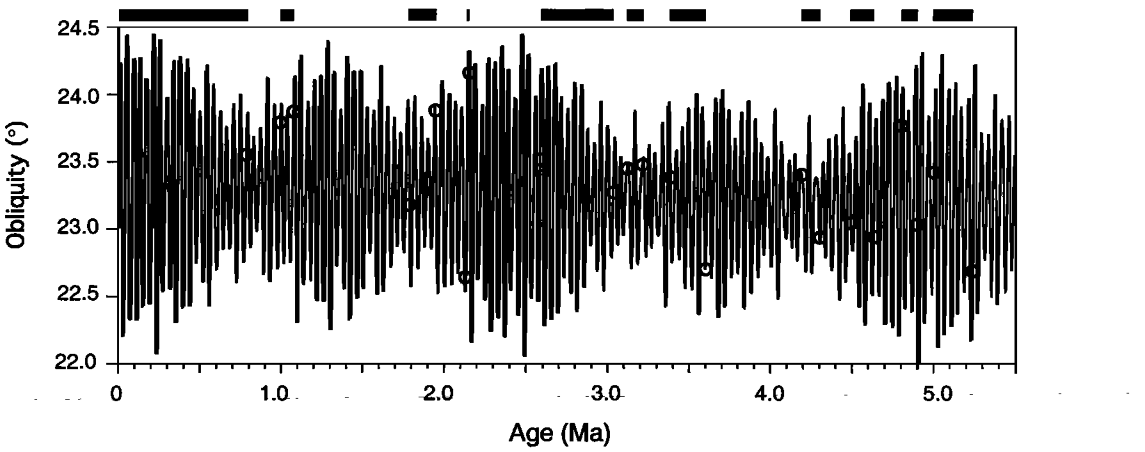

Figure 1. The astronomical ages of geomagnetic polarity reversals determined by *Lourens et al.* [1996] plotted with respect to obliquity variations over the past 5.5 Myr based on the same astronomical solutions of *Laskar* [1990]. See Table 1.

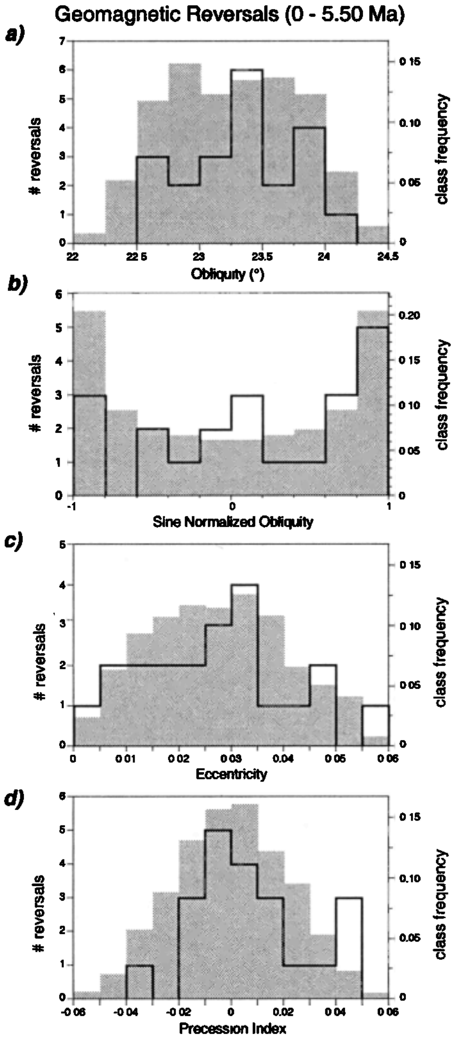

Figure 2. Histograms of a) obliquity, b) normalized obliquity, c) eccentricity, and d) precession index corresponding to astronomical ages of 21 geomagnetic reversals between 0 and 5.50 Ma as determined by *Lourens et al.* [1996] (heavy lines) compared to frequencies of orbital parameters over same age range (shaded) from *Paillard et al.* [1996]. See Table 1.

(Fig. 3b), does not point to an underlying modality. The lack of any obvious preference also applies to the distribution of excursion eccentricities (Fig. 3c). Interestingly, excursion precession indices show a more distinct bias toward positive values (Fig. 3d) that was also apparent in the distribution of reversal precessional values (Fig. 2d).

Discussion

Our analysis shows no evidence for a systematic relationship between geomagnetic reversals and excursions, and the decreases in paleointensity characteristically associated with these features, on one hand and fluctuations in obliquity on the other. The lack of supporting data for any obliquity dependence could mean either that precessional energy is not a significant power source for the geodynamo e.g.,[*Rochester et al.*, 1975] and/or that the obliquity fluctuations due to motions of Earth's orbital plane with respect to the invariable plane of the solar system e.g.,[*Laskar et al.*, 1993; *Bills*, 1994; *Rubincam*, 1995] do not result in appreciable changes in precessional torques on the core.

With regard to the apparent bias in the distribution of excursion (and reversal) precession values, we note that *Van Hoof and Langereis* [1991] and other workers have shown that the magnetization acquisition process in cyclic sediments is often quite variable. In the eastern Mediterranean, a key area for astronomical dating of excursions in the Brunhes [*Langereis et al.*, 1997], sapropels and sedimentation under more reducing conditions tend to correspond to negative peak values of the precession index [*Rossignol-Strick*, 1983; *Hilgen*, 1991]. Since reduced sediments are poor paleomagnetic recorders and have a tendency to suffer magnetochemical alteration [*Van Hoof and Langereis*, 1991], the recording of any contemporaneous geomagnetic signal such as an excursion is less likely or might be offset as a result of diagenesis-related delay of NRM acquisition. This might account for the overall bias toward positive values of precession index when the sediments might have more favorable magnetic recording properties.

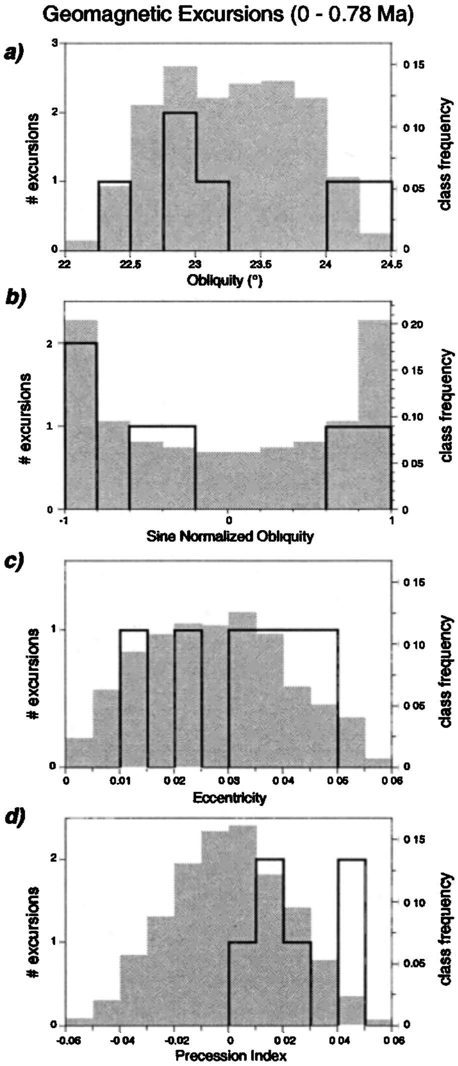

Figure 3. Histograms of a) obliquity, b) normalized obliquity, c) eccentricity, and d) precession index corresponding to astronomical ages of the 6 geomagnetic excursions within the Brunhes (0 – 0.78 Ma) as determined by *Langereis et al.* [1997] (heavy lines) compared to frequencies of orbital parameters over same age range (shaded) from *Paillard et al.* [1996]. See Table 2.

We conclude that there is no convincing evidence that changes in the geomagnetic field are causally related to periodic orbital forcing. This is consistent with correlation times of geomagnetic field variation which are generally thought to be on the order of 1000 years or less [*Hongre et al.*, 1998; *Carlut et al.*, 1999a]. The general absence of any direct systematic relationships between geomagnetic reversals and orbital parameters also does not support a causal relationship between geomagnetism and Milankovitch climate change as sometimes proposed e.g.,[*Worm*, 1997].

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