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A New Palaeomagnetic Result from the Lower Cretaceous of East-Central Africa

J. C. Briden*

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Summary

The mean direction of natural remanent magnetization (NRM) in eight samples of syenite of Lower Cretaceous age from the Mlanje Massif, Malawi, has declination 333° and inclination −54° (upward) after magnetic cleaning. The stability of remanence in alternating magnetic fields suggests that the NRM is primary. On the assumption of a geocentric dipole field, the palaeomagnetic pole is calculated at 60° N, 98° W. This is in agreement with previous results from volcanics of the Lupata Series nearby in Mozambique, which are of similar age. Combination of results from the Mlanje Massif and the Lupata volcanics yields an estimate of the palaeomagnetic pole for the lower Cretaceous of this part of Africa at 60½° N, 99½° W, with circular standard deviation (related to palaeosecular variation) of 10°·0.

1. Introduction

Directions of natural remanent magnetization in eight samples from the Lauderdale erosion crater (16° 1′ S, 35° 32½′ E) on the southern side of the Mlanje Massif in south-eastern Malawi are reported. The massif is a syenite–granite complex and has been mapped by Garson & Walshaw (in preparation). The samples were collected from the outer syenite ring of the complex, along about 150 metres of a stream running at right-angles to its contact with the Palaeozoic basement. The boundary of the complex is transitional, the adjacent basement having been syenitized. Only the intrusive body has been sampled. It is several kilometres in diameter, and it is likely that the section which has been sampled represents a long period in the cooling history of the body. Therefore, in spite of the small collection there is reason to believe that palaeosecular variation may have been effectively averaged out in calculating the mean direction, and that the dispersion may be a fair estimate of the palaeosecular variation. Two recent K–Ar age determinations by Snelling (1966) indicate the Cretaceous age of the complex : biotite from perthosite (sample W1108) from the outer ring at Chambe indicated 116∓6 m.y., and biotite–hornblende mixture from quartz–syenite (sample W1112) from the Nanchidwa Hills, some 19 km east of the Lauderdale Crater gave 128∓6 m.y.

Gough & Opdyke (1963) have reported the palaeomagnetism of the Lupata alkaline volcanics and also of one site in redbeds of the Lupata Series, some 160 km south-west of Mlanje, in Mozambique. McDougall made two determinations on anorthoclases from the Lupata volcanics at 110·5 and 106·7 m.y. (Gough *et al.* 1964). Because Gough & Opdyke sampled seven sites in single lava flows, and hence sampled no more

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* Now at Geology Department, University of Oxford, England.

than seven flows, the small dispersion which they observed might possibly be due to the lavas having been extruded over a short period of time, and palaeosecular variation would not have been effectively averaged out. The evidence that the ages of the Lupata and Mlanje rocks are similar, and their proximity to each other, makes it possible to combine the previous results with those of the present study to give an accurate estimate of the palaeomagnetic field direction in this region in Lower Cretaceous time, together with a realistic estimate of the palaeosecular variation which is reflected in the dispersion of results.

2. Field work

The mountain stream flowing south from the Lauderdale crater exposes fresh, hard syenite in its bed. Three of the samples were short cores, 2·5 cm in diameter, drilled with a portable petrol-driven drill; five hand samples were also taken. The spacing of the samples along the section, number 6 being nearest to the contact, was (6) 20 m, (5) 60 m, (4) 20 m, (3) 15 m, (7 and 8) 15 m, (2) 35 m, (1). Fifteen specimens (2·5 × 2·5 cm cylinders) were cut from these, but two proved to be too weakly magnetized for measurement. The orienting technique for cores was similar to that described by Gough & Opdyke (1963), to obtain the bearing of the Sun relative to the sample, and the dip of the core. The hand samples were oriented using prismatic compasses and a Brunton compass–clinometer. The results did not reveal any systematic differences between the two methods.

3. Palaeomagnetic results

Direction and intensity of remanent magnetization were measured using the spinner magnetometer described by Gough (1964). Directions of total NRM (Table 1, Fig. 1a) were well grouped about a mean direction $D = 333°$, $I = -51°$ (giving unit weight to samples in the analysis). It is most unusual in this part of Africa for total NRM directions to be so well grouped, because surface weathering and lightning

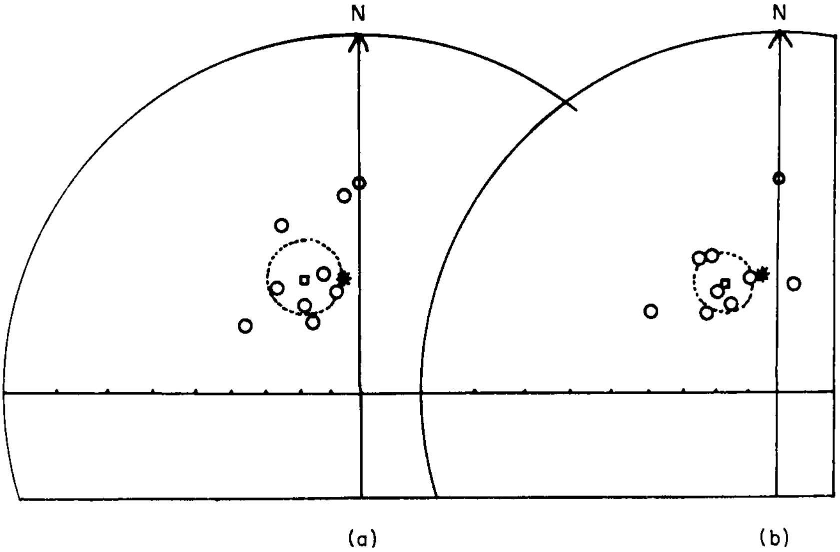

FIG. 1. Sample mean directions (a) before and (b) after magnetic cleaning. Stereographic projection, all directions upwards. The mean is denoted by a square, the geocentric dipole field by a hexagon and the approximate present field direction by a star. α_{95} is also shown.

Table 1

NRM directions

Treatment	*N*	*D*	*I*	*R*	*k*	a_{95}
Total NRM	8	333°	−51°	7·740	26·9	10°·9
30 mW.m^{-2} (peak)	8	333°	−54°	7·808	36·4	9°·3

N = Number of samples
D = Declination (E of N)
I = Inclination (negative upwards from horizontal)
R = Resultant of *N* unit vectors
k = Estimate of precision (Fisher 1953)
a_{95} = Semi-angle of cone of 95% confidence about the mean direction.

commonly contribute viscous or isothermal components which have to be removed by partial demagnetization techniques (see, for example, Gough & Brock 1964). The absence of detectable components of these types in these rocks may be attributed to their situation at the foot of a crater wall some 2000 m high, and to the exposure of absolutely fresh rock by the torrential stream.

Nevertheless it was desirable to carry out some partial alternating field demagnetization of these rocks, using the apparatus of McElhinny (1966) in order to remove any small temporary or secondary components of NRM and to confirm the stability of the remanence. It is especially necessary to test stability because, as is well known in Mesozoic rocks from the southern half of Africa, directions of primary NRM are commonly close to that of the present magnetic field (Gough, Opdyke & McElhinny 1964); in this case the mean direction of total NRM was only just significantly different ($p = 0{\cdot}05$) from the present field (Fig. 1a).

Treatment of pilot specimens in alternating fields up to 45 mW.m^{-2} peak (450 Gauss) was sufficient to demonstrate the stability of NRM. The demagnetization curves (Fig. 2) are typical of thermoremanent magnetization, and no appreciable changes of direction were detected at any stage of the treatment.

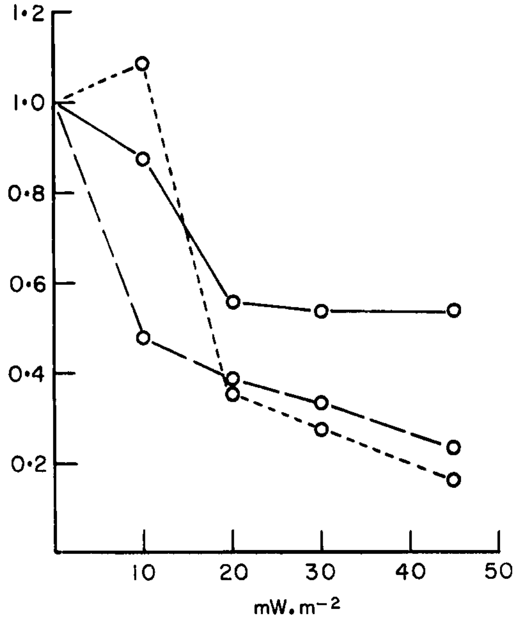

Fig. 2. Normalized alternating field demagnetization curves for three specimens from the Mlanje Massif.

Alternating field of 30 mW.m^{-2} (peak) was chosen for magnetic cleaning of the whole collection of thirteen measurable specimens, because this field was sufficient to remove the bulk of the soft component of remanence, and treatment in higher fields did not result in the removal of further substantial amounts. The precision of directions (Table 1) improves slightly after magnetic cleaning which suggests that small components having random directions may have been removed by magnetic cleaning, even though the improvement in precision cannot be shown to be significant at the 95% probability level (McElhinny 1964). The results (Table 1, Fig. 1b) confirm that the NRM is stable, and demonstrate that the mean direction is significantly different from the present field.

Intensity of total NRM ranged from $0{\cdot}99\times10^{-3}$ to $160{\cdot}3\times10^{-3}$ A m^{-1} (i.e. $0{\cdot}99\times10^{-6}$ to $160{\cdot}3\times10^{-6}$ Gauss) and two specimens were too weakly magnetized for measurement. After magnetic cleaning, the range of intensities was $0{\cdot}532\times10^{-3}$ to $43{\cdot}4\times10^{-3}$ A m^{-1}. An average of 52% of total NRM was removed by cleaning. The variation in intensity may be attributed to variation in the amount of magnetic material in the rock, which shows considerable local variation in grainsize though variation in composition of the minerals is slight (Garson & Walshaw, in preparation).

The Fisher (1953) analysis of directions after cleaning has been performed in several ways. If specimens are given unit weight, then $k = 33{\cdot}5$. The calculations when samples are given unit weight are given in Table 1. When the data are combined into four 'sites' (grouping adjacent samples together as follows: Site A—1; Site B—2, 7, 8; Site C—3, 4; Site D—5, 6) then k is estimated as 62·8 or 64·6 according to the procedure adopted for calculating site-mean directions. This suggests that there is at least as much dispersion within samples as there is between samples and between 'sites', and it may be concluded that the individual *specimens* satisfy the criterion normally attributed to a *site* (Irving 1964) as a spot reading of the palaeomagnetic field. However, in order to avoid the risk of giving an artificially small estimate of a_{95} the procedure here has been to give unit weight to samples. On this basis the mean direction corresponds on the geocentric dipole model to a pole position at 98° W, 60° N with $d\psi = 9^\circ{\cdot}1$, $d\chi = 13^\circ{\cdot}0$, where $d\psi$, $d\chi$ are the semi-axes of the oval of 95% confidence centred on the palaeomagnetic pole, along and perpendicular to the line joining the sampling site to the palaeomagnetic pole. The alternative procedure of calculating the mean pole from the eight sample-poles yields a pole at 98½° W, 60° N, and estimates $a_{95} = 12^\circ$.

4. Combination of results from Lower Cretaceous rocks from Malawi and Mozambique

This pole is almost identical to (and certainly not significantly different from) that calculated by Gough & Opdyke (1963) for the Lupata alkaline volcanics from seven sites. They measured from seven to ten samples or specimens from each site and made a correction for the dip of the flows. In making a combined calculation for the Lupata volcanics and the syenite from Mlanje, unit weight will be given to each *site* in the Lupata (N = 7). Unit weight will be given to each *sample* from Mlanje (N = 8) for the reasons outlined in the preceding section. This seems at first sight to exaggerate the status of the Mlanje results compared with those from the much larger collection of Gough & Opdyke, with its wide lateral spread of over 25 km, but the important point is that in the Lupata volcanics each flow (i.e. each site) is likely to give a single independent record of the palaeomagnetic field, whereas in the large intrusion of Mlanje it is thought that each *sample* gives an independent reading. No tilt correction is considered necessary for the Mlanje rocks.

Because the whole sampling area (Lupata and Mlanje together) covers only 160 km, the mean direction may be calculated for all the rocks: $N = 15$, $D = 334\frac{1}{2}^\circ$, $I = -54^\circ$, $k = 66{\cdot}2$, $a_{95} = 4^\circ{\cdot}7$. This gives a pole at 99½°W, 61°N with $d\psi = 4^\circ{\cdot}6$ and $d\chi = 6^\circ{\cdot}6$. Alternatively, poles may be calculated for each of the fifteen field readings, and the mean pole is then calculated by Fisher's method as 99½°W, 60½°N with $a_{95} = 6^\circ{\cdot}1$.

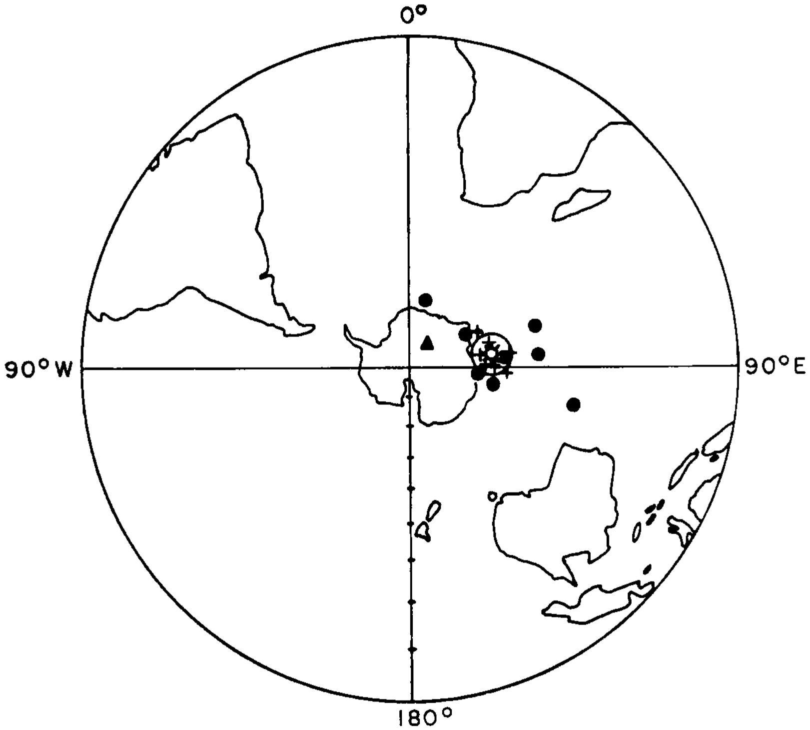

FIG. 3. Pole positions for each of the eight samples from Mlanje Massif (circles), the seven sites in the Lupata volcanics (crosses) and the one site in Lupata redbeds (triangle). The mean pole from Mlanje and the Lupata volcanics is denoted by a star and α_{95} is shown. South polar stereographic projection.

These fifteen poles, together with their mean, are shown in Fig. 3. Also in Fig. 3 is the pole from the single site in redbeds of the Lupata Series and studied by Gough and Opdyke. The site mean direction in the redbeds is 18° from the mean direction in the igneous rocks. Using a statistic devised by Watson & Irving (1957) it is shown that this direction lies outside the cone which contains 95% of observations belonging to the Fisher population from the igneous rocks (see Irving 1964, Fig. 4.5). Therefore it would not be correct to incorporate this result from the redbeds with those from the igneous rocks.

The best estimate of the palaeomagnetic field direction and pole for the Lower Cretaceous of this part of Africa is, then, to be obtained from the combination of results from the Mlanje Massif and the Lupata volcanics. The dispersion $\Delta = 81k^{-\frac{1}{2}}$ which they indicate is 10°·0, which is a best estimate of the palaeosecular variation for Lower Cretaceous time at palaeolatitude 35° S. The 95% confidence limits of Δ correspond to 6°·3 and 15°·7. This indicates that Δ is not significantly less than the total secular variation at 35° S at the present time, which is slightly greater than 15° (Creer 1962).

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Physics Department,
University College of Rhodesia,
Private Bag 167*H*, *Salisbury.*

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