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Palaeomagnetic Differences Between Normal and Reversed Field Sources, and the Problem of Far-sided and Right-handed Pole Positions

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Summary

Analysis of palaeomagnetic data from the USSR, which Khramov and Sholpo have separated into normal and reversed mean data, reveals that there is considerable and obvious dissimilarity between normal and reversed regimes of the geomagnetic field source.

These new data also strengthen the case for a world-wide eastward declination of the geomagnetic field during normal regimes, and westward (west of south) declination during reversed regimes. The question of how such fields could be maintained is discussed.

1. Introduction

In three earlier papers (Wilson & Ade-Hall 1970; Wilson 1970; Wilson 1971) which will be called I, II and III, evidence was produced to show that the time-average source of the palaeomagnetic field over the past 25 My was closely that of an axial dipole which had been offset north of the equatorial plane 285 ± 74 km. This is equivalent to the existence of a dipole plus a quadrupole source, both axial.

Because each mean direction of magnetization drawn earlier from various sources usually consisted of mixed normal and reversed contributions, there was too little data to permit a separate examination of dipole offset in any of these papers, except that in Paper II (p. 432) the sea-core data from Opdyke & Henry (1969) suggested that the normal field might be closer to a purely centred dipole field than is the reversed field. That is, the dipole offset may be greater for reversed than for normal fields.

In this paper, some new data is examined which is now available from the book of Khramov and Sholpo, which has been conveniently divided into *N* and *R* (normal and reversed) types of information. This data also suggests that the reversed source is a more offset dipole than the normal source.

2. The basic data

Through the services of the Scientific Documentation Centre in Dunfermline, Fife, I obtained a translation of the tables of palaeomagnetic data from the USSR, contained in the book of Khramov & Sholpo (1967). Over the period Upper Tertiary and Quaternary, they list 65 mean directions and site locations. Five of the mean directions are based on mixed polarity sources, but 24 are based on *R*, and 36 on *N* sources only. This provides an opportunity to examine *N* and *R* data separately.

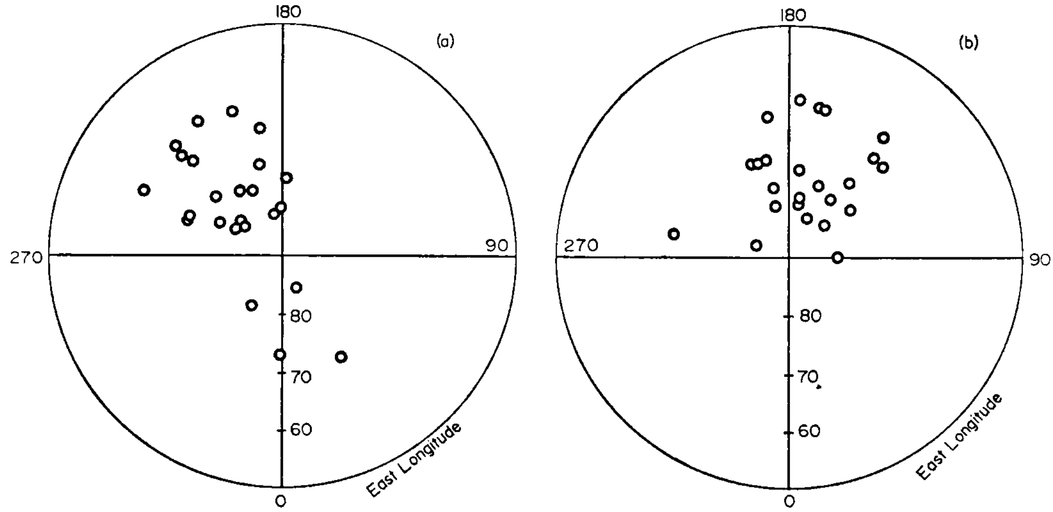

FIG. 1(*a*). Twenty four reversed Upper Tertiary or later mean pole positions (inverted into the Northern Hemisphere) in the usual representation (original site longitude).

FIG. 1(*b*) Twenty four reversed mean pole positions plotted in the common site longitude representation, where every observer is placed on a common line of longitude, taken as zero.

Most but not all of these mean directions meet the earlier selection criteria in II and III. Nevertheless, because of the small amount of date here, I have accepted it all, and merely note that selection of data introduces very slight differences and would not alter the final interpretation.

A majority of these data arises from investigation of sedimentary formations. I have previously rejected* this kind of data because of the danger that detrital remanence might give misleadingly false magnetic inclination. However, the distinction between N and R inclinations, in the present case, suggests that at least the *difference* is real, even if there is some superimposed systematic inclination error on both N and R material.

3. Analysis of the separate *N* and *R* information

The site locations happen to be grouped in the longitude intervals 30° to 60° and 130° to 160° East of Greenwich with very few in-between sites. The difference of 100° between these groups permits an admittedly weak comparison of pole positions as seen.

(*a*) In the usual geographic co-ordinates (original site longitude representation), in Figs 1(a), 2(a), and 3(a).

(*b*) As seen from each site simultaneously, taking each site to be at zero longitude and rotating the palaeomagnetic poles so that they keep the same longitude relative to the observer (common site longitude representation), in Figs 1(b), 2(b) and 3(b).

It was found in III that when observers from all over the world were gathered on a common line of longitude, their poles then fell predominantly into the quadrant

*With the exception of Opdyke & Henry's sea-cores in Paper II.

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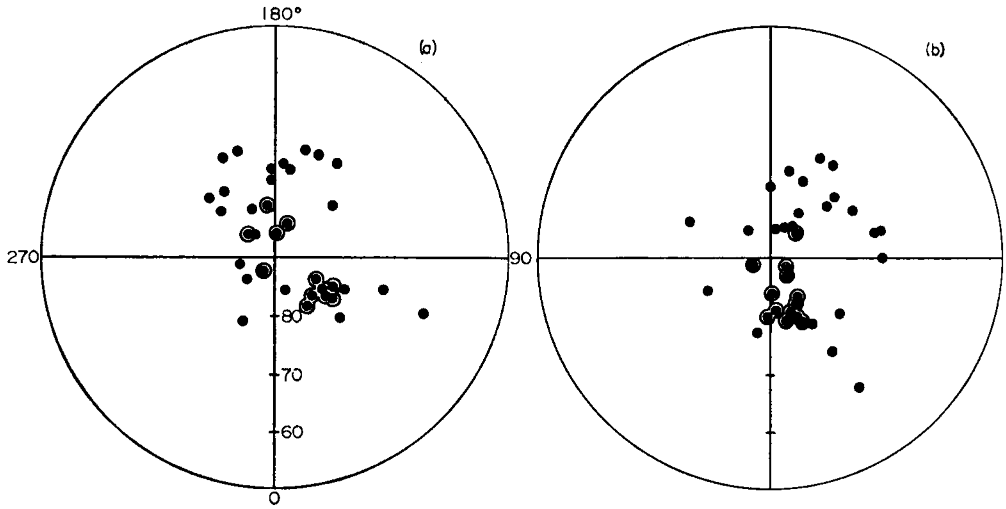

FIG. 2(*a*). Thirty-six normal mean pole positions in the original site longitude representation. Circled dots refer to the youngest 'Q' poles.

FIG. (2*b*). Thirty-six normal mean pole positions in the common site longitude representation.

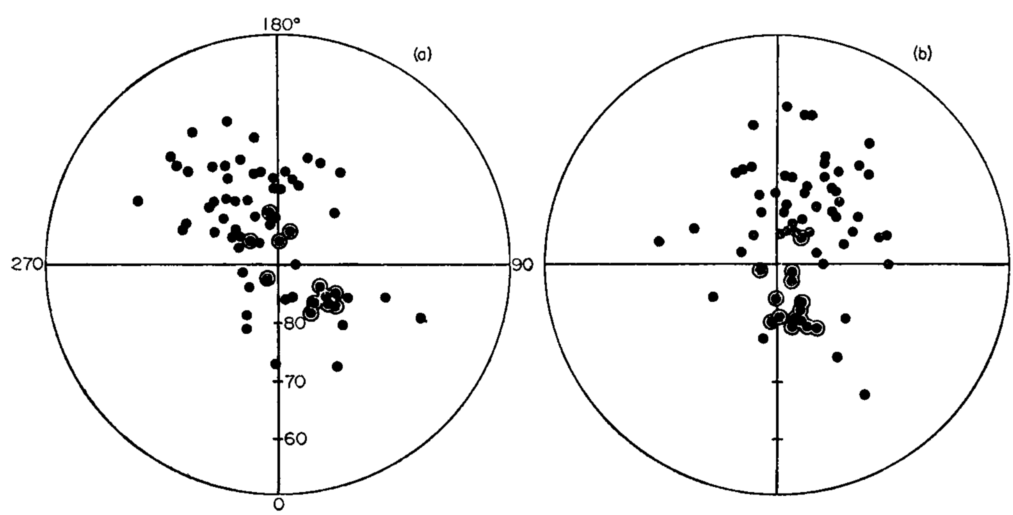

FIG. 3(*a*) 24 *R*, 36 *N*, and five mixed polarity pole positions in the original site longitude representation.

FIG. 3(*b*). 24 *R*, 36 *N*, and five mixed polarity pole positions in the common site longitude representation.

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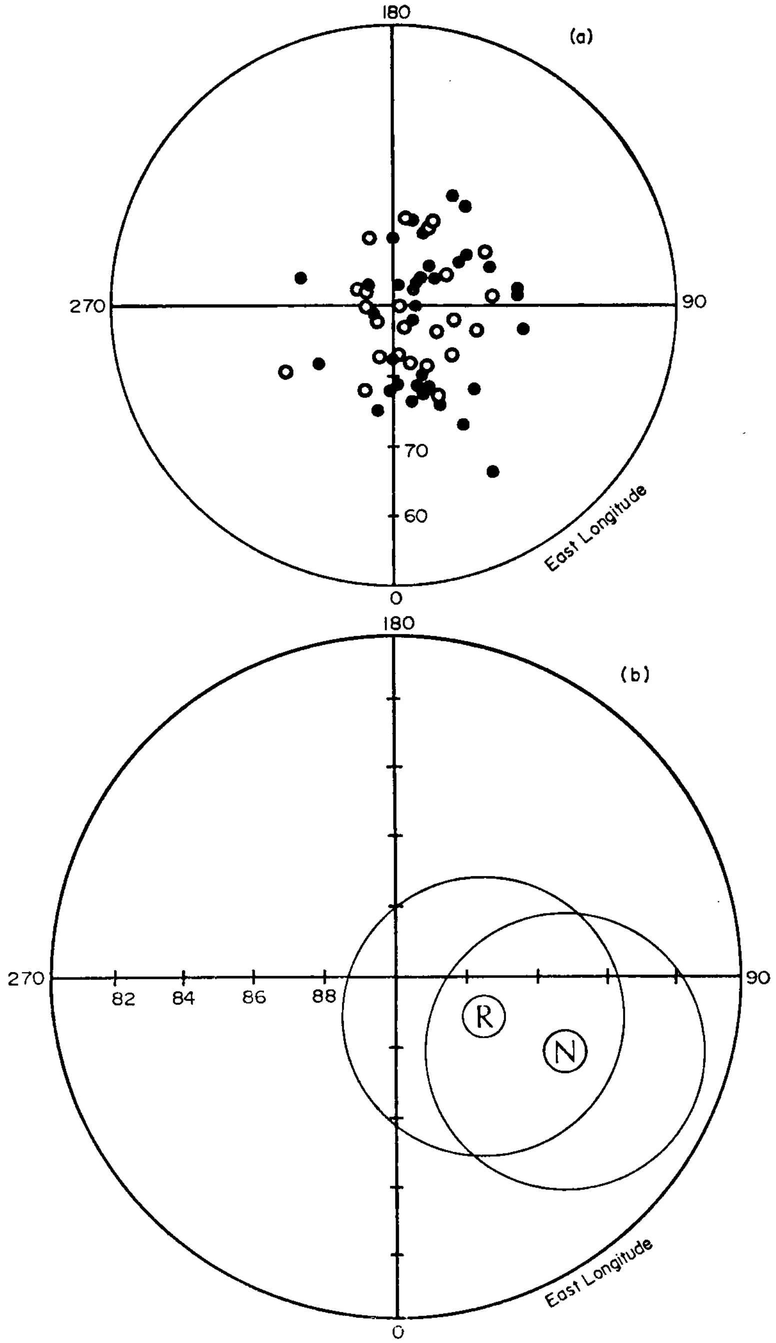

FIG. 4(*a*). *N* and *R* (black and open circles) poles in the common site longitude representation and corrected for dipole offset.

FIG. 4(*b*). The mean pole position and α_{95}'s for the *N* and *R* poles in Fig. 4(*a*), in common site longitude representation, and corrected dipole offset.

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90° to 180° east of the observer. That is, the poles were 'far-side' from their observers' and 'right handed' in that they were to the right (or east) of geographic north.

Fig. 1(a) and 1(b) show the *R* poles (*inverted* into the Northern Hemisphere) in both original and common site longitude representations. It is clear that they are in Fig. 1(b) somewhat more closely grouped and are predominantly in the 90° → 180° quadrant, as in Paper III. The new factor is that the *R* poles are far more (13·5°) far-sided than previous studies have suggested (3·2° is the world average for *N* and *R* combined in Paper III although the Russian data were 6·8° far-side even in III).

By contrast, Fig. 2(a) and 2(b) show that *N* poles are much less far-sided (0·02°) but are still right handed. The *N* case is somewhat complicated in that what Khramov and Sholpo term '*Q*' poles (circled black dots), apparently belonging to the latest normal (Brunhes) epoch, are strongly localized in Fig. 2(a) and 2(b), and they do not differ very much from the geographic pole. This agrees with Professor N. D. Watkins' criticism (private communication and a talk at the 1971 *Reading Conference*) that the poles of the Brunhes epoch are not generally far-sided. Perhaps they are not indeed.

Nevertheless, with or without these circled (Brunhes) poles in Fig. 2(a) and 2(b), the *N* poles are observably less far-sided than the *R* poles, and both *N* and *R* poles are right handed by the same order of magnitude as earlier studies suggested (III).

In Paper III it was suggested that the pole positions were far-sided because they were calculated *assuming* a central axial dipole source. Relaxing the 'central' condition, and allowing the dipole to move northwards along the rotation axis, permitted the calculation of the northwards displacements necessary to minimize the scatter about the geographic pole. In the present case this leads to northward offsets of 1050 km for the *R* source; 175 km for the *N* source; 600 km for both *N* and *R* combined.

Carrying the process formally forward, we can modify the individual *R* and *N* poles as in Paper III to take account of the two dipole offsets for *R* and *N* epochs separately. Fig. 4(a) shows that this brings the *R* and *N* poles into good coincidence

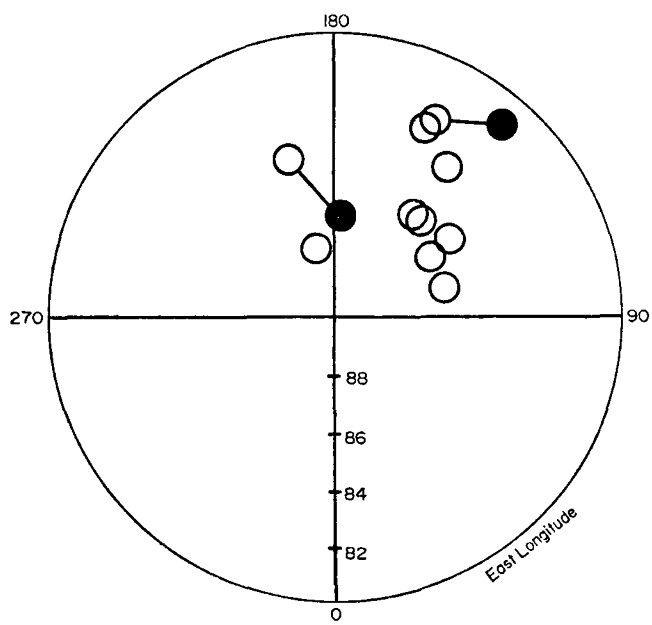

FIG. 5. The 10 regional mean pole positions from Paper III, plus two new sets of data (black dots) from the southern USSR (upper right) and Far East (upper centre). The black dots are joined to earlier mean poles from the same regions. Common site longitude representation.

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with each other near to the geographic pole. Figs 4(a) and 4(b) both show that the poles tend to lie to the right of the geographic pole by a few degrees. The large circles are 95 per cent confidence circles. Table I contains the statistics of the various configurations of poles.

4. Interpretations concerning far-sidedness

This Russian data by itself could not establish the offset dipole hypothesis. There is insufficient data and insufficient spread of longitude. It is only with the hindsight afforded by Papers II and III that we may interpret the present case in this way. The facts are, in summary.

1. The 36 *N* poles are far-side by an amount suggesting a 175 km dipole offset. Also these *N* poles are on the mean 4·9° to the right of the geographic pole as seen by all observers simultaneously. This is outside the α_{95} of 3·7° and is therefore significant.

2. The 24 *R* poles are far-side by an amount suggesting a 1050 km dipole offset, which is the largest yet encountered, by a considerable factor. When the 175 and 1050 km dipole offsets are used to modify the *N* and *R* pole positions respectively, the two sets of poles come into very good coincidence (Fig. 4(a) and 4(b). The *R* mean pole is also right handed, by 2·9°, which is less than the α_{95} of 4·1°, and is not by itself significant.

What conclusions may we draw? Many of these data arise from sedimentary rocks, so that we must take into consideration that the absolute inclinations of magnetization (and hence the pole positions) could be biased by any of the effects normally associated with depositional remanence (King & Rees 1966) or with, say, compaction of the sediments. Nevertheless, there has never been any suggestion that normal and reversed magnetizations ought to be perturbed differently by any of these effects. Further, 15 of the 60 *N* or *R* mean data do come from igneous rocks and they show the same *N–R* difference as the rest of the data, when viewed separately. Even if some systematic depositioned effect were at work on these rocks, it could not explain the great *difference* between *N* and *R* poles.

Nor are the ages of the poles going to explain the *N–R* difference. The *N* and *R* mean poles are completely interlaced in time back to the beginning of the Miocene. The only time difference observed is that the *N* poles of the normal period (Brunhes) are abnormally concentrated together. But taken in conjunction with the earlier *N* poles they form a sensible distribution, and there is no reason for excluding them. Even if we do exclude them, the gross difference between *N* and *R* fields persists. This time-interlacing also makes impossible any explanation in terms of continental drift.

Since we do not have a world-wide distribution of data in this paper, and since the data are somewhat limited, it would be wrong to draw strong quantitative conclusions. What seems clear however is that the data presented here agrees with the earlier analysis in Paper II of Opdyke & Henry's (1969) sea-core results, in suggesting that the *N* source is more nearly a centred axial dipole than is the *R* source. An alternative statement of the same phenomenon is that the *N* and *R* sources each consist of centred axial dipole and quadrupole components, but that the quadrupole component is stronger in the *R* case. This is a statistical result—a time average look at the source nature.

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Table 1

Mean pole positions and statistics (all quantities in degrees)

Data group	(1) Original site longitudes				(2) Common site longitudes						(3) Common site longitude modified poles			
	long.	lat.	δ	α_{95}	long.	lat.	δ	α_{95}	F.S.	R.H.	long.	lat.	δ	α_{95}
24 *R* poles	223·2	78·4	13·4	5·1	167·7	76·2	11·0	4·1	13·5	2·9				
36 *N* poles	144·2	85·8	12·4	3·7	92·6	85·1	12·1	3·7	0·02	4·9				
60 *N*+*R* poles	197·2	84·3	14·0	3·2	143·4	83·1	13·4	3·1	4·1	5·5	65·7	85·8	11·1	2·6
14 Far East poles	313·0	87·9	12·9	6·6	176·4	86·5	12·6	6·5	3·5	0·2				
51 Southern USSR poles	194·5	81·7	13·3	3·3	139·1	81·2	13·0	3·3	6·6	5·8				

The 14+51 = 65 poles in the two regions Far East and Southern USSR, are the 60 *N* and *R* mean poles plus 5 mean poles of mixed polarity.

δ = standard deviation of the distribution of poles being meaned

α_{95} = 95 per cent circle of confidence

F.S. = far-sidedness of mean pole = (90° − pole latitude) × (−COS (common site pole longitude))

R.H. = right-handedness of mean pole = (90° − pole latitude) × SIN (common site pole longitude))

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5. Interpretations concerning right handedness

There is no significant difference between the right handedness of the *N* and *R* mean poles (see Fig. 4(b). It is valid therefore to leave *N* and *R* mixed together and to separate the data into two regional sets, one from the Southern USSR (site longitudes almost all 30° to 60° East) and one from the Far East (site longitudes 130° to 160° East) as in Paper III.

An error in Paper III should be indicated here; of the 10 regional mean poles, two were left handed. They were said to be those from (1) the Southern USSR, and (2) the Argentine plus South Shetland Islands. It should have said they were from (1) Far East and (2) the Argentine plus the South Shetland Islands.

In Fig. 5 we plot the 10 regional mean poles from paper III. The two regions for which new data presented in this paper are for the Far East and the Southern USSR. They are represented by two black dots linked to the earlier mean poles from the same two regions. The new Southern USSR pole (upper right) is even more right handed than the earlier estimate. The new Far East pole just manages to be right handed rather than left handed like the original one. Therefore the new data tips the balance somewhat more in favour of a general eastward declination of the geomagnetic field vector, with the problems which that entails, as mentioned in Papers II and III.

There is however, one point which may become crucial to an ultimate interpretation of the problem of the general eastward declination. The point is that for the *reversed* regimes of the field, the corresponding declination is *west* of south. The new USSR data, which has been split into *N* and *R* sets, shows this unequivocally, and it is implied by all the earlier (mixed *N* and *R*) data used. *R* declinations are only eastward after inversion of the *R* data for combination with *N* data.

In the earlier papers, a general eastward toroidal field at the Earth's surface was inferred from the data, and this required a steady (time-average) earth–air electric current system which was 10^6 of the presently observed currents. Now it appears (and I should have seen it before) that this apparently toroidal field reverses when the main field reverses. It now seems reasonable to consider an oscillating phenomenon wherein not true current J, but displacement current dD/dt was flowing back and forth and charging the Earth's hemispheres alternately. However, this leads to (during any one polarity regime) a rate of increase of the vertical field E in the atmosphere, of the order of 40 000 Volts m^{-1} s^{-1} which is clearly absurd.

One interesting observation concerning the places which have been sampled palaeomagnetically is that for Tertiary times, these places tend to be where basalts are being extruded; that is, in or near orogenic regions. Our 10 regional mean poles comes from the following regions

Eastern Australia and New Zealand; The Far East (Phillipines, Taiwan, Japan, Sakhalin, Kamchatka); North America (exclusively the western side); Argentine and S. Shetland Islands; (the above encompass the Pacific Ocean).

Canaries, Madiera and Cape Verde Islands; Southern Europe; Southern USSR. (the above take in the Atlas–Alpine–Himalayan Orogeny).

East Africa and Arabia (which takes in the E. African rift zone).

The Hawaiian Islands; Iceland (typifying sea-floor basaltic extrusion).

If the non-dipole geomagnetic field were partially connected with these orogenic areas, it would perhaps be possible to explain both far-sidedness and right-handedness of pole positions as being due to an earth-current system (but *not* a system of *permanent* magnetization because that could not reverse when the main field reverses) which, averaged over the whole earth, would not show far-sidedness or right-handedness

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(or one of those two). Since we are unlikely to get many Upper Tertiary results from non-orogenic continental regions, the sea-cores seem to be our only recourse in testing this idea on a wide enough scale. If totally oriented sea-cores also show right-handed mean poles we shall have a very puzzling problem to think about—how can a predominantly eastward field declination be maintained at the Earth's surface during Normal regimes (and westward during Reversed)? According to Maxwell's equations and present observations, there are no electric current distributions adequate to maintain such toroidal fields above the Earth's surface.

6. Discussion

A review of new data from Khramov & Sholpo's book (1967), which data was separated into normal and reversed mean poles spread throughout Upper Tertiary times, has shown that

(1) Reversed mean poles from Southern USSR and the Far East are conspicuously more far-sided than normal poles (Figs. 1 and 2). In terms of offset dipoles, the reversed dipoles are more offset than the normal ones.

(2) The separated mean poles from these two areas confirm the general right-handed nature of the geomagnetic declination so far discovered (Fig. 5). Right-handedness means east-of-north declinations for normal fields and west-of-south declinations for reversed fields.

The far-sidedness of poles is explicable in terms of internal current distributions—offset dipoles being a simple but not physically very revealing model. The right-handedness of poles is not explicable in terms of internal current distributions if right-handedness is a world-wide phenomenon. Yet there do not exist adequate earth–air current systems to support world-wide toroidal fields at the Earth's surface, if Maxwell's equations govern the phenomenon observed. This leads to the observation that the 10 regions of the Earth which provide us with Upper Tertiary and later palaeomagnetic information may be *special*, in that they are almost all near to major plate boundaries where basalts are being produced. The speculation arises naturally that these plate boundaries (both separating and coalescing) are regions wherein earth-currents are producing the observed (far-sided and right-handed) perturbations of the main field. This idea has the advantage of being a single hypothesis which might explain both far-sided and right-handed poles. The geometry of such a current system is not impossible (like that of a toroidal field in the atmosphere) but implies that at other places far from plate boundaries, the field should often be found to be left handed, so as to average to zero declination over the entire Earth's surface, as it must. The difficulties of finding palaeomagnetic Upper Tertiary information in shield areas suggests that totally oriented sea-cores far from plate boundaries will best provide the test for the left-handedness of declinations in such areas. Against this hypothesis are the facts that Opdyke & Henry's sea-cores (far from plate boundaries) did still provide evidence for far-side poles (but no evidence about right or left handedness). Also, the Hawaiian data (again far from plate boundaries) provided a right-handed and far-sided mean pole.

To explain the facts presented in this paper, the postulated electric current system would have to reverse its sense everywhere when the main field reverses. This implies that the current system is a leakage current from the core into the mantle. That could account for the geographic localization of the field perturbations we are observing, since the electrical conductivity structure of the mantle would determine where and how the leakage currents will flow (but not the *sense* of flow).

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For the moment there is not enough geographical spread of data to specify precisely the full nature of the field perturbations implicit in the existing Upper Tertiary data.

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