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Palaeomagnetism of Some Recent Basalts from New Guinea

by

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1. FOREWORD

To assist those not familiar with palaeomagnetism, this foreword has been written, in fairly general terms, to give an introduction to, and the reasons for, the main palaeomagnetic models of the Earth's magnetic field.

Secular Variation and Palaeomagnetism

In the reduction of palaeomagnetic data, it is assumed that the magnetic field of the Earth can be represented, on the average, by a geocentric axial dipole of appropriate strength. Yet from even a cursory examination of the configuration of the magnetic field in recent times (observatory measurements go back approximately 400 years), it is obvious that this, in detail, is not so. The present field is only very approximately that of a geocentric dipole - not axial, as it is inclined at $11\frac{1}{2}^{\circ}$ to the spin axis, with the magnetic (dip) poles at some distance from the geographic poles. And it has numerous other components superimposed upon it (called non-dipole components for convenience). As well, the whole field, when observed at any one place, undergoes variations with time which constitute the transient and secular variations.

Transient variations are variations in the strength and/or direction of the Earth's magnetic field observed at any particular place which are of short duration - usually of the order of hours or days. These variations have been shown by spherical harmonic analysis to be of external origin, caused by ionospheric current changes. Variations with a periodicity of a greater order (10 to 10^4 years) are known as secular variations and are of internal origin.

The successive annual mean values of the magnetic elements at an observatory, or the values obtained for different epochs by magnetic surveys, show that the Earth's field undergoes secular changes - that is, changes long continued in the same sense, though not necessarily or usually at a constant rate. This is called the secular magnetic variation; over a long period the total change is very considerable, though it may not continue indefinitely without reversal.

These secular variations are of internal origin, as shown also by spherical harmonic analysis of the whole field at different epochs.

It is obvious that, owing to their extremely short periods and relatively small magnitudes, the transient variations are of no significance in palaeomagnetic work - they are too short to be recorded adequately in the remanent magnetism of the rock. As well, the time intervals studied in any one rock formation are usually very much greater than the period of this variation, so that it would be completely averaged out since the variation is, to all intents and purposes, random in nature. But the secular variation, being of the same time order as the time of formation of the rocks studied, is recorded in the rocks' remanent magnetism, and is of considerable importance in palaeomagnetism.

It is assumed for palaeomagnetic work that, averaged over a sufficiently long interval of time (about 10^3 to 10^6 years), the secular variation of the field is averaged out, and the average of the total Earth's magnetic field is that of a geocentric axial dipole. There is considerable evidence to support this hypothesis, both from studies of the variation of the present field and from the internal consistency of palaeomagnetic results, but the matter has not been settled completely satisfactorily. This study is intended to consider principally the secular variation in relation to the various theoretical models of the Earth's magnetic field, and to see if any light can be thrown on the subject by the comparison of actual palaeomagnetic measurements with the results to be expected from these models.

The present Earth's field

The secular variation is usually expressed in terms of the changes in the magnetic elements (X, Y, Z, H, D, I, etc.) and plotted on maps as contours of equal change in any one of these elements; [illegible] the contours are called isopors. The secular variation has the following general properties:

(i) The isopors form a series of oval-shaped closed curves surrounding points, termed isoporic foci, at which the changes are most rapid.

(ii) At any epoch, such sets of isopors cover areas of continental size, which can be called active areas, and are separated by areas over which the changes are small, which can be called quiescent areas.

(iii) The isopors in a region may change considerably in form in the course of a few decades, and active areas may decay or establish themselves during that time.

(iv) Each isporic focus and its associated set of isopors appears to drift to the west at a mean rate of about 0.3° of longitude per year.

A comparison of the secular variation at a number of stations shows no correlation between them. That is, the secular variation cannot be accounted for by a simple movement of the total field. It is a regional phenomenon, not a planetary one.

It has been shown that the secular variation field can be represented by a number (13 or 14) of vertical dipoles at a depth of approximately half the radius of the Earth and suitably distributed. These small, disturbing magnetic dipoles would be caused by 'horizontal circuits of current flow' originating in a very thin shell at the surface of the core. That is, by relatively small current-carrying fluid eddy-systems at the outer boundary of the Earth's core, which generate disturbing magnetic fields by some electromagnetic process.

A spherical harmonic analysis of the present Earth's magnetic field shows that it can be represented to a first approximation by a geocentric inclined magnetic dipole (or alternatively, a geocentric axial dipole, together with two dipoles in the plane of the equator, of magnitude about 15 percent of the main dipole). The higher harmonics of the analysis constitute the residual or non-dipole field, of magnitude about 5 percent of the geocentric field. If the field due to the geocentric (inclined) dipole is subtracted from the observed total field, the non-dipole field is left. This field is concentrated into about 10 areas of continental extent. This distribution is of the same sort as that of the secular variation, which suggests a connexion between the two.

The non-dipole field also drifts westwards with time, but at a different rate, apparently, from that of the secular variation field. The rates have been estimated as:

$0.18 \pm 0.015^{\circ}$ per year for the non-dipole field.

$0.32 \pm 0.067^{\circ}$ per year for the secular variation.

Recently, however, doubt has been cast on the constancy of these drift rates, and consequently the difference between the two rates quoted may not be at all significant and their absolute magnitudes may be somewhat debatable.

The non-dipole field has also been shown to be explicable in terms of a discrete number of radially directed magnetic dipoles situated at the boundary of the Earth's core. This is very similar to an explanation for the secular variation field, which again suggests a connexion between the two.

A causal relationship has been sought between the non-dipole field and the secular variation. It was found that 'the dipole field changes only comparatively slowly and most of the secular variation is due to the time variation of the non-dipole field', and that 'movement of the non-dipole field regional sources accounts for a very appreciable part of the secular variation'. It was found that about one-third of the secular variation can be accounted for by the westward drift movement of the non-dipole field, and the remainder is probably due to changes in the magnitude and orientation of the magnetic dipole sources of the non-dipole field.

It thus appears that the secular variation can be explained as follows:

(i) The westward drift of the dipoles that generate the non-dipole field contribute one-third of the secular change.

(ii) The majority of the remainder is caused by random changes in the magnitude and orientation of these dipoles.

(iii) A smaller contribution is made by the overall movement of the main dipole field.

With regard to (iii), the main dipole field probably moves, since the magnetic dip poles have moved geographically with time. The orientation of the main geocentric dipole with respect to the geographic (spin) axis thus seems to change with time. A complete rotation of the total field is also suggested by the westward movements of all non-axial components of the field, and by the apparent northwest movement of the north magnetic dip pole.

It seems not an unreasonable assumption, then, that the Earth's magnetic field consists of two main parts :

(i) The main field due to the main geocentric dipole, generated by some large-scale mechanism in the Earth's core.

(ii) A much smaller disturbing field, generated by a finite number of discrete mechanisms near the boundary of the core, which undergo changes with time and so give rise to at least the major part of the observed secular variation.

Periods of the secular variation

There seem to be three time orders of the secular variation:

(i) Short-period changes of the order of 100 years and less, caused by random fluctuations in the intensity and orientation of the magnetic dipoles near the core boundary.

(ii) Longer-period changes of the order of 500 years due to the westward drift of these dipoles (it has been shown that the movement of a dipole westwards beneath an observing station will give a clockwise movement of the magnetic vector at the station. And measurements at London show that the distribution due to this movement can, at least, be oval).

(iii) Very-long-period changes of the order of 1200 to 2000 years due to the oscillations or overall movements of the main geocentric dipole.

These last two periods appear also in the spherical harmonic analysis of the field.

The above considerations have given rise to two main models of the Earth's field for palaeomagnetic work.

Models of the Earth's magnetic field

To be useful for most palaeomagnetic work, a physical or mathematical model of the Earth's magnetic field must be averaged, or rather statistical, in form. It must be a picture of the field such as would appear if the field was averaged over a period of time from about 10^3 to 10^6 years. This is because the time periods studied in palaeomagnetism are usually of this order - the time taken for a sedimentary formation or a sequence of basalts or intrusives to be formed. Since this order of time is greater than the periods of the secular variations, presumably a spectrum of directions will be obtained in the palaeomagnetic measurements, which will cover the total possible range of the secular variation at that particular (palaeomagnetic) position in space and time (unless of course the palaeomagnetic measurements are made on a rock body formed over a shorter period than this, e.g. a single lava flow or a single small dyke, in which case no conclusions can be reached as regards the position of the main dipole or the geographic poles).

The form of the spectrum of directions could possibly be used to differentiate between the models proposed.

(1) Model B : The Whin Sill Model

The simplest model proposed is that due to Creer, Irving and Nairn (1959). It consists of a non-axial geocentric dipole oscillating in a random (Fisherian) fashion (Fisher, 1953) about the mean position, which lies along the geographic (spin) axis (i.e. the mean is the geocentric axial dipole). This model is suggested by the non-axial position of the present main geocentric dipole and by the movement of the magnetic poles and the apparent westward drift of the non-axial components of the present field. It completely ignores any secular variation effects of a purely regional nature (and we have shown that the greater part of the present secular variation is of a regional rather than a planetary nature), and considers that the secular variation over the lengths of time studied can be taken to be that due to the movements of the main geocentric dipole field. That is, the secular variation of the main dipole field would be far greater in magnitude than the regional secular variation, so that the pattern of variation observed would be that of the main dipole variation, with only a very small random variation superimposed upon it by the regional secular variation. In this case, the regional secular variation could be neglected.

Consider now a number of palaeomagnetic site direction measurements, and the pole positions calculated from them on the geocentric dipole theory. It is obvious that, according to Model B, the distribution of pole positions around the mean axial pole position, being due to a random oscillation, will be random (i.e. Fisherian) in form. The distribution of directions as measured at the sites will be oval (i.e. non-Fisherian) in form, the dimensions of the oval varying with palaeolatitude. The variation in declination (dD) and in inclination (dI) calculated from this model are:

$$dD = \Theta_o \,(1 + 3\cos^2 \lambda)^{-1/2}$$

$$dI = 2\,\Theta_o \,(1 + 3\cos^2 \lambda)^{-1}$$

where λ is the palaeomagnetic colatitude and Θ_o is the Fisherian circular standard deviation of the oscillations of the pole around the mean pole position.

Given a circular (random or Fisherian) distribution of poles, the observed directions of magnetization of rocks from low palaeomagnetic latitudes should have oval distributions with $dD = \frac{1}{2}\,dI$, while in rocks from high palaeomagnetic latitudes the observed directions of magnetization should have a circular distribution, the variation in inclination and declination being one-half the variation for declination in low latitudes.

Thus it should be possible to test this model by a study of the observed forms of the distributions of directions and pole positions as obtained in palaeomagnetic work, particularly from rocks in low latitudes.

(2) Model A : The Random Perturbation Model

In this model, (Irving & Ward, 1964), it is assumed that the main geocentric dipole field (H) is constant in form and magnitude, and this field is perturbed by randomly positioned and directed field components of constant magnitude (h).

The main dipole field varies with latitude according to the equation:

$$H = H_o\,(1 + 3\sin^2\lambda)$$

where H_o is the field strength at the equator and λ is the latitude.

At any particular point of observation on the Earth's surface, there is the main field whose strength varies with latitude as above, and upon this is superimposed a randomly directed component of field of constant magnitude h. As H increases with higher latitude, and h remains constant, the effect of the perturbing field - that is, the magnitude of the secular variation - decreases with higher latitudes.

From an analysis of a sample of directions at a particular latitude, an estimate k of a precision parameter (Fisher, 1953) can be made, and from this an estimate of the circular standard deviation χ obtained using the relations:

$$\chi = 81/k^{1/2}$$

$$= 46.8\,\sigma_e\,(1 + 3\sin^2\lambda)^{1/2} \text{ degrees}.$$

where $\sigma_e = h/H$ at the equator.

According to this model, the form of the secular variation should always be circular (i.e. Fisherian in distribution), and the magnitude should increase appreciably with decreasing latitude. That is, all the distributions of palaeomagnetic directions measured should be Fisherian in form, and the precisions of such measurements should increase perceptibly with higher palaeomagnetic latitudes. The distribution of pole positions, on the other hand, should always be non-Fisherian, most appreciably for directions measured at the equator and approaching a Fisherian distribution at the poles.

These conclusions should also be easily checked from palaeomagnetic data.

2. PALAEOMAGNETISM OF SOME RECENT BASALTS FROM NEW GUINEA

Abstract

The palaeomagnetic directions are given from 22 sites in the Recent basalts of New Guinea, situated within 5° of latitude of the equator. The mean direction ($D = 000^{\circ}$, $I = -16^{\circ}$, $\alpha_{95} = 6\frac{1}{2}^{\circ}$) is not significantly different from the present axial dipole field direction ($D = 000^{\circ}$, $I = -8^{\circ}$). The data provide support for the Random Perturbation Model (Model A) of the Earth's magnetic field suggested by Irving and Ward (1964). The between-site precision ($k = 21$) provides an estimate of the angular dispersion $\Theta_0 = 20^{\circ}$ ($+2^{\circ}$, -7°) which is related to the palaeosecular variation. This estimate is not significantly different from that estimated (Creer, 1962) by rotating the present geomagnetic field directions about the Earth's rotational axis (21°). The data suggest that the Pacific region of low non-dipole field variation (Cox, 1962) is a temporary phenomenon.

INTRODUCTION

The Territory of Papua & New Guinea and its surrounding islands lie close to the equator, and have a considerable volume of Recent volcanic material. Thus it is an important area of studies of secular variation using palaeomagnetic techniques (i.e. of palaeosecular variation), particularly from the point of view of distinguishing between the two palaeomagnetic models of the geomagnetic field - Model A of Irving and Ward (1964), and Model B of Creer, Irving and Nairn (1959).

This area is of interest also because it lies within the Pacific region of low secular variation of the non-dipole components of the present field (Cox, 1962).

GEOLOGY AND SAMPLING

Samples of Recent volcanics were collected in 1961 from four distinct areas (see Figure 1):

(a) Baluan Island. This island lies south of Manus Island, at position 147°17'E, 2°32'S. It is a volcanic island with a single peak and fringing coral reefs. It is regarded as being of Recent age because of the dissected nature of the topography, the freshness of a great proportion of the volcanics, and the presence of active volcanic islands nearby.

The collection sites on this island were all near the north coast. Three rock types were collected: fine-grained vesicular basalt; vesicular basalt with scattered small feldspar phenocrysts; and vesicular basalt with a large proportion of feldspar phenocrysts up to one centimetre across. The individual flows could not be distinguished in the field because of the vegetation cover and the lack of extensive outcrops, but the samples collected were all quite fresh.

(b) Karkar Island. This island consists of a single, large volcanic peak about 1800 metres high, with fringing coral reefs. It lies off the north coast of New Guinea at position 145°57'E, 4°34'S, and is visible from the New Guinea coastal town of Madang. This island also is regarded as being Recent in age because of the dissected nature of the topography and the freshness of the basalts. Again, however, the individual flows cannot be distinguished because of the vegetation cover.

The collection sites were all near the northwest coast of the island. The samples collected were all vesicular basalt with feldspar phenocrysts. The proportions of both vesicles and phenocrysts varied considerably from site to site. All samples were quite fresh and unweathered.

(c) Lolobau Island. This island lies just off the north coast of New Britain, in position 151°11'E, 4°55'S. It is a volcanic caldera modified by younger cones, one of which erupted about 1905. It lies within sight of Mount Ulawun, an active volcano on the north coast of New Britain.

The samples here were collected on the south coast and in a small valley inland from this point. Two rock types were collected: a basalt with medium sized feldspar phenocrysts and a large proportion of vesicles up to 0.5 cm across; and a basalt with extremely small feldspar phenocrysts and a few tiny vesicles. They were quite fresh.

(d) Rabaul, New Britain. The town of Rabaul lies on the northeast tip of New Britain, in position 152°12'E, 4°13'S. It is on the shores of a bay which appears to be a breached caldera flooded by the sea. The volcanics of this caldera are regarded as Recent in age since the caldera still has several small active vents. Separate flows can be distinguished in the walls of the caldera, and samples were collected from sites in different flows on the northeast and southwest sides of the bay.

The three rock types collected were: vesicular basalt with feldspar phenocrysts; glassy black vesicular basalt with small feldspar phenocrysts; and glassy black basalt with small feldspar phenocrysts but consisting principally of vesicles. All samples were quite fresh.

The sampling was as follows:

Area	Number of sites	Number of samples
Baluan Island	5	11
Karkar Island	7	13
Lolobau Island	3	8
Rabaul	7	12
TOTAL	22	44

A number of specimens were cut from each sample for measurement.

Even though, in all cases except Rabaul, it was impossible to differentiate between flows in the field, it is thought that most of the sites are in different flows. The reasons for this are the differences in lithologies between most of the sites, and the distances between sites. Thus we can regard the sites as separate sampling points in time of the palaeomagnetic field.

The total time spanned by these sites is not known, but since they come from four separate areas, some still active and some not, it is thought that sufficient time is covered to give a representative coverage of the pattern of the secular variation.

PALAEOMAGNETIC RESULTS

All measurements were made on astatic magnetometers. The natural remanent magnetizations (NRMs) were measured and then, to remove any extraneous magnetic components of low coercivity, a number of specimens (pilot specimens) from each area were demagnetized in alternating magnetic fields in steps between 75 and 600 gauss (peak). The remainder of the specimens from each area were then demagnetized in that particular field which gave the closest grouping of the pilot specimen directions in each area. These demagnetized directions were then the final, cleaned directions used.

The measuring instruments and the alternating field demagnetization apparatus used were the same as, and the technique similar to, those described by Irving, Stott and Ward (1961).

In Table 1 are listed the mean palaeomagnetic directions of the NRMs from each site, and the mean directions after demagnetization, together with the magnetic pole positions calculated from the cleaned directions. These cleaned site mean directions and pole positions are plotted in Figure 3. In Table 1, D and I are the declination and inclination of the mean direction, and R is the vector resultant of the mean (Fisher, 1953).

The mean directions and poles from each area, calculated from the cleaned site mean directions, and an overall mean direction and pole, calculated from all 22 cleaned site mean directions, are listed in Table 2.

It was thought that the geographical separation of the four collection areas might introduce an appreciable artificial scatter in the plotted directions. However, upon approximate correction for this according to the present geomagnetic field configuration, no significant difference was found. Thus the geographical scatter of the collection areas is ignored.

Table 1

Area	Site	Samples	NRM direction			Cleaned direction			Pole position	
		S	D	I	R	D	I	R	°N	°E
Baluan	54	3	001	-9	2.990	003	-6	2.987	87	241
	55	2	004	-9	1.960	350	-7	1.965	88	032
	56	2	358	-19	1.990	004	-17	1.986	83	294
	57	2	355	+2	1.998	356	+4	1.989	84	102
	58	2	256	-8	1.988	310	-3	1.963	40	059
Karkar	43	1	020	-2	-	007	-14	-	83	257
	44	2	356	-11	1.980	000	-16	1.974	87	323
	45	2	357	-18	1.985	354	-26	1.996	79	357
	46	2	027	-39	1.962	023	-39	1.972	62	276
	47	2	009	-15	1.998	010	-14	1.994	79	251
	48	2	014	-25	1.951	011	-23	1.986	77	270
	49	2	356	-21	1.950	004	-17	1.975	84	293
Lolobau	83	2	359	-28	1.989	000	-24	1.981	82	332
	84	3	302	+23	1.596	335	-22	2.791	65	046
	85	3	357	-24	2.975	357	-26	2.995	81	351
Rabaul	76	1	015	-21	-	018	-19	-	72	260
	77	1	004	0	-	000	-8	-	89	152
	78	3	347	-4	2.925	350	+1	2.910	78	085
	79	1	348	-18	-	358	-17	-	85	357
	80	2	011	-25	1.975	005	-25	1.962	80	303
	86	3	007	-22	2.860	023	-19	2.985	68	256
	87	1	011	-11	-	011	-10	-	79	246

Table 2

Area	Position	Sites N	Samples S	Mean direction D	I	R	k	α_{95}	Pole position °N	°E
Baluan	147°17'E 2°32'S	5	11	350	-6	4.6636	12	23	80	054
Karkar	145°47'E 4°34'S	7	13	007	-21	6.8672	45	9	81	279
Lolobau	151°11'E 4°55'S	3	8	351	-24	2.9511	41	20	78	020
Rabaul	152°12'E 4°13'S	7	12	006	-14	6.8221	34	11	83	268
ALL	150°E 4°S	22	44	000	-16	20.982	21*	6½*	86	330

* from two-tier analysis

N = number of sites

S = number of samples

D = declination

I = inclination

R = vector resultant

k = precision of the scatter of directions

α_{95} = half-angle of the cone of 95% confidence about the mean direction

To test whether the distribution of the site mean directions, and of the pole positions, are in accordance with the statistics of Fisher (1953) (i.e. whether they are "Fisherian") at the $P = 0.05$ level, the χ^2 test (Watson & Irving, 1957) was carried out on both distributions.

For the site mean directions,

χ^2 for $D = 6.4$, which is below the limit of 11.07;

χ^2 for $I = 4.9$, which is below the limit of 7.82.

Thus the site mean directions are a Fisherian distribution at the $P = 0.05$ level.

For the pole positions,

χ^2 for longitude = 16.5, which is above the limit of 11.07;

χ^2 for latitude = 11.1, which is above the limit of 7.82.

Thus the pole positions are a non-Fisherian distribution at the $P = 0.05$ level.

MODELS OF THE GEOMAGNETIC FIELD

When considering palaeomagnetic results, it is necessary to have some hypothetical model which expresses the average behaviour of the geomagnetic field over periods of a thousand years or more. This is because it is impossible to obtain accurate measurements of the field's configuration at a single point in time from palaeomagnetic data. Only averages taken over a period of one thousand years or more can be determined with any degree of certainty.

The simplest model is that of a geocentric axial dipole - a single dipole at the Earth's centre oriented along the axis of rotation. This model is inadequate since it does not take into account the secular variations of the geomagnetic field. Two more elaborate models have been proposed:

Model A : The Random Perturbation Model was proposed by Irving and Ward (1964). This model assumes that the geomagnetic field is that of a steady geocentric axial dipole whose field is perturbed at the Earth's surface by randomly directed non-dipole fields of constant magnitude. Such a model would produce a Fisherian distribution of field directions at any one point on the Earth's surface, but the virtual pole positions calculated from these directions would form a non-Fisherian distribution. The contrast between the Fisherian distribution of directions and the non-Fisherian distribution of pole positions would be most pronounced for directions measured at the equator.

Model B : The Whin Sill Model was proposed by Creer, Irving and Nairn (1959). It supposes the geomagnetic field to be a geocentric dipole which undergoes random secular oscillations around the mean dipole position (the axis of rotation of the Earth). Averaged over a sufficient period of time, this model would produce a Fisherian distribution of magnetic pole positions around the mean pole position. However, the geomagnetic field directions at any point on the Earth's surface would form a non-Fisherian distribution. The contrast between the non-Fisherian distribution of directions and the Fisherian distribution of pole positions would again be most pronounced for directions measured at the equator. The distribution of directions would become nearer to Fisherian for directions measured closer to the poles.

Since the samples under consideration were collected within five degrees of latitude of the equator, the palaeomagnetic directions and poles should enable a choice to be made of the Random Perturbation or the Whin Sill model as being the more appropriate fit to these results.

As the site mean directions form a Fisherian distribution, whereas the pole positions form a non-Fisherian distribution, it is apparent that Model A (the Random Perturbation Model) is the better fit.

Fit of data to Model A

Let σ = h/H where H is the strength of the main dipole field, and h is the strength of the random perturbing field. Then, from Irving and Ward (1964), the circular standard deviation χ of a sample of vectors is

$$\chi = 81/k^{1/2} \text{ where } k = N - 1/N - R \text{ (Fisher, 1953)}$$

$$= 46.8 \ \sigma_e \ (1 + 3\sin^2 \lambda)^{1/2}$$

where σ_e is h/H at the equator, λ is latitude, N is the number of vectors, and R is the vector resultant.

For these data, $\lambda = -4^{\circ}$, so that

$$81/k^{1/2} = 46.8 \ \sigma_e \times 1.0073$$

Therefore $\sigma_e = 0.37$ since k = 21.

This value of $_e$ agrees closely with the estimates obtained by Irving and Ward for the present geomagnetic field, and for other palaeomagnetic data.

MAGNITUDE OF THE SECULAR VARIATION

The New Guinea Recent basalt directions can be used to estimate the dispersion of directions of the magnetic field caused by the palaeosecular variation in the New Guinea region, and this can then be compared with the estimates of Creer (1962) and Cox (1962).

Creer has calculated the angular dispersion $\Theta_0 = \cos^{-1}(R/N)$ of the present secular variation with respect to latitude, on the theory that the deviations from an axial dipole field around a line of latitude for a given epoch are the same as those which would occur at any point on that latitude over a long period of time. That is, the distribution of directions caused by secular variation at any point on the Earth's surface is the same as that given at the point by the rotation of the present geomagnetic field bodily about the axis of rotation of the Earth. This variation includes, therefore, both the movement of the non-dipole field and the movement of the main dipole field through a circle of approximate radius 11½° (the angle between the rotation axis of the Earth and the present geomagnetic axis).

Cox (1962) considered separately the dispersion due to the non-dipole component of the present geomagnetic field, and the dispersion due to the superimposition of the non-dipole field on a movement of the main dipole field. For the non-dipole components only, he calculated the virtual geomagnetic poles from the non-dipole directions measured on a 10° grid covering the Earth. He found an area of low non-dipole variation in the Pacific region, and calculated the angular dispersion around lines of latitude of the virtual poles for: (a) all data; (b) data from the area of low dispersion in the Pacific region; and (c) all data except those from the Pacific region.

Analysis of dispersion of the Recent basalt directions

The between-site dispersion of the palaeomagnetic directions from the Recent basalts of New Guinea is calculated as follows, after McElhinny (1967):

Source	Degrees of freedom	Sum of squares	Mean square	Expectation of mean square
Between sites	42	1.90	0.0453	$\frac{1}{2}\left(\frac{1}{\omega} + \frac{2}{\beta}\right)$
Within sites	44	0.77	0.0175	$\frac{1}{2}\left(\frac{1}{\omega}\right)$
Total	86	2.67		

ω is the within-site precision parameter, and β is the between-site precision parameter.

Twenty-two sites were sampled, with between 1 and 3 samples from each site. Thus

$B = 22$ (total number of sites)

$W = 1.90$ (average number of samples per site)

$N = 44$ (total number of samples)

$\Sigma R_i = 43.23$ (sum of the vector resultants from all sites)

$R = 41.33$ (vector resultant of all sample directions)

Thus $F_{42,44} = 2.59$ which is significant.
Solving for ω and β

$$\omega = 28.57 = 29$$

$$\beta = 34.16 = 34$$

Thus
$$k' = \frac{1}{(\omega N)^{-1} + (\beta b)^{-1}} = 470$$

$$k = k'/B = 21$$

The semi-angle α_{95} of the cone of 95% confidence is

$$\alpha_{95} = 6\tfrac{1}{2}^{\circ}$$

The angular dispersion Θ_0 of the directions is

$$\Theta_o = \cos^{-1}(R/N) = 20^{\circ}$$

For $B = 22$, $F_{42,42} = 1.67$ at the 5% level.

Then the limits of k are

$$k_{max} = k \cdot 1.67 = 35$$
$$k_{min} = k / 1.67 = 13$$

So that the limits of R are

$$R_{max} = 21.40$$
$$R_{min} = 20.38$$

Therefore the limits of Θ_0 are

$$\Theta_{o\ max} = 22^{\circ}$$

$$\Theta_{o\ min} = 13^{\circ}$$

Thus the true angular dispersion of the directions of magnetization of the Recent basalts lies between 13° and 22°, and the true precision k of these directions lies between 13 and 35.

In Table 3 below are listed: the angular dispersion of the Recent basalt palaeomagnetic directions; the angular dispersion of the total present field for 0° latitude given by Creer (1962); and the angular dispersions of the directions of the non-dipole components at 0° latitude calculated from Cox (1962). The angular dispersions of the pole positions from the non-dipole components taken from Cox are corrected to give the angular dispersions of the non-dipole field directions according to his equations:

$$d' = dC$$

$$C = \tfrac{1}{4}\left[1 + 3\cos^2 I + (1 + 3\cos^2 I)^{\frac{1}{2}}\right]$$

where d' is the angular dispersion of the directions

d is the angular dispersion of the poles

I is the mean field inclination (= 22°).

Table 3

Source	Angular dispersion of directions Θ_o
Creer (1962) at 0° latitude	21°
Cox (1962) at 0° latitude	
(a) all data	11°
(b) Pacific only	3.1°
(c) excluding Pacific	12°
New Guinea Recent basalts	20° (max 22°, min 13°)

It can be seen from Table 3 that the dispersion of the total field from Creer (1962) lies within the limits of the results from the Recent basalts. However, the dispersion of the non-dipole components only (Cox, 1962) is too low for the dispersion of the Recent basalt directions to be attributable solely to the non-dipole components of the present geomagnetic field, especially since New Guinea lies within Cox's Pacific region of low dispersion.

Cox also considered the effect of a main dipole wobble superimposed on the non-dipole field. The precision parameter $k = 21$ obtained from the Recent basalts can be taken in this case to correspond to the precision of the total present non-dipole field variation superimposed on a main dipole wobble of approximately $11½^{\circ}$.

Let k_N = the non-dipole precision parameter for 0° latitude,

k_D = the main dipole precision parameter,

k_T = the total precision parameter.

Then $k_N = 103$ from Cox (1962, Table 2),

$k_D = (67.5^{\circ}/d_m)^2$

where d_m is the angle of wobble of the main dipole.

Then $k_D = 34.5$ for a main dipole wobble of $11½^{\circ}$.

Since $1/k_T = 1/k_N + 1/k_D$, then

$k_T = 25.8$

Correction of this precision parameter k_T, which applies to the pole positions calculated from the directions, gives the precision parameter of the field directions k_T' to be

$$k_T' = k_T/C^2 = 13.8$$

This value of k_T' lies just within the limits of k (13 to 35) obtained from the dispersion of the Recent basalt directions.

However, if this model of Cox were true, it would mean that the major part of the secular variation would be due to main dipole wobble (compare $k_D = 34.5$ and $k_N = 103$). Thus the observed dispersion of pole positions must be Fisherian (i.e. must agree with model B). This is not found to be the case in the results from the Recent basalts.

It is apparent that, since these results support model A, the major part of the secular variation observed must be due to variations in the non-dipole components of the geomagnetic field (assuming that the random perturbing fields of model A are due to non-dipole components). To have produced the results obtained, these non-dipole components must have been of greater magnitude than those of the present geomagnetic field in the region.

Thus the Pacific region of low non-dipole variation (Cox, 1962) appears to be a temporary phenomenon.

CONCLUSIONS

The following deductions can be made :

(a) The mean direction (000°, -16°) is not significantly different from the geocentric axial dipole field direction (000°, -8°) at present; this supports the assumption made in palaeomagnetic work that the Earth's magnetic field, averaged over a long enough interval of time, reduces to that of a geocentric axial dipole.

(b) The dispersion of the results is in accordance with the Random Perturbation Model of Irving and Ward (1964).

(c) The rotation of the present field about the Earth's axis (Creer, 1962) can account for the magnitude of the dispersion observed.

(d) The pattern of the dispersions (directions and poles) cannot be adequately explained by a small non-dipole variation superimposed on a main dipole wobble. It seems that the dispersion is due to the secular variations of the non-dipole components, with only a small part, if any, due to variations of the main dipole field.

(e) The magnitude of the dispersion, together with point (d), suggests that the area of low secular variation of the non-dipole components in the Pacific region (Cox, 1962) is not a permanent feature of the region.

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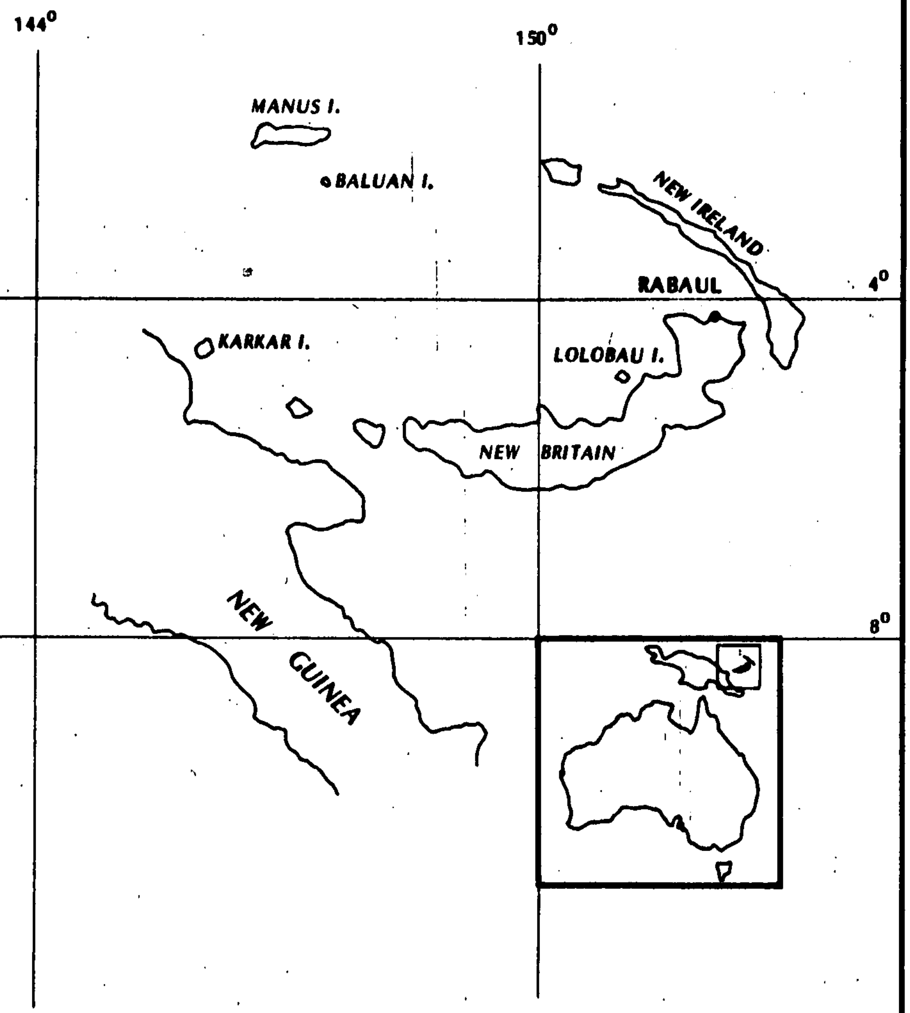


Figure 1. Locality Map

To accompany Record No. 1971/45

G456–31A

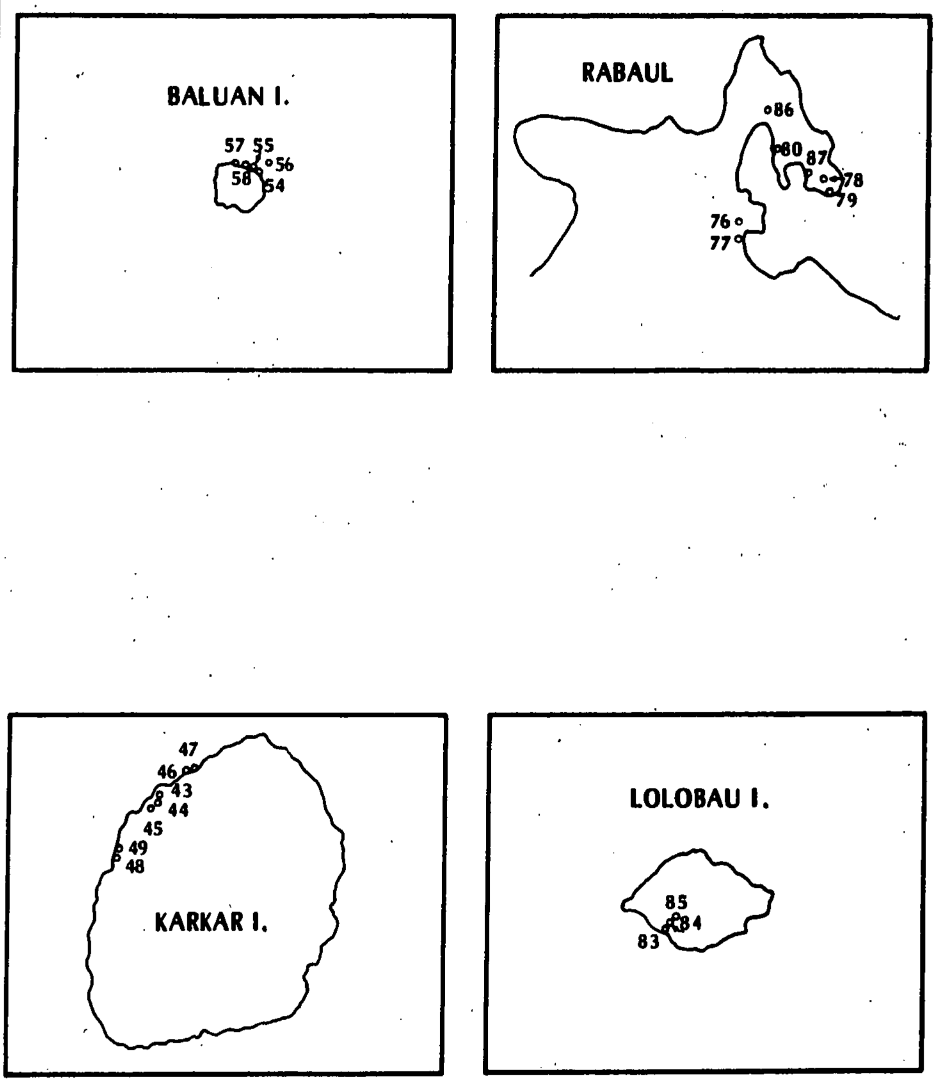
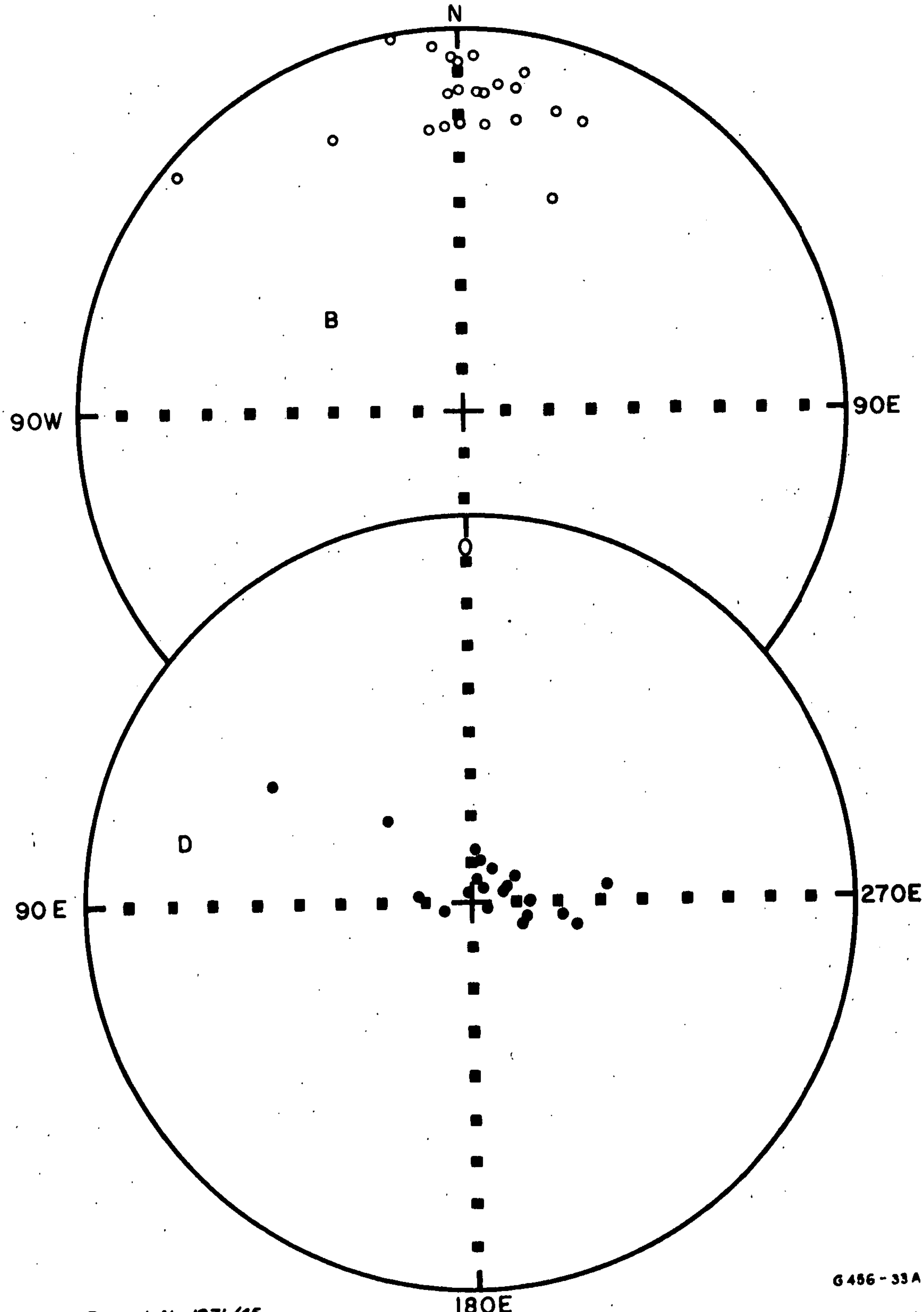


Figure 2. Details of palaeomagnetic sampling sites

To accompany Record No. 1971/45

G456–32A



To accompany Record No. 1971/45

Figure 3. Stereographic plots