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The Testing of Geomagnetic Reversal Models: Recent Developments [and Discussion]

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The testing of geomagnetic reversal models: recent developments

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The number of available palaeomagnetic records displaying detailed transitional field behaviour has increased significantly over the past few years. The expanded data set of transitions now includes records of sequential reversals from the same site locality as well as multiple recordings of a particular reversal from widely separated sites. Such data are most useful with regard to the testing of geomagnetic reversal models. First, records of successive reversals may make it possible to distinguish whether transitional fields originate primarily with the configurational characteristics of the reversing geodynamo or whether a non-reversing portion of the field is responsible. Such an analysis does not yet provide conclusive evidence in support of either hypothesis. Second, multiple records from distant sites furnish the best possible data with regard to the determination of the harmonic content of particular transitional fields. In this regard, two quite independent, testable models have been applied to the several recordings of the Matuyama–Brunhes transition. Findings support the hypothesis that the intermediate field geometry during this particular polarity transition was indeed controlled by non-dipole zonal harmonic terms. Moreover, analysis of the paths of the virtual geomagnetic pole associated with the available records strongly suggests that the most extreme dominance of transitional fields by axisymmetric components occurs during the onset of the reversal, a finding that now has support on purely theoretical grounds. Finally, field behaviour associated with existing igneous-recorded palaeomagnetic excursions is not unlike that observed at the onset of field reversals. Hence, there is growing evidence in support of the hypothesis that attempts by the geodynamo to reverse are not always successful. These recordings of apparent abortive reversals may be of considerable value with regard to our understanding of transitional fields and geomagnetic reversal.

1. Introduction

The palaeomagnetic record offers the only source of observational data about the behaviour of the geodynamo during field reversals. Over the past two decades several recordings of polarity transitions have been discovered in both igneous and sedimentary structures, and the revealed geomagnetic behaviour has been the subject of various reviews (e.g. Creer & Ispir 1970; Dagley & Lawley 1974; Hoffman 1977; Fuller *et al.* 1979). In the latest of these reviews, Fuller *et al.* (1979) provide guidelines for the classification of existing reversal records in terms of overall detail and then suggest which are most suitable for analysis and testing of geomagnetic reversal models. In this regard, those records possessing the highest resolution were designated 'category A'.

In this review we address the following current questions about geomagnetic reversal: (1) Does the morphology of transitional fields associated with available records of Cainozoic reversals display consistent, recognizable systematics, as has been claimed (e.g. by Hoffman 1977)? (2) Do transitional fields arise primarily from the time-dependent configurational characteristics associated with the reversal process in the core, or does a major contribution arise from a standing (i.e. non-reversing) portion of the field? (3) What dominant field geometries are associated with particular polarity transitions? In order to shed light on these aspects of the geomagnetic reversal process we utilize palaeomagnetic data associated with the original category A listing as well as detailed transition records reported in the literature since 1979. In order to complement these data we also consider acceptable records of palaeomagnetic excursions that may display field behaviour during abortive reversals. As will be seen, this revised and expanded data set now contains highly useful information with regard to the testing of various hypotheses regarding both the mechanism of reversal as well as the geometry of transitional fields.

2. Site dependence of transitional field data

In the review by Fuller *et al.* (1979) 15 records were found to satisfy requirements to be considered category A. However, with regard to a total understanding of the geomagnetic reversal process, this data set was found to be deficient in two important ways. First, the geographical distribution of sites at which the recordings were obtained is poor. More specifically, *all* category A records are associated with sites located in the Northern Hemisphere. Moreover, apart from three Icelandic records and two records from a site in the east-equatorial Pacific, all were obtained from mid-latitudes. Second, reversal records associated with the transition sense from normal to reverse (N–R) are poorly represented. Only two such records are found in the category A listing and both were obtained from the same site.

The need for additional records has been clear, especially N–R records obtained from the Northern Hemisphere and records of either transition sense from the Southern Hemisphere. Nevertheless, observed palaeomagnetic behaviour associated with the relative abundance of R–N recordings from low and mid-northern latitudes listed by Fuller *et al.* (1979) suggests that transitional fields are controlled by axisymmetric non-dipole term(s). That is, these data, when viewed as paths of the virtual geomagnetic pole (v.g.p.), have been found to display a dramatic dependence on the locality of the recording site consistent with this hypothesis (Hoffman 1977; Hoffman & Fuller 1978; Fuller *et al.* 1979). Specifically, transitional paths of the v.g.p. associated with R–N transitions are found to reside almost exclusively on the hemisphere centred about the site longitude, the so-called 'near-side'. Similarly, v.g.p. paths corresponding to N–R transition records from low and mid-latitude sites tend to be found on the 'far side'. Notwithstanding the relative small number of transitions represented by available data, such an overall dependence of the geometry of reversing fields on both the locality of the site of observation and the sense of the transition, if confirmed, would indicate that (1) intermediate fields associated with polarity transitions are significantly axisymmetric, (2) configurational characteristics of the reversal process in the core are not dependent on the transition sense, and (3) the entire field takes part in the reversal (i.e. stationary, non-reversing field components, if present, do not significantly affect the geometry of transitional fields). Moreover, it has been pointed out (Hoffman & Fuller 1978) that given the recognition of site-dependent characteristics associated with records obtained from the Southern Hemisphere, the geometry of the controlling axisymmetric term (whether quadrupole or octupole), as well as particular configurational systematics of the reversal process (e.g. the region(s) in the core where reversals originate) would, in principle, be identifiable. Implicitly, the question of whether the dominating zonal geometry is similar for all reversals would be answerable as well.

The question now is: in what way, if any, do the recently acquired transition records reported since the 1979 review alter the claim of a general site-dependence? Interestingly, these newly available data include (1) two sets of sequential transitions – one pair from marine sediments of Miocene age from Crete (Valet & Laj 1981) and the other pair from basalts of Pliocene age from Kauai (Bogue & Coe 1982), (2) a low latitude R–N recording from an intrusion of Miocene age from the Philippines (Williams & Fuller 1981 *a*), and (3) a record corresponding to the Gauss–Matuyama (N–R) transition (Liddicoat, this symposium) obtained from sediments in California.

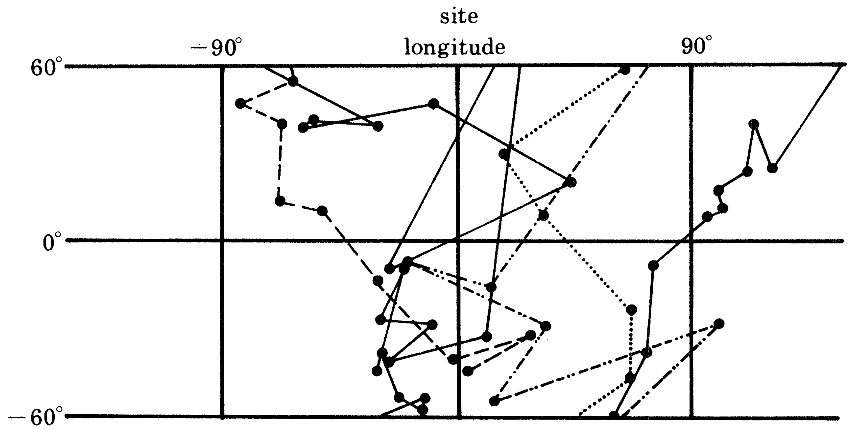

FIGURE 1. Matuyama–Brunhes (R–N) v.g.p. paths corresponding to representative data from each of five site localities in the Northern Hemisphere (see figure 4) and plotted with respect to a common site longitude. The 'near side' lies between −90° and +90° meridians.

Of particular interest with regard to the possible site dependence of R–N transition data is the finding of an unambiguous *far-sided* v.g.p. path associated with the newly acquired record from the Philippines (Williams & Fuller 1981 *a*). Such an observation is exceptional to this particular subset of transition data from low and mid-northern latitude sites.

There is also a possibility that the N–R transition recorded at Kauai (Bogue & Coe 1982) produced a *near-sided* v.g.p. path at that site. However, the data lack low-latitude v.g.ps and cannot be classified as category A.

In general, the overall effect of including newly acquired palaeomagnetic transition records with those previously available is to make somewhat less convincing any claim of a general site dependence. Indeed, as Williams & Fuller (1981 *b*) point out, there is no guarantee that each reversal has the same harmonic content. Consideration of this enlarged data set now suggests that such an overall characteristic, if it exists at all, may be time-dependent or may be determinable only in a statistical manner.

On the other hand, this conclusion does not alter the claim of an axisymmetric site dependence of v.g.p. paths corresponding to particular transition fields. Such appears to be the case for the Matuyama–Brunhes (R–N) transition. The axisymmetric control of this transition field is clearly seen in figure 1 where representative data from each of five site localities are plotted with respect to a common site longitude.

Of particular interest in figure 1 is the observation that the distribution of v.g.ps about the site longitude shows far less dispersion during the initial stage of the transition (Southern Hemisphere v.g.ps) than those associated with the final stage (Northern Hemisphere v.g.ps).

This feature suggests that the field is more strongly controlled by zonal components during the onset of the reversal process. Such an observation has been pointed out previously (Fuller *et al.* 1979). More recently, Hide (1981) came to this very conclusion on purely theoretical grounds, suggesting that axisymmetric terms dominate transition fields primarily during the decay phase of the main field.

3. Palaeomagnetic excursions as abortive reversals

Given either a general or statistical site dependence of intermediate v.g.p. data, the present complete absence of detailed reversal records from sites in the Southern Hemisphere makes the thorough recognition of dominant transitional field geometries extremely difficult, if not impossible (see Hoffman & Fuller 1978). However, the analysis of palaeomagnetic records of certain field excursions may significantly help in this regard. The possibility that reversa attempts may sometimes be unsuccessful has been suggested on numerous occasions (see, for example, Doell & Cox 1972). The inspiration behind such a hypothesis is the occasional observation of dramatic palaeomagnetic behaviour that terminates with the field vector returning to the initial polarity state, rather than changing polarity. The question of whether such excursion records accurately represent actual geomagnetic behaviour, particularly when derived from sediments, has been the source of considerable debate (see, for example, Verosub & Banerjee 1977). Even if found to be valid, such behaviour displayed in a given record does not necessarily furnish information relevant to transitional fields. In particular, large amplitude loopings of the field vector may be within the bounds of secular variation (Harrison & Ramirez 1975; Dodson *et al.* 1979). On the other hand, strong support to the claim that at least some palaeomagnetic excursions are abortive reversals does exist. For example, Hillhouse & Cox (1976) observe an excursion in the dry sediments of Lake Tecopa, California just before the recorded Matuyama–Brunhes transition. Moreover, the corresponding v.g.p. behaviour is seen to trace a single, highly defined event that runs in very close proximity to the path associated with the subsequent reversal.

Recently, Hoffman (1981*a*) analysed existing igneous-recorded palaeomagnetic data containing dramatic features consistent with the concept of an excursion. The behaviour revealed by these records is seen to be not unlike that associated with the onset of many polarity transitions in that the directional changes appear to be rapid, spike-like events with v.g.ps that are constrained in longitude. Hoffman argues that it is reasonable to consider these palaeomagnetic excursions as records of aborted reversals. If so, the displayed geometric characteristics may be quite relevant to investigations of transitional field behaviour. That is, the records of transition-like palaeomagnetic excursions may provide a data set that can be analysed alongside that associated with successful reversals.

The intermediate v.g.p. data corresponding to excursion records that satisfy strict criteria for acceptability (Hoffman 1981*a*), are reproduced in figure 2. Recalling the principal deficiencies associated with the revised category A transition data, the currently available set of acceptable excursion data (figure 2) contains both N–N and R–R v.g.p. paths. Moreover, three of the four records shown were obtained from sites at mid-latitudes in the Southern Hemisphere.

The strong axisymmetric control of the intermediate field geometries is evident by the unambiguous near-sided or far-sided nature associated with each v.g.p. path. Although the number of such excursion records is small, it is notable that these data currently support the hypothesis that during at least an aborted reversal attempt the transition field is dominated by a zonal quadrupole (g_2^0) term, a finding consistent with a reversal process that starts in the Southern Hemisphere of the core (see Hoffman & Fuller 1978). Whether such an unambiguous site dependence as is presently seen in figure 2 is further supported or obscured by additional data remains to be seen.

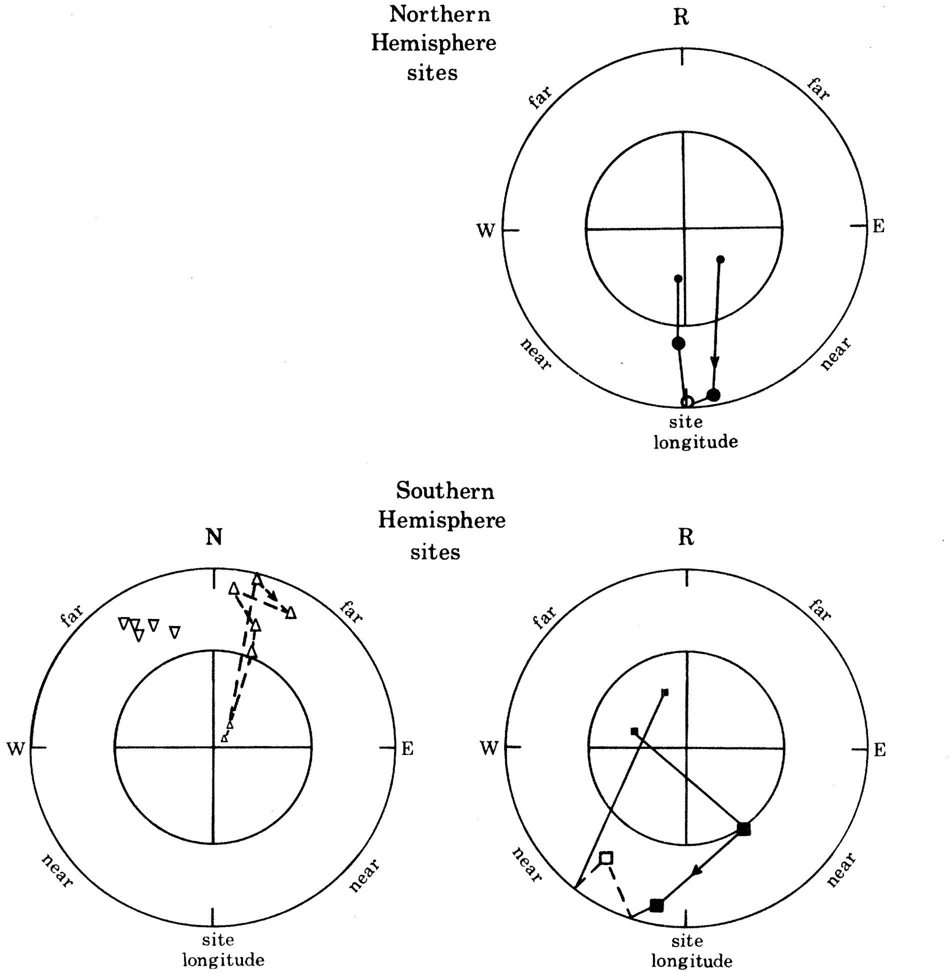

FIGURE 2. Polar stereographic plots with respect to site longitudes of v.g.p. paths corresponding to Cainozoic igneous-recorded excursions. Records are separated by site location as well as full polarity sense at the time of excursion. Solid and open symbols represent Southern Hemisphere v.g.ps and Northern Hemisphere v.g.ps, respectively. (From Hoffman (1981 *a*).)

The claim that these apparently well defined, axisymmetric excursions are associated with an abortive reversal process is consistent with the theoretical hypothesis (Hide 1981) and observational evidence (see figure 1) that transitional fields produced during the initial stage of the reversal process are highly axisymmetric. Further support comes from Coe *et al.* (1975), whose palaeointensity determination on one of the Oahu excursion flows (figure 2, upper right) rendered a value approximately 25% of the present field intensity for that site.

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4. Source of the transition field

The observation that transitional v.g.p. paths are often confined in longitude resulted in the early suggestion that the geomagnetic field remains predominantly dipolar during reversals (Creer & Ispir 1970; Steinhauser & Vincenz 1973). However, once multiple recordings of the last reversal became available (Hillhouse & Cox 1976) and the dipole hypothesis was shown to be incompatible with the observed data, non-dipole models of the origin of intermediate fields were proposed. In particular, Hillhouse & Cox (1976) suggested that transitional fields may arise from components that do not take part in the reversal process. That is, during the decay through zero and the subsequent regeneration of the main field, any stationary non-reversing components would control the intermediate geometry. Provided that such a standing field remains for the most part invariant for times far longer than the average recurrence time interval associated with the reversal process, such a hypothesis is associated with a clear prediction: that transitional field behaviour experienced at any given site locality is expected to be similar during successive reversals. More specifically, intermediate field geometries associated with sequential reversals should be alike and not dependent on the sense of the transition.

Following the kinematic approach to geomagnetic reversals developed by Parker (1969) and Levy (1971, 1972), Hoffman (1977) showed that the available transition data were compatible with a hypothesized reversal process that starts at low latitudes in the core and subsequently extends, or 'floods', north–south (axisymmetrically) until the transition is complete. That is, in contrast to the standing field model, this approach suggests that transitional field geometries arise from the configurational characteristics of the reversal process. Thus, during a transition, the field direction experienced at a given site will rotate either through a vertically downward orientation (producing a near-sided v.g.p. path) or through a vertically upward direction (producing a far-sided path) depending on the location of the site and the sense of transition. Hence, provided that the configurational aspects of the reversal process remain for the most part invariant for times far longer than the average recurrence interval for transitions, at a given site this model predicts the field vector to follow essentially antipodal paths for consecutive reversals. More recently the flooding model has been extended to include the distinguishable possibility that reversals originate at high latitudes in the core (Hoffman & Fuller 1978) and also generalized to incorporate non-axisymmetric behaviour as well (Hoffman 1979). However, the prediction of antipodal v.g.p. paths for sequential transitions remains unaltered, provided that the reversal process for both transitions starts in the same region of the core.

The important point to be made here is that, in general, the standing field model and the flooding models predict field behaviour associated with sequential reversals that theoretically is easily distinguishable. Fortunately, we now possess sets of transition data suitable for such a test (see discussion by Bogue & Coe 1982).

In this regard, Valet & Laj (1981) present transition data associated with sequential reversals from Miocene sediments in Crete for which the v.g.ps are plotted with respect to site longitude (figure 3*a*). As can be seen, the v.g.p. behaviour associated with the prior (R–N) transition is what might be termed borderline near-far to the west of the recording site. In contrast, the later transition from N–R (although a detailed path, it is not rigorously classifiable as category A) is clearly far-sided with v.g.ps residing almost exclusively to the east of the site. Moreover, the final equatorial crossings by the v.g.p. for these sequential records are seen to be nearly antipodal.

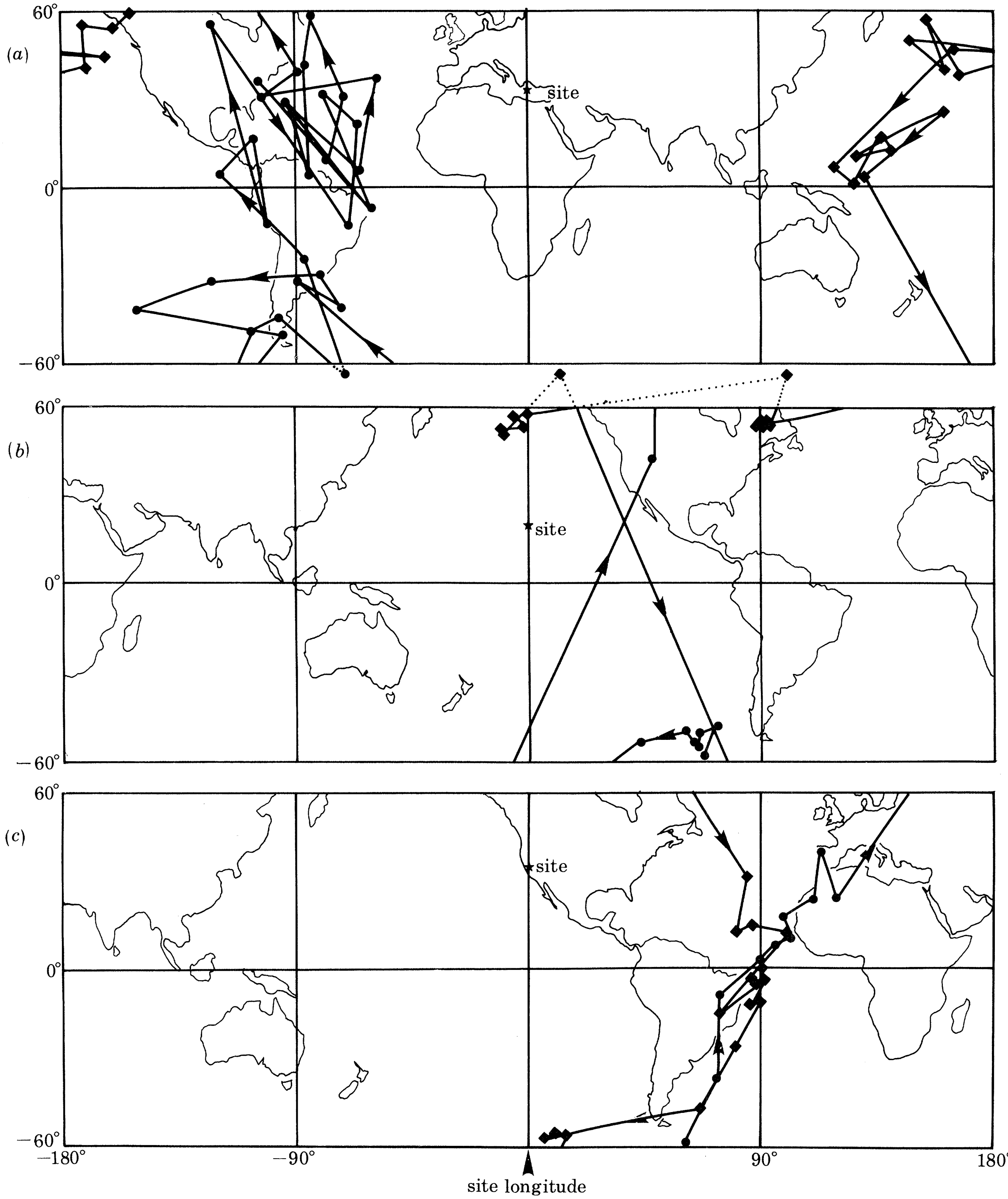

FIGURE 3. V.g.p. paths, plotted with respect to site longitude, corresponding to reversal pairs: (*a*) sequential Miocene transitions from Crete (Valet & Laj 1981); (*b*) sequential Pliocene transitions from Kauai (Bogue & Coe 1982); (*c*) Gauss–Matuyama (Liddicoat, this symposium) and Matuyama–Brunhes (Hillhouse & Cox 1976).

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Valet & Laj (1981) conclude from this observation that the generalized flooding model of the geomagnetic reversal process is supported.

Quite recently Bogue & Coe (1982) presented an analysis of consecutive reversal data from early Pliocene basalts from Kauai for which the v.g.ps are shown (figure 3*b*). Bogue & Coe suggest that both reversal paths are similar and near-sided. However, the sparseness of intermediate v.g.ps, especially with regard to the N–R transition, leaves this interpretation in some doubt. Bogue & Coe suggest that these v.g.p. data are more easily explained by the standing field model, but note that the flooding approach can also simulate such directional behaviour provided that the R–N transition is assumed to start in the Southern Hemisphere of the core while the N–R transition is assumed to start in the Northern Hemisphere. Furthermore, they argue that the variation in palaeointensity with v.g.p. latitude is more consistent with the flooding model (Bogue & Coe 1981).

In addition to the above studies, the Gauss–Matuyama (N–R) polarity transition has recently been revealed in sediments from Searles Valley, California (Liddicoat, this symposium). Following Liddicoat, these v.g.p. data are reproduced in figure 3*c* together with those associated with the Matuyama–Brunhes (R–N) transition recorded at nearby Lake Tecopa (Hillhouse & Cox 1976). Although not successive reversals (they differ in age by some 1.7 Ma), the similarity of the transition field is striking. Bogue & Coe (1982) point out that these data, together with intermediate palaeomagnetic behaviour revealed in Matuyama epoch volcanics from nearby Clear Lake (Mankinen *et al.* 1980), support more convincingly the long-term standing field hypothesis. On the other hand, there exist several Matuyama epoch reversals for which no detailed palaeomagnetic records are currently available.

Thus available records of reversal pairs do not yet furnish sufficient evidence to eliminate either approach from consideration. The acquisition of additional records of sequential transitions would be most helpful.

5. Field geometries during particular reversals

(*a*) *Testable models*

To determine a refined description of the transitional field corresponding to a particular reversal, multiple recordings obtained from distant sites are required. At present there exist two testable quantitative models that may be applied to such data sets. First, the generalized flooding approach (Hoffman 1979) involves a phenomenological simulation of the reversal process in the core. The model utilizes a Busse-type geometry (Busse 1975) for the magnetic source region and simulates a reversal through the movement of magnetic poles about the surface of this region from a point of initiation. Both north–south as well as east–west flooding of reversed flux is involved. Furthermore, Hoffman (1981*b*) has shown that the variation of the dominant transitional field components can be calculated direct. Hence, when successful, this model provides a quantitative description of the variation of the most important axisymmetric as well as non-axisymmetric non-dipole terms present in the modelled solution. From this description specific predictions can be made about the behaviour of the transitional vector field (e.g. v.g.p. paths, plots of intensity against v.g.p. latitude) for a given site.

Williams & Fuller (1981*b*) have taken a different approach to the problem, providing a model that quantifies the zonal harmonic content throughout a reversal. Rather than simulating the path of the virtual geomagnetic pole, Williams & Fuller analyse the inclination records associated with a given reversal. They argue that since axisymmetric terms appear to dominate transitional fields, the observed time-dependent features in inclination at a given site can be regarded as a signature of the zonal geometries present. Such a claim is clearly demonstrated by the authors through the production of synthetic inclination records based upon a redistribution of energy assuming an exponential decay of the dipole field into g_2^0, g_3^0 and g_4^0 terms.

(*b*) *The Matuyama–Brunhes* (*R–N*) *transition*

There currently exist no less than ten palaeomagnetic records corresponding to the Matuyama–Brunhes transition associated with five distinct site localities in the Northern Hemisphere. However, owing to the total lack of data from the Southern Hemisphere, some ambiguity must exist with regard to distinguishing the axisymmetric harmonic content during the transition. For this reason, the parameters associated with the general flooding model for this reversal were

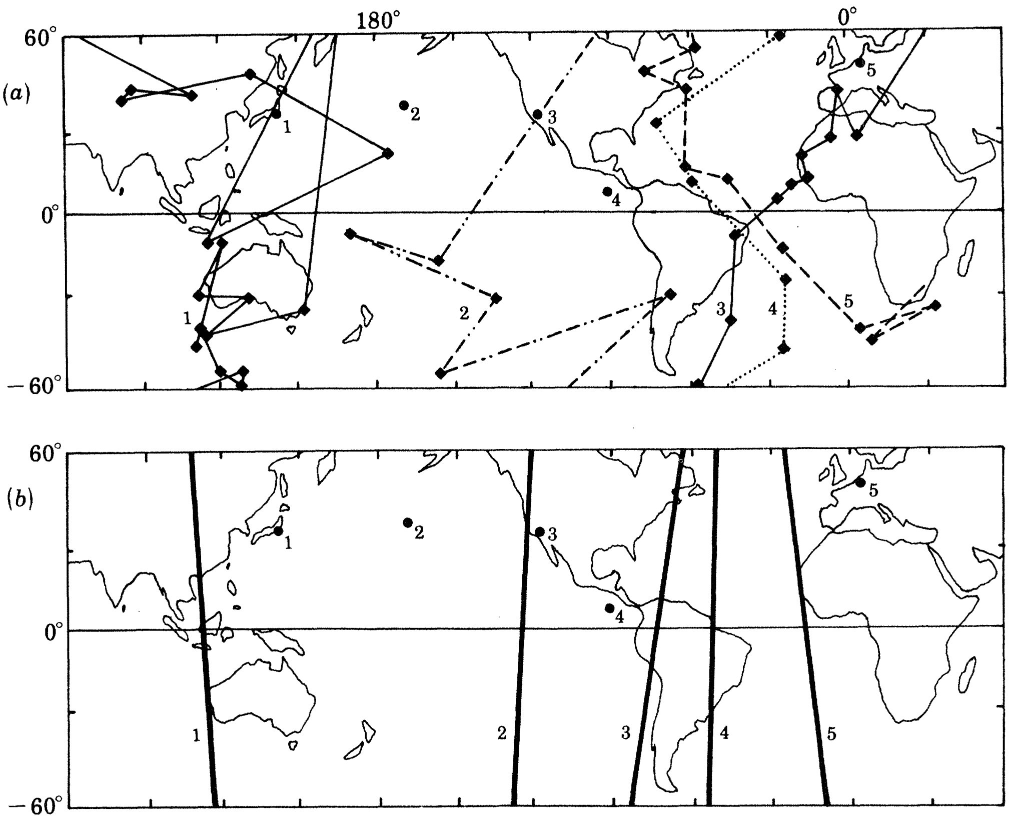

FIGURE 4. V.g.p. paths corresponding to the Matuyama–Brunhes (R–N) transition: (*a*) observed, (*b*) predicted by the generalized flooding model. From Hoffman (1981 *b*).

only loosely fitted (Hoffman 1979, 1981 *b*). In particular, by placing the starting point for this transition along the equator of the core, a zonal octupolar (g_3^0) geometry was assumed with no quadrupole (g_2^0) contribution. Transition paths predicted by the modelled solution are reproduced in figure 4, together with representative v.g.p. data obtained from each site locality. To first order, the simulation appears to be successful. Moreover, the predicted intensity behaviour associated with this modelled solution reflects well that observed in the single, credible intensity record currently available for this transition (see Hoffman (1979) for further details).

It should be pointed out that a simulation that fits as well as that shown in figure 4 may be generated by placing the initiation point for this reversal at low latitudes within the Southern Hemisphere of the core. Therefore a significant contribution to the axisymmetric geometry by g_2^0 cannot be ruled out, but can only be quantified with the attainment of records from sites at southern latitudes.

Finally, regardless of the latitudinal placement of the starting point for the reversal, the dominant non-axisymmetric geometry associated with the model is that of a (g_2^1, h_2^1) quadrupole. This result is consistent with the comparison by Liddicoat (this symposium) of v.g.p. paths

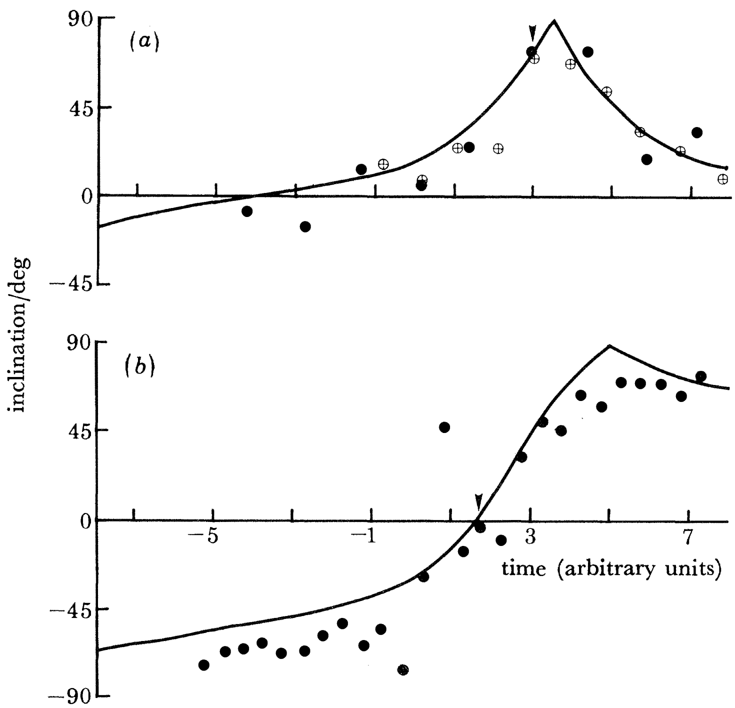

FIGURE 5. Comparison of observed and synthetic inclination records corresponding to the Matuyama–Brunhes reversal at the following site localities: (*a*) east-equatorial Pacific, (*b*) Bruggen, West Germany. (From Williams & Fuller 1981 *b*.)

associated with two records of the Gauss–Matuyama (N–R) transition, one from California and the other from Turkmenia. The sites have nearly the same latitude while separated in longitude by approximately 180°. Interestingly, the two paths are seen to traverse the equator nearly 180° apart and, when plotted with respect to a common site longitude, appear quite similar. Such a result is most easily explained by the presence of a non-axial quadrupole term in the transition field.

Williams & Fuller (1981 *b*) point out that the form of the inclination records associated with equatorial sites, in particular, places strong constraints on the possible distribution of non-dipole zonal harmonics present in the transition field. Finding a good fit of the Matuyama–Brunhes data to involve a redistribution of dipole energy to g_2^0, g_3^0 and g_4^0 components in the ratio 2 : 3 : 5, Williams & Fuller produce synthetic inclination logs that simulate very well the time-dependent behaviour experienced at most site localities. More specifically, this solution is associated with a dominant quadrupole (g_2^0) whose effect is tempered in the Northern Hemisphere by a g_3^0 contribution of opposite sign and to a lesser extent the g_4^0 component. An interesting prediction for transitional field behaviour at mid-southern latitudes is a minimal variation in intensity throughout the reversal (Williams & Fuller 1981*b*). Figure 5 shows this simulation for the case of the low-latitude records from the east-equatorial Pacific as well as for a mid-latitude record from eastern Europe. Application of the same model to the high-resolution R–N Tertiary transition record from Mt Rainier (Dodson *et al.* 1978) renders an excellent fit in both inclination as well as relative palaeointensity (Williams & Fuller 1981*b*).

6. Conclusions

The following list of statements summarize the findings associated with this review.

1. The general site dependence of transitional v.g.p. data, once clearly visible, has become somewhat obscured by the addition of certain recently acquired reversal records. The harmonic characteristics of certain transitional fields may perhaps differ markedly. However, at least for the Matuyama–Brunhes reversal, for which many records are available, the v.g.p. data display an obvious near-sidedness and therefore a strong zonal harmonic content, especially during the onset of the transition.

2. Palaeomagnetic records of igneous-recorded excursions which, unlike currently available transition records, have been acquired from mid-latitude sites in both hemispheres, display field behaviour that supports the hypothesis that the geodynamo undergoes abortive attempts to reverse. More specifically, the corresponding paths of the v.g.p. are either strongly near-sided or strongly far-sided and therefore appear to be associated with largely axisymmetric fields. At this time the site dependence found for these apparently unsuccessful transitions is consistent with the hypothesis that a zonal quadrupole term dominates such reversing fields and, furthermore, that these reversal attempts start in the Southern Hemisphere of the core. It remains to be seen whether such a conclusion will be supported, or again obscured, by additional data.

3. The source of the controlling geometries in transition fields is highly debatable. While certain data support the hypothesis that a long-term standing field is a dominant factor in the definition of such intermediate fields, other data equally support the hypothesis that the controlling influence is due to the configurational characteristics of a reversal process that involves the entire field.

4. The application of two quantitative models to the available set of multiple records corresponding to the Matuyama–Brunhes transition has resulted in determinations of the harmonic content during this reversal. More specifically, both approaches, (*a*) the phenomenological generalized flooding model (Hoffman 1979, 1981*b*), which considers primarily the transitional path of the v.g.p., and (*b*) the zonal harmonic model (Williams & Fuller 1981*b*), which considers the time-dependent variation in inclination as well as energy, find this particular transition field to be strongly axisymmetric and dominated by non-dipole terms of low order. Specific predictions, especially with regard to field behaviour experienced at Southern Hemisphere sites, provide a means to evaluate further the relevance of these models. Of course. reliable Matuyama–Brunhes transition data from such sites must first be made available.

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Discussion

R. Hide, F.R.S. (*Meteorological Office, Bracknell, U.K.*). Dr Hoffman has emphasized the difficulties of finding suitable models of the origin of the geomagnetic field that can be used in the interpretation of the important palaeomagnetic observations of the behaviour of the field during polarity reversals or excursions. As I shall discuss in my paper later in this symposium, there is one general theoretical result that might be useful in this connection, i.e. that while decaying magnetic fields may have an axis of symmetry (not necessarily the rotation axis of the system), growing or steady fields must exhibit suitable departures from axial symmetry (see Hide, R. 1981 *J. geophys. Res.* **86**, 11 681–11 687). Coriolis forces associated with the Earth's rotation promote departures from axial symmetry when Lorentz forces associated with the magnetic field are weak, but not otherwise. Thus archaeomagnetic and palaeomagnetic data *might* show evidence that departures from axial symmetry in the geomagnetic field are systematically less during the decay phase of a polarity reversal or excursion than during the recovery phase (see Hide, R. 1981 *Nature, Lond.* **293**, 728–729) and I wish to stress the importance of analysing available and new data with this possibility in mind. It has often been remarked that dynamo theory has never predicted anything about the Earth's magnetic field. Here I offer a prediction. If observations show that the geomagnetic field is typically more symmetric during the decay phase than the recovery phase, it is likely that the Lorentz forces are on average comparable in strength with Coriolis forces, and this would imply that the toroidal magnetic field in the core is about 10^{-2} T, nearly 10 times that of the poloidal field.

K. A. Hoffman. The observation from palaeomagnetic records that field configurations during geomagnetic reversal are at least sometimes controlled by axisymmetric, non-dipole components has been noted (see, for example, Hoffman 1977). Furthermore, it has been pointed out (see Fuller *et al.* 1979) that field behaviour associated with the second half of transitions frequently exhibits greater scatter in direction than the first half, as well as a greater deviation from axisymmetry. The Matuyama–Brunhes transition data, in particular, display this characteristic (see figure 1 of this paper). Hence Professor Hide's theoretically based comment is supported by at least some of the currently available palaeomagnetic records of polarity transitions.

It should be noted, however, that the first half of a reversal as viewed in palaeomagnetic records might not be truly representative of a 'decay phase' as Professor Hide suggests. Rather, the field vector at a given site may be the resultant of competing effects from region(s) of the core that first experience reversal, that is, those that first generate flux of opposite sign, with region(s) at which the reversal process has not yet developed. Such regional definitions may be as simple as the North and South Hemispheres of the core. Such a situation may imply that the observed duration of a recorded reversal is far longer than the characteristic time associated with reversal of flux regionally in the core.

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