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Application of Palaeomagnetism to Proterozoic Tectonics

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Application of palaeomagnetism to Proterozoic tectonics

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Assessment of current Proterozoic palaeomagnetic data and the assumptions necessary for applying them to tectonic problems shows that first order tectonic phenomena (involving the creation and/or destruction of Atlantic-sized oceans) should now be detectable. Although lesser relative motions are difficult to prove or disprove in individual cases, it is shown by reference to Africa (from where new data for the Palabora Igneous Complex and lavas of the Transvaal System are presented which contribute to this discussion) that their occurrence between some of the African cratons is improbable. It is necessary, then, to entertain the notion that some tectonically deformed belts, though not necessarily all, developed without associated destruction of large amounts of oceanic crust on their site. Some ways in which palaeomagnetic study may throw further light on this problem are suggested, but a wide range of geological techniques will be needed to solve it, and to assess its broader implications.

1. Introduction

About 200 palaeomagnetic studies of Proterozoic rocks conform to the fairly lenient reliability criteria set by McElhinny (1973). They cover a time interval of about 2000 Ma (from *ca.* 2600 to *ca.* 600 Ma B.P.) and hence provide a density of coverage of about 1 per 10 Ma worldwide. This compares unfavourably with the 1500 or more such studies of Phanerozoic rocks which provide about 25 per 10 Ma interval. Even if we acknowledge that only about 15 % of present continental outcrop is Proterozoic, there is still a deficiency of a factor 3. Recall, however, that definite indications of the reality of Phanerozoic drift – as evidenced by the systematic differences in apparent polar wander paths from the various continents – were discernible as long ago as 1956 when Phanerozoic palaeomagnetic coverage was no denser than Proterozoic coverage is today. Those primitive Phanerozoic polar wander paths have subsequently been considerably revised as new data have come to hand, but although few of their details survive intact today, their general divergent pattern has been shown to be valid. By this token, and despite their less precise age control, currently available Proterozoic data should be adequate to discern the gross features of polar movement relative to each craton that has been studied, though we should expect much more detail to emerge as new data come to hand in the future.

Phanerozoic palaeomagnetic data are applied to tectonic problems by a two stage argument: first their conformity to a testable geomagnetic field configuration is established, and they are then compared with a range of tectonic models. This same procedure will be applied to the Proterozoic in this paper.

2. Data coverage

Proterozoic data are unevenly distributed; their locations are illustrated in figure 1 on the basis of one symbol per locality. Several formations have been studied at some localities, and each such study comprises observations on a large number of rock samples. This compilation may not be complete, particularly for North America and Australia for which the reader is referred to papers by Irving & McGlynn and by McElhinny & Embleton (this volume). The data are also unevenly distributed in time. Only for the Canadian Shield, from which come about half of the total worldwide data, are they adequate to provide anything like a continuous record from within a single structural province. In Africa and Australia it is possible to build up a composite record from each continent as a whole, but this procedure immediately raises questions about the relative positions of the various structural elements within each continent, a point which will be elaborated in subsequent sections of this paper.

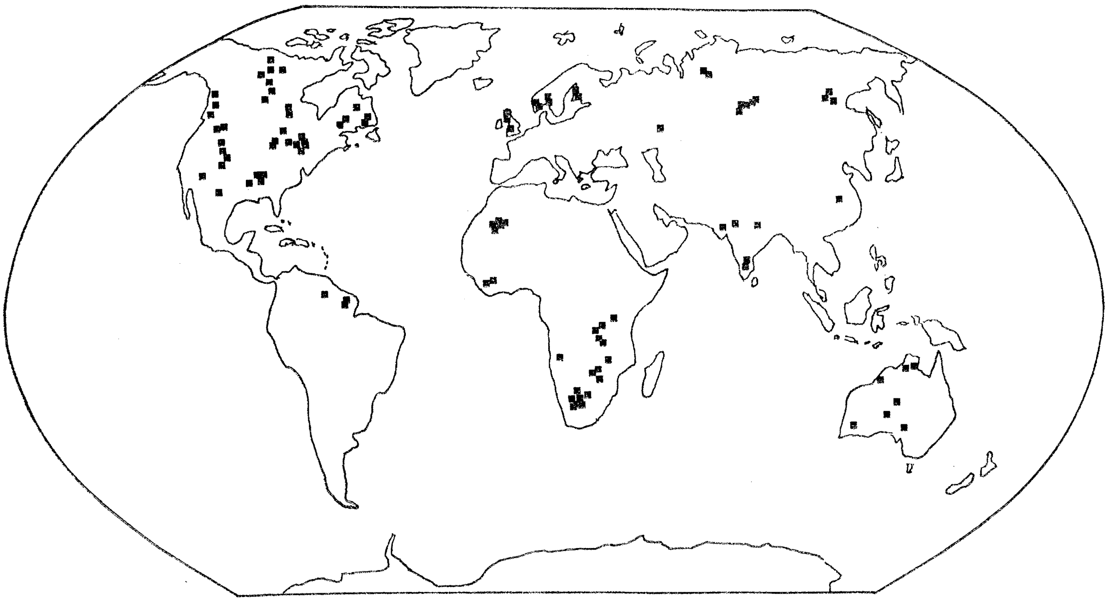

FIGURE 1. Generalized geographic distribution of Proterozoic palaeomagnetic studies.

3. GEOCENTRIC DIPOLE FIELD

With the available scanty data coverage the only tractable geomagnetic model with which they can usefully be compared is that of a geocentric dipole. The relevant features of such a field are (i) that it has two antipodal poles, (ii) that field lines lie in the meridians joining these poles and (iii) that inclination varies smoothly with geomagnetic latitude, through only one cycle per polar circuit of the Earth. This is the model which has proved satisfactory to first order in describing the present and recent geomagnetic field, and has produced plate-tectonically sensible hypotheses of Phanerozoic crustal movement (namely most notably, the aggregation of Palaeozoic continents into a single large mass 'Pangaea' by Permian time, its drift as a unit until the end of the Triassic, and its subsequent dispersal towards present day geography).

In the Proterozoic the number of tests to which the model can be put is limited. Detailed worldwide coverage such as we have for the present and historic geomagnetic field is not available. Information on variation of Proterozoic field intensity with latitude is scanty and of uncertain validity. The magnetization record of the ocean floor which has contributed substantially to geomagnetic studies of the past 200 Ma is not available for the Proterozoic or Palaeozoic. Nevertheless there are a number of lines of evidence in favour of the dipole model.

(*a*) The finding of polarity reversals of comparable degree of perfection to those recognized in more recent time, in Proterozoic rocks as old as 2700 Ma (Evans & McElhinny 1966), and of polarity transitions of similar character to more modern ones (Bingham & Evans 1975) is probably diagnostic of a dipole field.

(*b*) To test whether the field direction varies over the Earth's surface at each instant of time as predicted by the dipole model, it is necessary to have an array of data over a continent-sized region, because the variation should be very gradual – more gradual, in fact, than on any other model in which higher order terms would be more pronounced. There is no single region of Proterozoic crust large enough for this test which was undoubtedly a single rigid unit at the relevant time. Hence one can only test the *joint* hypotheses of dipolar field and crustal unity of the test region. An example is illustrated in figures 3*b*, *c* in which inferred pole positions relative to South and West Africa are seen to match at *ca.* 2200 Ma when they fall south of the present south coast of Africa (poles labelled 8 and 10), and at *ca.* 1950 Ma when they fall to the north-east of Africa (poles labelled 16–19). If the supposition of crustal unity were correct then such a degree of agreement would not be expected on any but the geocentric dipole model field.

(*c*) Rates of change of field direction (or inferred pole positions) as viewed from single regions, are comparable to rates observed in Phanerozoic sequences. Support for this comes from Africa (e.g. figures 3 and 7), North American (figure 13 of Irving & McGlynn, this volume) and Australia (McElhinny & Embleton, this volume), in which apparent polar wander paths for, say, 500 Ma intervals of Proterozoic time are of comparable length to Proterozoic polar paths from single continents. This observation also suggests that loss of record of large amounts of drift in a longitudinal direction (arising from the axial symmetry of the dipole field) has been no more common in the Proterozoic than it has more recently.

(*d*) The model is predictive to the extent that published polar paths are commonly reinforced by data obtained subsequently. Large features of the path for the Laurentian shield (Irving & McGlynn, this volume) are preserved from earlier versions (see, for example, Irving & Park 1972) despite the advent of large amounts of new data in the intervening years. New African data (§5(*c*)) fall where expected on the already-drawn polar path for that region. It should be noted, however, that there are many cases where concordance of age and palaeomagnetic data is not evident, but the impression is that the uncertainties lie in assigning the correct age to determined magnetizations, rather than in the dipole model itself, because the pole positions from rocks of ill-defined age commonly fall on pre-drawn polar paths at points which are not inconsistent with their limited age control.

(*e*) Latitude dependence of dispersion of palaeomagnetically determined field directions is critically dependent on the sources of secular variation of the geomagnetic field. If the source is considered as a randomly directed non-dipole field (Irving & Ward 1964) angular dispersion (θ_{63}) decreases by a factor 2 from geomagnetic equator to pole, and hence Fisherian precision k (given by $\theta_{63} = 81°/k^{\frac{1}{2}}$) increases by a factor 4. On the other hand the polar error, whether calculated as an oval or as a circle of radius A_{95}, should be independent of palaeolatitude for a given number of observations, because the decrease of dispersion balances the increase of co-latitude error. More sophisticated models of secular variation (e.g. Cox 1970) predict different inclination-dependence of dispersion. Analysis of all current Proterozoic data in the compilation of Hicken, Irving, Law & Hastie (1972) shows them to be too scattered for any conclusions to be drawn about the field configuration. Nevertheless these kinds of analyses may become decisive when more refined data come to hand.

The calculation of a precise palaeomagnetic pole is independent of the calculation of its associated errors. If dispersion arises from sources other than secular variation then for a given estimated precision (k) the calculation of the mean pole itself will be subject to an uncertainty which quadruples from geomagnetic equator to pole. This would show itself as a broadening of the swathe-like polar paths (see figures in all the palaeomagnetic papers in this volume) as they approach their source region; such variation is not immediately evident in the data as they stand, but closer scrutiny is warranted.

(f) If palaeomagnetic and palaeoclimatic indications of past latitude agree, then this is not merely confirmation of the geocentric dipole model, but additionally suggests that it was axially oriented. McElhinny, Giddings & Embleton (1974) have correlated the incidence of glaciations of various Late Proterozoic and Early Palaeozoic ages in Africa with the transit of the pole over the glaciated region. Irving & McGlynn (this volume) suggest a similar situation around the time of Huronian glaciation in Canada.

(g) The ultimate test of the geomagnetic model will, however, be the same as in the Phanerozoic, namely 'does it lead to tectonically sensible conclusions'? I suggest that the interim verdict, based on the palaeomagnetic information given in this volume, is encouraging, and that at the very worst its adoption need not lead to demonstrably nonsensical inferences.

4. Palaeomagnetic expression of various tectonic models

On the dipole model, polar paths from different regions will only agree if the relative position of those regions is correctly drawn on the base map. Agreement of polar paths in general implies that their source regions have been correctly related, though there are special exceptions to this rule which arise from the axial symmetry of the dipole field about its poles. Subject to the same caveat, convergence of polar paths as time proceeds reflects the convergence of their source regions, and divergence of paths reflects source region separation. A range of examples is illustrated schematically in figure 2. Note in the case (d), of local rotations, the shapes of the polar paths from two blocks should be the same for all intervals in which they were fixed relative to each other and that this applies equally before and after episodes during which they rotate.

5. Application to African data

(a) *Before ca.* 2300 Ma

There are only five palaeomagnetically studied rock formations in Africa dated at more than *ca.* 2300 Ma. Four of these are in the Transvaal craton; the poles from three of them fall in sequence (figure 3a) and the fourth can reasonably be argued to have been remagnetized at *ca.* 2200 Ma (figure 3c). The remaining study is from Rhodesia, and the pole falls on the Transvaal curve at an appropriate point for its age (*ca.* 2520 Ma) in accord with the well established conclusion that the Rhodesia and Transvaal cratons have been a single unit since the last *major* metamorphism in the intervening Limpopo Belt at *ca.* 2600 Ma (van Breemen & Dodson 1972).

(b) *Ca.* 2300–*ca.* 1950 Ma

Next in sequence in southern Africa was a study of lavas from the Transvaal System by the present author for which the mean pole was quoted by Piper, Briden & Lomax (1973). The data on which this was based have not hitherto been published and are given in table 1.

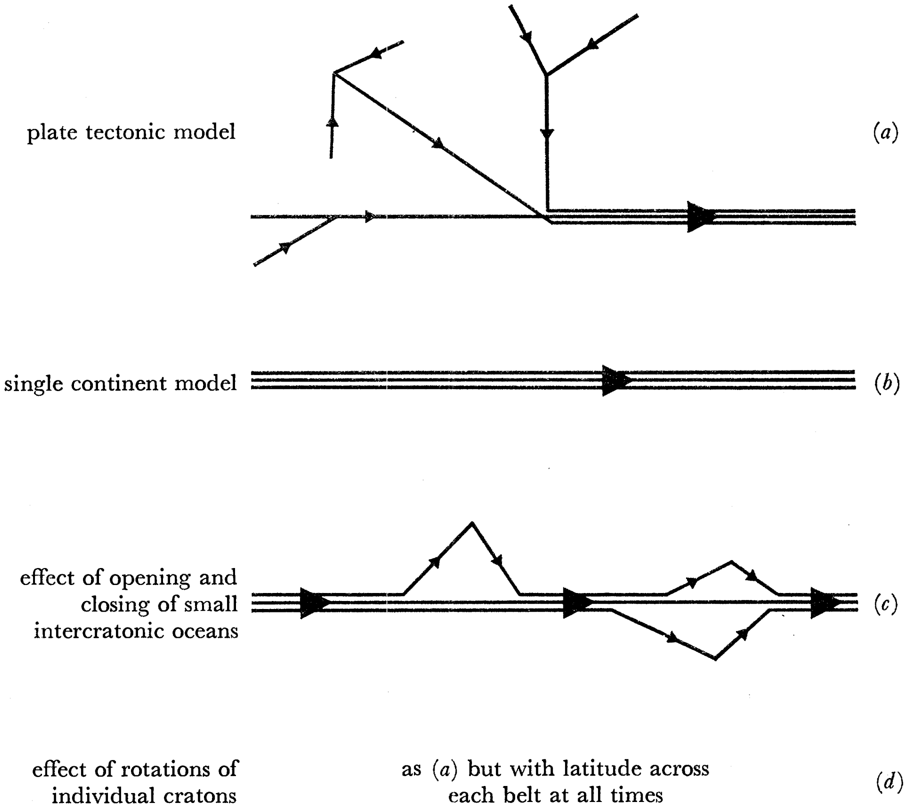

FIGURE 2. Schematic patterns of apparent polar wander paths for various tectonic models, after Piper *et al.* (1973).

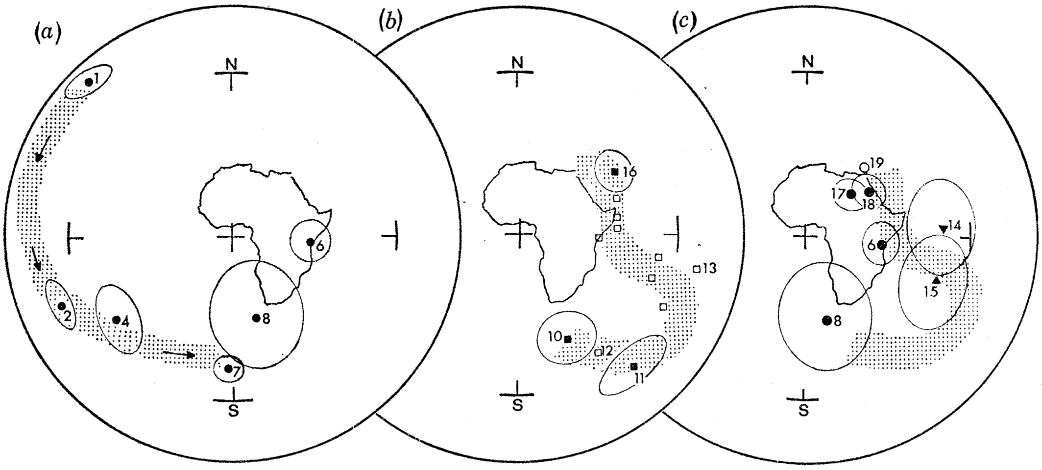

FIGURE 3. Apparent polar wander paths for (*a*) southern Africa from *ca.* 2700 to *ca.* 2350 Ma; (*b*) West Africa from *ca.* 2250 to *ca.* 1950 Ma; (*c*) southern African data for *ca.* 2350 to *ca.* 1950 Ma are superimposed on the data of (*b*). Numbers refer to appendix 1 of Piper's paper (this volume). Circles, Kaapvaal craton. Squares, West African craton. Triangle, Orange River Belt. Inverted triangle, Angola–Kasai craton. Circles of 95 % confidence are illustrated. Open symbols denote data from single sites. Unnumbered symbols refer to Aftout Diorites (entry 13 of Piper). Equal area equatorial projection *of the whole sphere.*

This was a disappointing study insofar that of 22 sites sampled in all five main lava groups, only seven yield coherent data. Of the other sites, seven showed random and unstable magnetization; eight had statistically significant n.r.ms but their site means were randomly distributed and alternating field demagnetization in low fields was sufficient to randomize specimen directions and hence no palaeomagnetic information was derived from them. The interpretable data are from the oldest and youngest lava groups in the sequence (Wolkberg Group, sites 14–16, and Ongleluk lava, sites 3, 19, 21, 22 respectively), and are spread over a distance of 400 km. Even at these sites n.r.m. is dominated by magnetically soft components, and the alternating fields required to remove them differ from specimen to specimen (figure 4*b*). Hence a range of alternating fields was used for magnetic cleaning of the whole collection (table 1). The principal indication that this stable remanence (figure 4*c*) is original is that the mean at site 22, which is on the steeply dipping northern flank of the Vredefort Ring Structure, only swings into agreement with the remainder after tilt correction, raising the between-site precision from 4 *in situ* to 16. Hence the stable remanence appears to predate the Structure (*ca.* 2000 Ma). The large circle of confidence about the mean pole is an artefact of the calculation, and arises because of the high palaeolatitude of these lavas, as explained in §3(*e*).

TABLE 1. NEW PALAEOMAGNETIC DATA FROM THE TRANSVAAL SYSTEM

site no.	location	lat.	long.	tectonic dip	peak alt. field mT	N	R	k	α_{95}	D	I
14	Abel Erasmus Pass	24.4° S	30.6° E	16° at 194° E	40	5	4.98	217	5.2	46	−74
15	Abel Erasmus Pass	24.4° S	30.6° E	18° at 200° E	20	5	4.91	44	11.7	98	−70
16	Abel Erasmus Pass	24.4° S	30.6° E	18° at 200° E	20	5	4.96	104	7.5	94	−77
3	Kindergoed	25.6° S	30.4° E	7° at 285° E	20	3	3.00	624	4.9	130	−69
19	Janie Theron Memorial	26.4° S	27.5° E	16° at 180° E	40–100	5	4.70	13	21.9	349	−67
21	Fochville	26.7° S	27.5° E	16° at 180° E	60	5	4.84	25	15.5	7	−62
22	N. flank of Vredefort Structure	26.7° S	27.4° E	75° at 355° E	30–70	5	4.97	44	11.6	308	−63
	Mean of seven site mean directions.					7	6.61	16	15.7	33	−79

Mean of seven site-mean poles: 40° N, 194° E ($A_{95} = 28.4°$).

There is a gap in the palaeomagnetic record from the Kaapvaal craton after the time of Transvaal lava extrusion until the emplacement of the Bushveld and related igneous complexes, from which pole positions near northeast Africa are deduced. This gap is neatly filled by data from the West African craton (figure 3*b*), and the smooth linkage which these provide forms a *prima facie* case that the Kaapvaal and West Africa cratons were already, to a first approximation, in their present relative positions by 2300 Ma. This conclusion is supported by results from the Orange River Belt and the Angola–Kasai craton, insofar that a path linking the poles from the Transvaal lavas, the Orange River lavas, cunene anorthosite and Bushveld group of intrusions, in a sequence consistent with the rather limited age control, closely matches the West African polar path for this time interval (figure 3*c*). On closer inspection there is a hint that southern African data points lie systematically to the west of the swathe, i.e. the paths could be offset longitudinally from each other by about 15°, and although this may be within the resolution of the data its implication in terms of relative displacement between southern and western Africa is illustrated in figure 5 in an attempt to depict the amount of 'slack' in the palaeomagnetic-tectonic control.

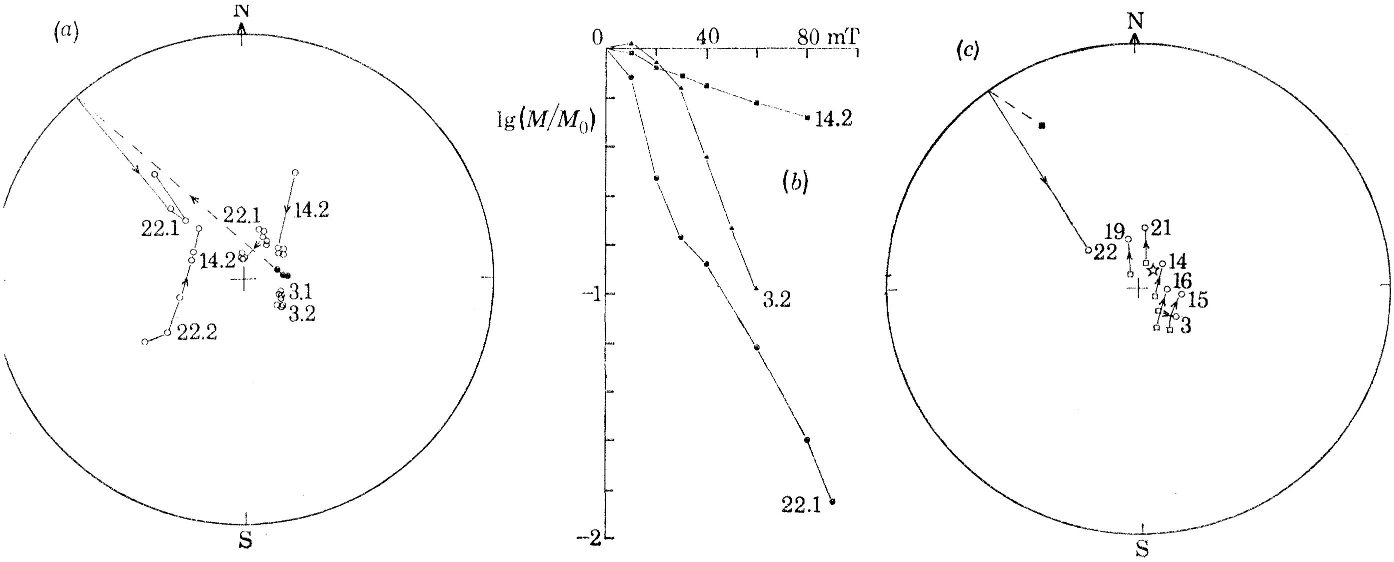

FIGURE 4. Palaeomagnetic results from lavas of the Transvaal System (*a*) and (*b*) changes of direction and intensity of remanence during progressive alternating field demagnetization of specimens from site 3, 14, and 22. (*c*) Site mean directions of remanence after a.f. cleaning before (squares) and after (circles) tilt correction by rotation about the present strike. The tilt-corrected overall mean is denoted by a star. (*a*) and (*c*) are stereographic projections, open symbols referring to the upper hemisphere.

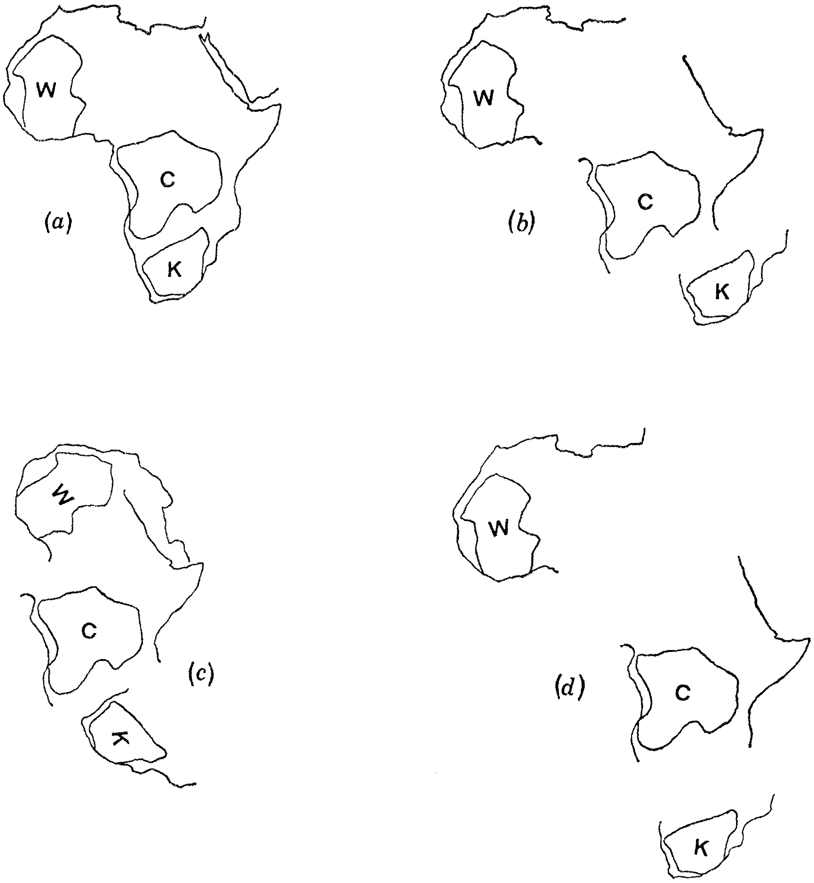

FIGURE 5. Schematic illustration of the amounts of relative movement between the West Africa (W) and Congo (C) and Kalahari (K) cratons which *are* (*a*) and (*b*) and *are not* (*c*) and (*d*) within the tolerance of their palaeomagnetic data.

(*c*) *Ca.* 1950–*ca.* 1100 Ma

Published southern African data indicate a polar shift to the southwest (in present day terms) between *ca.* 1950 and *ca.* 1880 Ma. This is now confirmed by new data from the Palabora Igneous Complex in the northeast Transvaal, a pyroxenite, syenite, carbonatite central complex emplaced *ca.* 2000 Ma B.P. into Archaean gneissic basement (Hanekom, van Staden Smit & Pike 1965).

Total n.r.ms in all samples from this complex fall into two general groups, both with moderate positive inclinations and with northerly and northwesterly declinations respectively. The former group derives from the central pyroxenites which were the oldest component of the complex to be sampled. These are extremely resistant to a.f. demagnetization (figure 6 and table 2), and the n.r.m. is attributable to very fine (*ca.* 1 μm) hematite dispersed through these rocks. The same stable magnetization direction emerges from a.f. cleaning of syenite from an old quarry at Vera Hill, an isolated body some 6 km northwest of the centre of the complex.

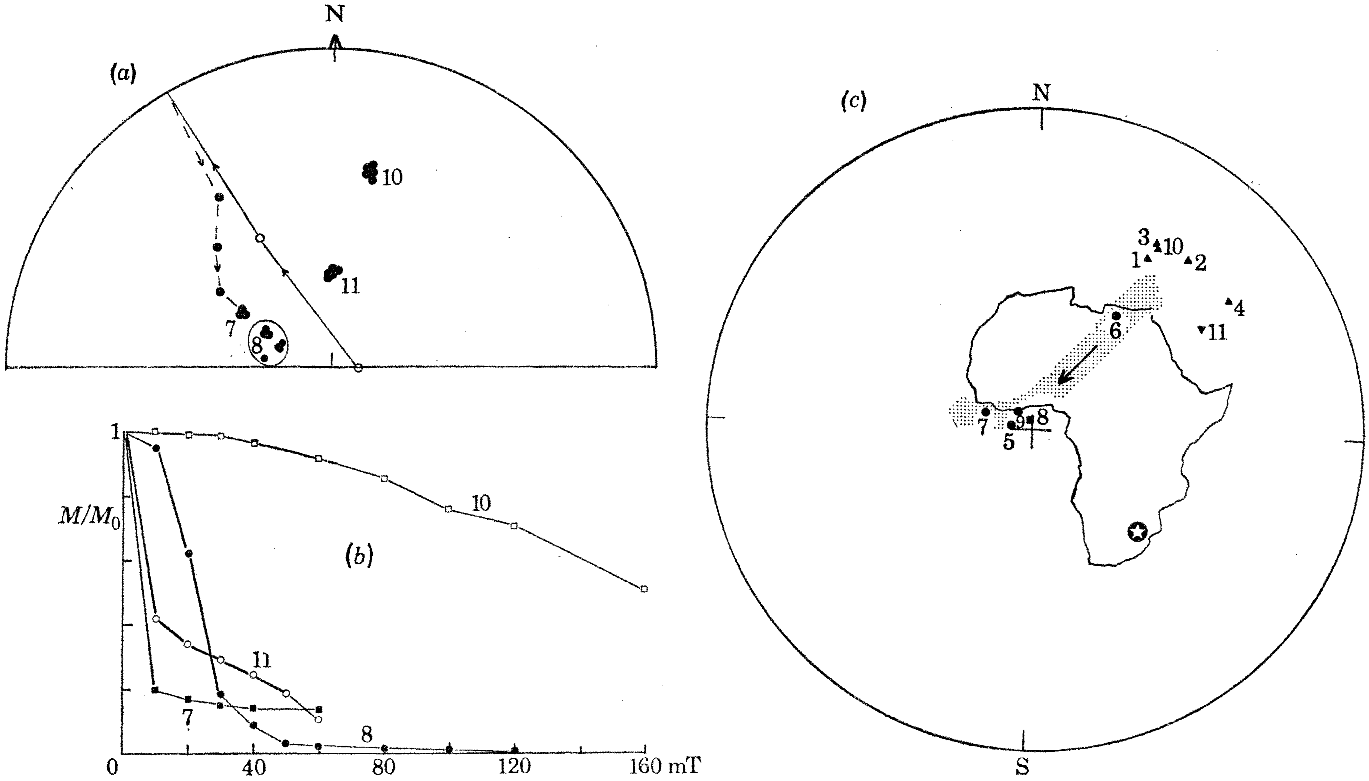

FIGURE 6. Palaeomagnetic results from the Palabora Igneous Complex. Changes of (*a*) direction and (*b*) intensity of remanence during progressive a.f. demagnetization of specimens from sites 7 (main syenite), 8 (dolerite), 10 (pyroxenite) and 11 (Vera Hill syenite). (*c*) Virtual geomagnetic poles from all sampling sites, plotted with the palaeomagnetic polar wander path for Africa in the interval *ca.* 1950–1880 Ma as in figure 7 on an equatorial equal area map *of the hemisphere.*

The syenites of this area are known to be of several generations, and the rest of those that were sampled show a much improved grouping of stable remanence after a.f. cleaning. Progressive a.f. demagnetization shows a range of stability which is reflected in the variety of their opaque mineralogy. Fine hematite is evident at site 7, and a.f. demagnetization is similar to that of the hematite bearing pyroxenites. One specimen from this site carries a large i.r.m.

which is removed in 10 mT peak field. The other syenites contain predominantly titaniferous magnetite in a wide range of grain sizes from < 1 to > 100 μm. These syenites all show northwesterly declination. This same direction emerges after a.f. cleaning of a dolerite dyke cross-cutting this syenite. Hence this dyke is likely to be of comparable age to its host syenite, i.e. a 'Waterberg' dyke in south African terminology, rather than Karroo as has been inferred

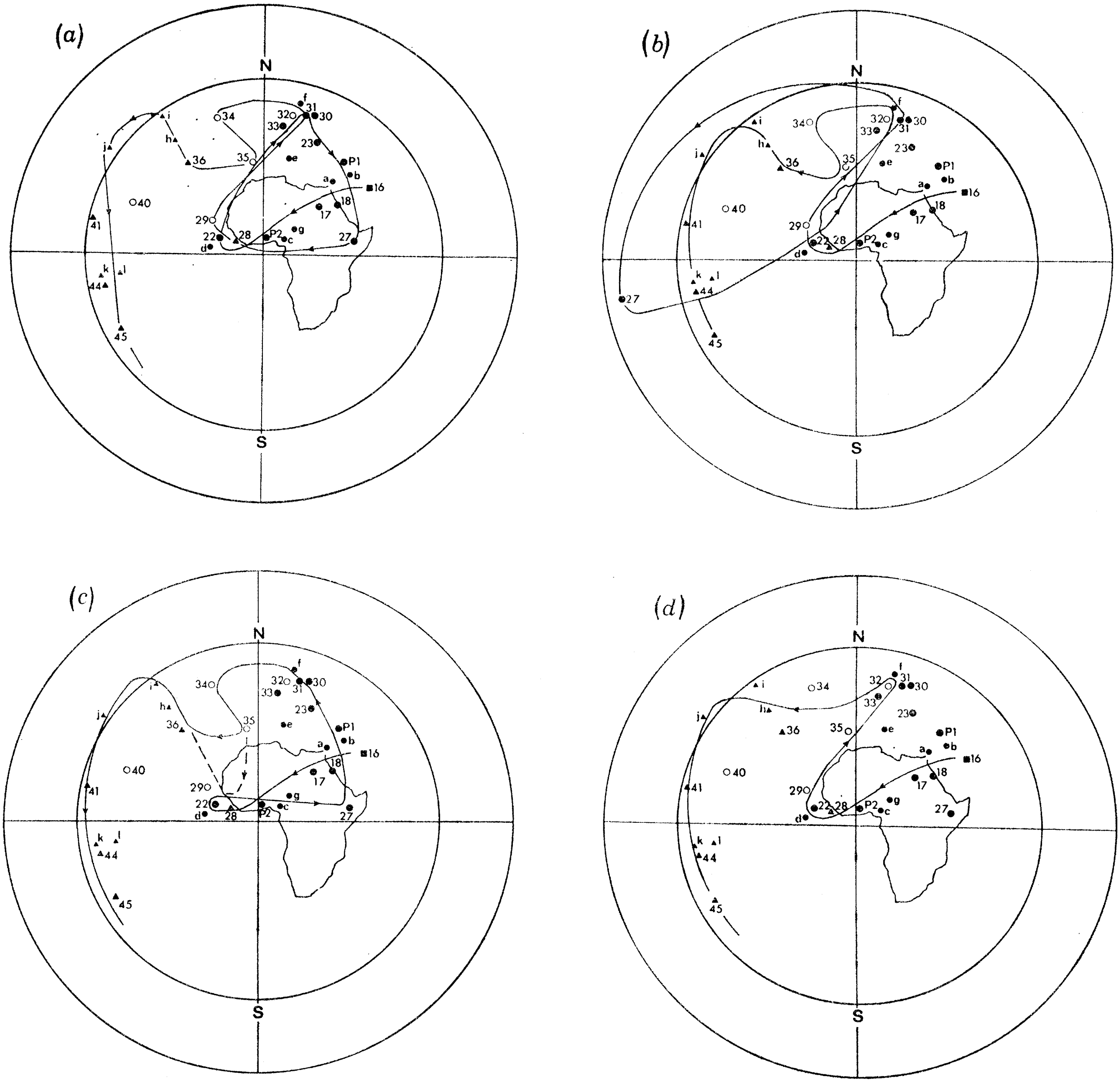

FIGURE 7. Four possible polar wander paths for Africa in the interval 1950 to 1100 Ma, all of which are compatible with currently available data. Numbers refer to appendix 1 of Piper (this volume) and refer to the more substantial data denoted by the larger symbols. Smaller symbols relate to lesser studies as follows a, Losberg Intrusion; b–f, successive horizons in Waterberg System sediments; g, Van Dyk Mine dolerite; h, Abercorn Sandstone; i, Plateau Series I; j, Ikarongo sediments; k, Mbala dolerite; l, Malagarasi Sandstone. (These are referred to as entries 19, 21, 25, 37, 38, 39, 43, 42, by Piper.) Symbols denote the different structural regions: solid circles, Kaapvaal craton; open circles, Orange River Belt; triangles, Tanzanian craton; squares, West African craton. Equal area equatorial projection *of the whole sphere.*

previously. A single K-Ar analysis on one of these samples by Dr R. M. McIntyre (1974, personal communication) is in agreement with this new conclusion. The stability of its remanence is in accord with its content of large granulated titanomagnetites with peripheral hematization. Both components are magnetized in the same direction and the latter resists demagnetization at 160 mT peak field.

Table 2. New palaeomagnetic results from the Palabora Igneous Complex

site no.	location	lat.	long.	rock type	peak alt. field mT	N	R	k	α_{95}	D	I
1	Foskor Pit	23° 58′ S	31° 08′ E	pyroxenite	60	5	4.93	60	10.0	5	+38
2					60	5	4.89	37	12.7	16	+36
3					60	7	6.80	31	11.1	9	+31
4					60	5	4.94	64	9.6	27	+47
10					50–80	6	5.93	77	7.7	9	+32
11	old quarry south of Vera Hill	23° 56′ S	31° 07′ E	syenite	40–60	3	2.89	18	29.8	19	+56
	Pyroxenite and Vera Hill syenite, N = 6 sites						5.90	52	9.4	14	+40
	Palaeomagnetic pole 41° N, 47° E ($d\psi = 7°$, $d\chi = 11°$) calculated from mean direction										
5	top of Cleveland Hill	23° 59′ S	31° 09′ E	syenite	50–60	5	4.85	26	15.3	301	+66
6	100 m down road from 5	23° 59′ S	31° 09′ E	syenite	40–60	5	4.93	60	10.0	352	+53
7	roadside, water purification plant	23° 59′ S	31° 09′ E	syenite	50–60	5	4.98	268	4.7	299	+60
9	water purification plant	23° 59′ S	31° 09′ E	syenite	50–60	4	4.00	751	3.4	310	+67
8	as site 7	23° 59′ S	31° 09′ E	dolerite dyke	60–80	4	3.98	175	7.0	313	+71
	Eastern syenite and cross cutting dyke N = 5 sites						4.91	44	11.6	317	+65
	Palaeomagnetic pole 2° N, 9° E ($d\psi = 15°$, $d\chi = 19°$) calculated from mean direction										

The results from Palabora reinforce the evidence from elsewhere in southern Africa of a polar shift from around 40° N, 45° E at about 2000 Ma towards 7° N, 20° W by *ca.* 1880 Ma. There is some slight evidence that this same *ca.* 2000–*ca.* 1880 Ma shift is observable in West Africa (K. Lomax 1975, personal communication). Between *ca.* 1880 and *ca.* 1100 Ma, published data come exclusively from southern Africa, but it is not possible to draw a unique path, partly because the data are sparse but mainly because there are acute uncertainties in the ages to be assigned to most of the data. At least four paths satisfy the present information (figure 7), and there could be others. The version in figure 7*b* is supported by presently unpublished West African data of K. Lomax (1975, personal communication). The version in figure 7*a*, was the one sketched by Piper *et al.* (1973) and is the simplest extension of the path first proposed by McElhinny, Briden, Jones & Brock (1968); the Z-shaped segment which it implies between *ca.* 1300 and 1100 Ma is the cornerstone of Piper's (this volume) matching of African and North American polar paths. The non-uniqueness of the African interpretation plus the uncertainty whether like polarities have been matched (see § 5(*d*)) are severe weaknesses in Piper's argument for the Proterozoic reassembly which he proposes. The intercontinental matching of data for other time-intervals which Piper uses in further support of his reassembly are even less secure. Hence his supercontinent configuration (Piper, this volume) is to be regarded as a base-map to be tested against palaeomagnetic as well as geological data, rather than a palaeomagnetically-based reconstruction.

(*d*) *Ca.* 1100 to *ca.* 550 Ma

Data from various parts of Africa in the time range *ca.* 1100–*ca.* 700 Ma are compatible with the common polar path illustrated in Piper's figure 1 (this volume, p. 470). Parts of this are well established, notably that determined by Piper (1972) in East Africa and the overall consistency is such that a fair amount of confidence can be placed on it. However there are weak links in its age control and future modification is not inconceivable. Two quite different paths have been published for the time interval *ca.* 700–*ca.* 550 Ma. One (Piper *et al.* 1973) links *ca.* 700 Ma poles near the present south geographic pole to early Palaeozoic poles in the Pacific; these in turn link with the Phanerozoic north polar wander path for Africa and hence this interpretation makes the whole path illustrated in Piper's figure 1 the north polar path. However McElhinny *et al.* (1974) drew a different path which linked with the Phanerozoic south polar wander path for Africa. Although it depended on maintenance of Smith & Hallam's (1970) reconstruction of the relative positions of Australia, India and Africa in late Proterozoic times, this latter version is the more satisfactory because it places the African data in a more acceptable chronological order and it has been adopted by Piper (this volume, figure 2*a*, p. 471). Pending further study, it must nevertheless be conceded that there is ambiguity in polarity of the whole African Proterozoic polar path.

6. DISCUSSION IN TERMS OF PLATE TECTONICS

Proterozoic palaeomagnetic studies show that continental crust was moving like present day crustal plates. Hence if there were separate continents it is probable that they would occasionally collide, and both palaeomagnetic and geological instances have been claimed to exist.

The more problematic questions are whether Proterozoic continental crust was as rigid and resistant to internal deformation as present day plates and whether *some* belts of Proterozoic rocks were deformed within a pre-existing continental block rather than by collision of two blocks with related subduction of former oceanic crust between them. It is difficult to prove continental collision in individual cases unless the component elements had previously been widely separated, because palaeomagnetic errors are too large to detect relative motions less than about 15° in relative translation or rotation, and geological evidence of subduction is largely self destructive on plate tectonic reasoning. Therefore until more sensitive criteria are recognized, it is more fruitful to pursue general arguments than individual instances.

In the case of Africa which has been presented at length in this paper, the general palaeomagnetic evidence is that the vector sum of relative cratonic movements was less than about 15° from 2300 to 1950 Ma *and* from 1950 to 1100 Ma *and* from 1100 to 700 Ma *and* from 700 to 550 Ma as well as throughout the Phanerozoic. Additionally the sum of all these relative motions from 2300 Ma to the present was less than about 15°. I contend that this implies that the relative motion of some Precambrian cratons was more closely constrained than are present day independent plates.

If this constraint is accepted one is reduced to determining whether the total amount of relative displacement of these cratons is the sum of all measurable strain and fault displacements across the intervening deformed belts, or whether there was an additional component which has since been lost by subduction. The measurements necessary to resolve this uncertainty have not yet been made. It is not clear whether they will be provided by yet more palaeomagnetic study, by further structural-petrological insight, or whether some extra line of attack will prove decisive. Meanwhile however, palaeomagnetists might be well employed in deciphering to which cratonic aggregate each individual craton belongs. It seems tectonically improbable that these aggregates should be determined by their *present* continental affinity (e.g. Africa): their Proterozoic affinity is the vital fact to discover, and this at least should be resolvable by palaeomagnetic study. Moreover it would be prudent to concentrate on times which are already particularly well recorded in at least one place (as is the interval 1950 to 1850 Ma in Africa) and try to match contemporaneous records from elsewhere.

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