ORGANIC DIVERSITY, PALAEOMAGNETISM, AND PERMIAN PALAEOGEOGRAPHY

by F. J. VINE

ABSTRACT. The latitude-dependent parameters of faunal diversity and magnetic inclination are assumed for 27 present-day and 27 Permian localities and utilized to predict the rotational and magnetic pole with respect to the present and Permian world maps. In this way the validity of the palaeogeographic map and the axial dipole assumption of palaeomagnetism are tested. The diversity data employed are those given by Stehli (1970), and the method of analysis is that suggested by Duncan (1972).

The Permian diversity data favour neither the Permian palaeogeography proposed by Smith *et al.* (1972) nor the alternative Permian reconstruction suggested here and based on a more literal interpretation of the Permian palaeomagnetic results. Of the geographies considered (present-day, Permian, Triassic, and Jurassic), the Permian diversity data fit best on the Jurassic coordinates. The analysis yields no evidence to suggest that the Permian geomagnetic field was dipolar but non-axial; instead it indicates that the field was probably axial but with large non-dipole components. The latter may have been sufficiently large to invalidate the use of Permian palaeomagnetic results in making Permian palaeogeographic maps or in assigning palaeolatitudes to other Permian reconstructions; however, this conclusion is dependent on the validity of the Permian diversity data as true palaeolatitude indicators.

PALAEOGEOGRAPHIC maps portray the relative positions of land masses at a particular time in the past, either with respect to an arbitrary frame of reference or with respect to palaeogeographic latitudes on the assumption that one can identify a palaeo-pole of rotation. Both types of map may be derived from palaeomagnetic studies if it is assumed that the ambient palaeomagnetic field approximated to that produced, in the first case, by a geocentric dipole, and in the second case by a geocentric dipole aligned along the earth's rotational axis. The palaeogeographic maps presented in this volume (Smith *et al.* 1972) are not entirely based on palaeomagnetic results in that geometrical and geological constraints have been given preference in making the continental reconstructions. However, the latitudinal positioning of the land masses is based on palaeomagnetic studies and is therefore dependent on the axial dipole field assumption of palaeomagnetism.

Within the science of palaeomagnetism it is possible to check the dipole field assumption since the palaeomagnetic inclination or dip (I) should vary systematically as a function of latitude (λ) along a palaeomeridian such that

$$\tan I = 2 \tan \lambda$$

and the declination (or variation) should be zero. The diagrams showing the inclination and declination of palaeomagnetic field directions at various localities on the above maps (Smith *et al.* 1972) for example, enable one to make a qualitative assessment of the validity of this assumption for any particular period. However, it is not possible within the science of palaeomagnetism to check the *axial* dipole field assumption; in order to do this one must therefore turn to some other latitude-dependent parameter, and perhaps the most useful of these, potentially, is organic diversity.

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The observation that faunal diversity decreases markedly from the equator to the poles at the present day was made many years ago by Wallace (1878) and has been reinvestigated by several authors more recently (e.g. Fischer 1960, Stehli 1968). Presumably it results from the temperature gradient between the equator and the poles and the associated changes in such factors as seasonality and trophic resource stability (Valentine 1971); however, the precise relationships between these parameters and organic diversity appear to be equivocal. Stehli, in particular, has demonstrated that the diversity of living organisms has a very high degree of symmetry about the present equator and rotational axis of the earth and can therefore be used to predict the position of the rotational pole (Stehli 1968). This work has been extended to an analysis of indices of faunal diversity at various Permian localities. Stehli concludes that these indices are more compatible with their present geographic latitudes than with their Permian palaeomagnetic latitudes, thus providing support for the present distribution of continents during Permian time rather than the Permian reconstruction of the continents and palaeolatitudes favoured by palaeomagnetism (Stehli 1970).

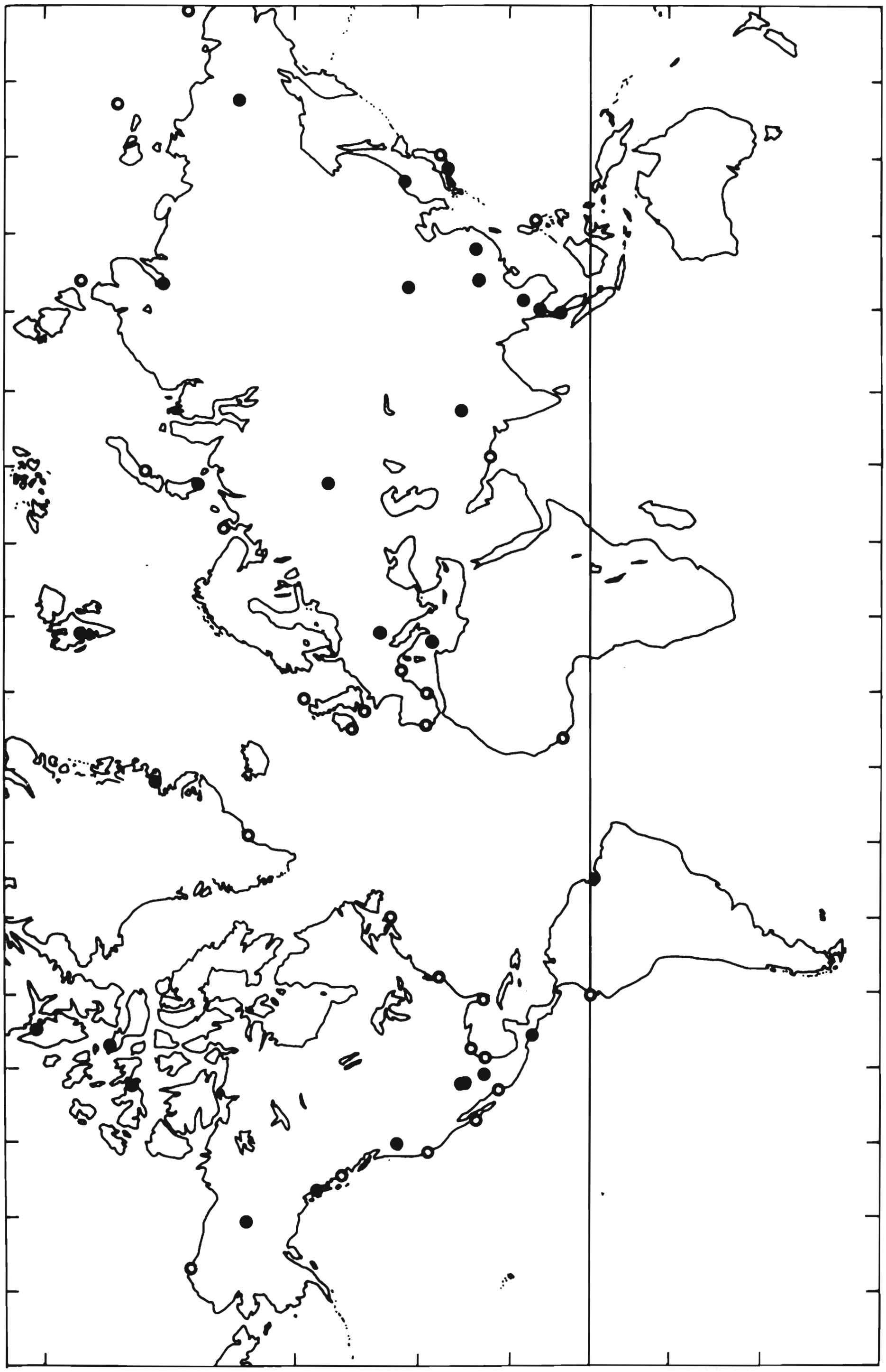
Recently Duncan (1972) has reanalysed Stehli's data and suggested that the Permian diversity data support neither the present continental configuration nor the Permian configuration suggested by palaeomagnetism. An attempt is made here to clarify and extend the conclusions of both these authors.

The first part of this paper is analogous to the recent analyses of Stehli (1970) and Duncan (1972) using Stehli's data, Duncan's method of pole prediction, and the Permian palaeogeographic map prepared for this symposium by Smith *et al.* (1972). However, an additional feature is the analysis of comparable magnetic data alongside that for present and Permian faunal diversity data in order to test the dipole and axial dipole assumptions of palaeomagnetism.

The second half of the paper is an attempt to identify a palaeogeography which is more compatible with the Permian faunal diversity data but would indicate certain shortcomings in the Permian palaeomagnetic results.

ORIGIN OF DATA

The taxonomic diversity data utilized throughout this paper are those given for present-day clams and Permian brachiopods by Stehli (1970). Diversity parameters for the 27 present-day and 27 Permian localities shown in text-fig. 1 were taken from this data; three present-day localities, i.e. those on Hawaii, Iceland, and Puerto Rico, were omitted, (*a*) because they cannot be plotted on a Permian reconstruction and (*b*) in order to make the number of data points in the two samples equal. The present magnetic inclination at the 27 present-day localities was determined and a palaeomagnetic latitude assigned to each of the 27 Permian localities as given in Tables 1 and 2. Clearly the assumption of a palaeomagnetic latitude for each Permian locality is subjective in that, in general, palaeomagnetic data are not available for each fossil locality and an extrapolation from palaeomagnetic sampling localities within the same land mass is involved. Details of the assumptions made in this instance are given below.



TEXT-FIG. 1. Map of sampling localities at which diversity ratios for Recent clams (open circles) and Permian brachiopods (solid circles) have been assigned. (After Stehli 1970.) See also Tables 1 and 2.

TABLE 1. Present-day localities (see text-fig. 1)

Station number	*Magnetic inclination*	*Clam diversity ratio*	*Present Lat. (N.)*	*Present Long. (E.)*	*Permian Lat. (N.)*	*Permian Long. (E.)*
1	81·5	0·34	74	58	40	31
2	87·0	0·36	78	109	52	31
3	83·5	0·32	77	153	62	21
4	79·0	0·30	71	178	67	6
5	72·0	1·00	59	−2	17	16
6	66·0	2·28	50	−7	8	15
7	68·0	1·49	52	−11	10	12
8	55·0	2·22	39	−10	1	11
9	54·5	2·16	39	−1	−2	18
10	59·0	2·20	43	5	2	24
11	0·0	2·00	7	−13	−17	−16
13	37·0	2·70	24	62	−27	60
16	48·0	2·10	35	141	65	120
17	13·0	2·66	14	125	39	127
23	80·0	0·43	71	−154	48	−17
24	72·0	1·50	52	−130	32	−32
25	62·0	1·68	38	−123	18	−41
26	53·5	2·05	28	−115	6	−43
27	50·0	1·85	23	−107	−2	−40
28	22·0	2·32	0	−81	−18	−51
32	58·0	2·00	25	−83	−11	−19
33	54·0	1·86	25	−98	−5	−33
34	59·0	1·46	28	−95	−3	−28
35	68·0	1·86	36	−75	−3	−11
36	72·0	0·94	45	−60	3	3
37	78·0	0·43	65	−38	18	12
39	78·0	0·80	69	44	33	33

Thus there are four basic data sets, two relating to the present day, two to Permian time, and all thought to be indicators of geographic latitude if the assumptions regarding the latitude dependence of faunal diversity and magnetic inclination are correct. In order to make the faunal and magnetic data directly comparable, and amenable to the same type of analysis, the additional geographic information regarding hemisphere and meridional direction, which is inherent in the magnetic data, has been discarded, and only a latitude or inclination between 0 and 90° assumed. In fact, although unnecessary from a mathematical standpoint, the complement of the magnetic inclination or latitude has been used in the analysis in order to produce a maximum value at the equator as in the case of faunal diversity.

METHOD OF ANALYSIS

The method of pole prediction utilized throughout is that suggested by Duncan (1972) for a limited and poorly distributed number of latitude-dependent parameters on the surface of a sphere. The latitude of each data point with respect to an arbitrarily chosen 'north pole' is calculated and a fourth-degree polynomial in

TABLE 2. Permian localities (see text-fig. 1)

Station number	Palaeomag. latitude	Brachiopod diversity ratio	Present Lat. (N.)	Present Long. (E.)	Permian Lat. (N.)	Permian Long. (E.)	Triassic Lat. (N.)	Triassic Long. (E.)	Jurassic Lat. (N.)	Jurassic Long. (E.)	Alt: Permian Lat. (N.)	Alt: Permian Long. (E.)
1	32	0·60	66	−141	43	−22	54	−40	62	−30	32	−68
2	29	0·33	77	−95	37	−1	55	−10	62	3	29	−49
3	21	0·33	73	−25	25	18	46	18	49	29	21	−27
4	33	0·19	79	15	38	18	58	17	60	34	33	−28
5	5	1·42	47	15	8	30	29	32	29	36	5	−12
6	26	0·94	54	57	27	49	46	59	40	66	26	3
7	12	0·80	42	107	46	85	53	113	42	112	12	77
8	31	0·40	42	133	64	99	62	146	51	137	31	77
9	36	0·53	70	55	38	34	59	41	55	56	36	−14
10	9	1·33	31	−105	3	−34	12	−34	24	−35	−9	−76
11	25	0·56	57	−133	36	−30	44	−44	56	−43	25	−75
12	6	0·81	37	13	−6	21	16	23	18	27	−6	20
13	40	0·94	32	75	−40	67	−22	62	125	62	−40	66
14	56	0·38	67	155	70	30	89	110	78	120	56	−67
15	51	0·33	73	105	52	37	73	52	67	78	51	−13
16	5	1·00	7	98	18	111	19	120	8	119	−5	107
17	10	0·60	44	−120	21	−36	29	−41	41	−42	10	−79
18	16	0·75	28	115	43	106	43	130	31	127	16	92
19	28	1·30	16	−91	−12	−30	−1	−23	10	−27	−28	−72
20	35	0·92	35	137	62	118	55	156	46	148	35	87
21	14	0·81	26	−102	−2	−35	7	−32	19	−34	−14	−76
22	8	1·00	32	−105	4	−34	13	−33	25	−35	−8	−75
23	30	0·17	76	−105	38	−4	55	−15	63	−3	30	−52
24	33	0·46	81	−90	40	4	58	−6	65	11	33	−46
25	1	0·75	17	102	28	107	28	121	18	119	1	99
26	2	0·85	12	100	23	108	25	120	13	118	−2	102
27	8	1·00	27	107	37	102	39	121	28	120	8	91

latitude fitted to the data. Odd powers of latitude are omitted to preserve symmetry about the equator. Hence:

$$y = k_1 + k_2\lambda^2 + k_3\lambda^4 + \text{‘residual’}$$

where $(\pi/2 - \lambda) = \cos^{-1}[\sin\theta^* \sin\theta_i \cos(\phi_i - \phi^*) + \cos\theta^* \cos\theta_i]$

y = value of latitude-dependent parameter

λ = latitude of locality with respect to trial north pole

(θ^*, ϕ^*) = co-latitude and longitude of trial north pole

(θ_i, ϕ_i) = co-latitude and longitude of i^{th} point

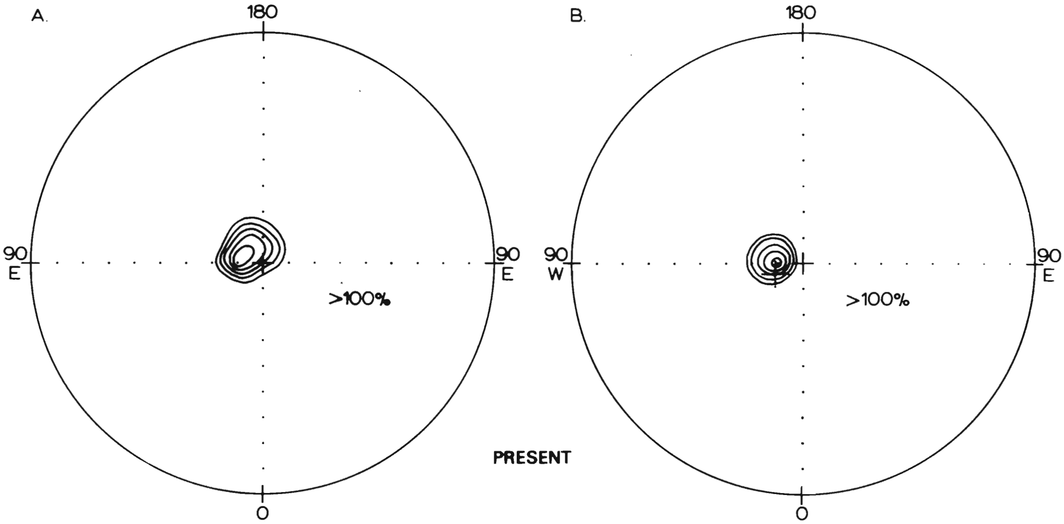
and k_1, k_2, and k_3 are obtained by least squares linear regression.

Thus if the computation is repeated over a grid of trial north poles and the sum of squares of residuals calculated for each pole position, the best-fitting pole can be identified from the minimum value, and a ‘confidence area’ may be defined by contouring the grid of sums of squares of residuals where the sum is say 10, 30, and 50 per cent above the minimum value. This method has obvious advantages over the spherical harmonic analysis employed initially by Stehli (e.g. Stehli *et al.* 1967) in that (*a*) one is only fitting three coefficients by regression in contrast to nine in the case of a second-order spherical harmonic analysis (this is important when relatively few data points are available) and (*b*) one can contour a ‘confidence area’ about the predicted pole to give an indication of the reliability of the result. Although the new method still has certain deficiencies which will become apparent below, it is considered to be perfectly adequate for the present purpose.

Throughout this paper magnetic inclinations and palaeomagnetic latitudes have been treated in the same way as the diversity parameters and subjected therefore to the method of analysis described above. This is an unnecessarily complicated way of analysing the magnetic data in that in this instance the precise relationship between the magnetic parameter and latitude is known if the axial dipole assumption is made. Thus one could simply compute the difference between the observed and calculated magnetic parameter at each data point for each trial pole position and analyse these residuals as described above. This has in fact been done for all the analyses of magnetic data described below but since, as one would hope, the results are not appreciably different, and in no way alter the conclusions derived from the more general method of analysis, they are not presented here.

ANALYSIS OF PRESENT-DAY DATA

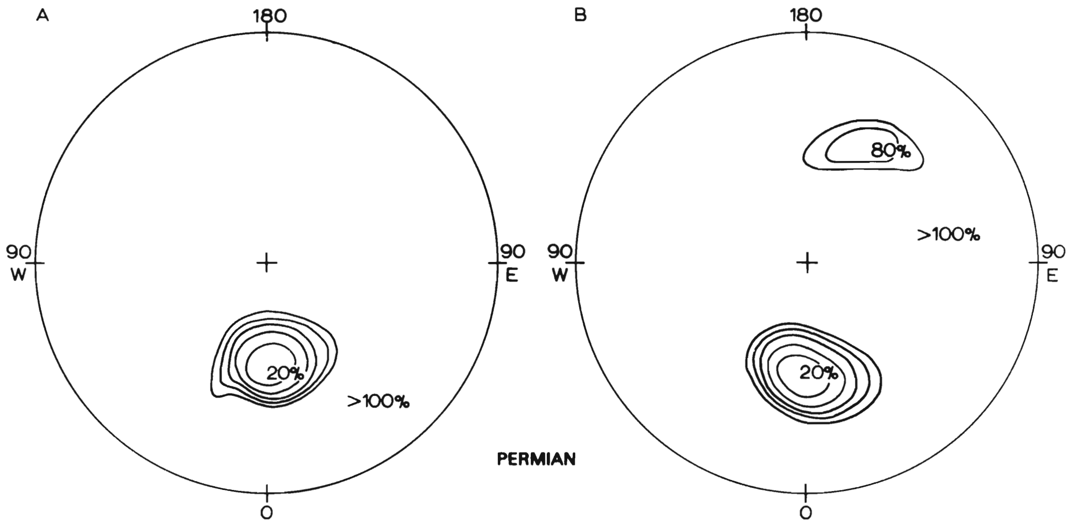
In text-fig. 2 the above method of analysis has been applied to the clam diversity ratios assigned by Stehli (1970) and the present magnetic inclinations at the 27 localities indicated by open circles in text-fig. 1. If the diversity and magnetic models are correct one would expect the clam ratios to predict the present rotational pole and the magnetic dips to predict the magnetic pole of the geocentric dipole which best fits the present magnetic field of the earth. It will be seen that the two parameters predict poles within 8 and 4 degrees respectively of the rotational and geomagnetic poles which are themselves within the 60 per cent confidence limit in both



TEXT-FIG. 2. Contoured plots of sums of squares of residuals for an array of trial north poles fitted to (*a*) Recent clam ratios and (*b*) current magnetic inclinations plotted at the 27 localities indicated by open circles in text-fig. 1. The contours join points 20, 40, 60, 80, and 100% higher than the minimum value. The faint cross at 78·5° N., 70° W. is the pole of the best-fitting geomagnetic dipole. These and all subsequent polar projections are azimuthal equi-distant projections of the Northern Hemisphere.

cases. Moreover the 'confidence areas' are remarkably small. These results demonstrate that given the magnetic inclination or an appropriate measure of faunal diversity at as few as 27 localities on the correct geographic frame of reference one can deduce the geomagnetic and geographic poles respectively with considerable accuracy. The accuracy is all the more remarkable when one considers that the 27 data points are very poorly distributed within only one hemisphere of the earth (see text-fig. 1).

The result of plotting and analysing the present-day data on the Permian reconstruction presented by Smith *et al.* (1972) is shown in text-fig. 3. Both predicted poles are in the vicinity of 45–50° N. on the 0° meridian (in all cases the central meridian of the palaeogeographic maps has been taken as 0° longitude and the margins 180°). These new pole positions reflect the fact that one can reproduce some of the essential features of the Permian reconstruction, particularly with regard to Eurasia, by rotating the present-day globe about an equatorial diameter joining 90° E. and 90° W., so that the north pole moves 40–45° southwards along the Greenwich meridian. If this were all that was involved the 'cones of confidence' about the new pole positions would be the same as those in text-fig. 2. However, to arrive at the Permian reconstruction the continents must also be brought together to form the single supercontinent of Pangaea and in so doing the correct frame of reference for the present-day data is destroyed and the 'confidence area' consequently enlarged. Text-fig. 3B illustrates one of the deficiencies of the analytical method as it stands since it may fit a minimum rather than a maximum at the trial equator and hence produce good fits at points approximately 90° from the required pole at which an equatorial maximum has been fitted. The position of these spurious minima will depend on the distribution of data points.



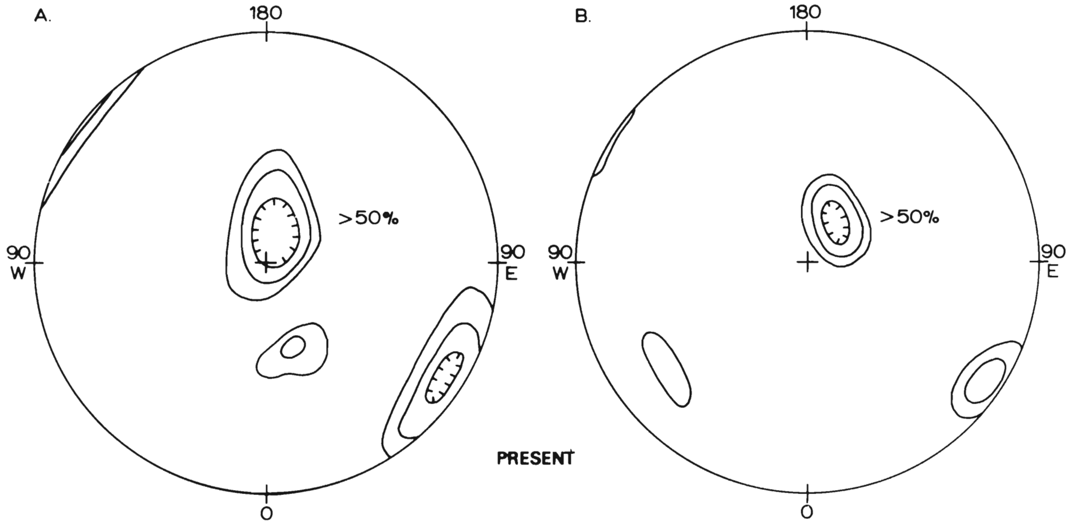
TEXT-FIG. 3. Contoured plots of sums of squares of residuals for an array of trial north poles fitted to (*a*) Recent clam ratios and (b) current magnetic inclinations plotted on the Permian reconstruction of Smith *et al.* (1972). Conventions as for text-fig. 2.

Note. The present geomagnetic field is known to contain quite large non-dipolar components and to vary fairly rapidly in time. Over a period of a few thousand years the mean orientation of the best-fitting dipole is thought to approximate to the rotational axis, this being a fundamental tenet of palaeomagnetism for which there is considerable evidence from archaeomagnetism (e.g. Kawai *et al.* 1965). Thus the present-day magnetic inclinations reflect the earth's magnetic field at an instant in geologic time and are not strictly comparable with the results of palaeomagnetic studies which average the field over appreciable lengths of geologic time in the hope of obtaining the orientation of the mean, axial, dipole.

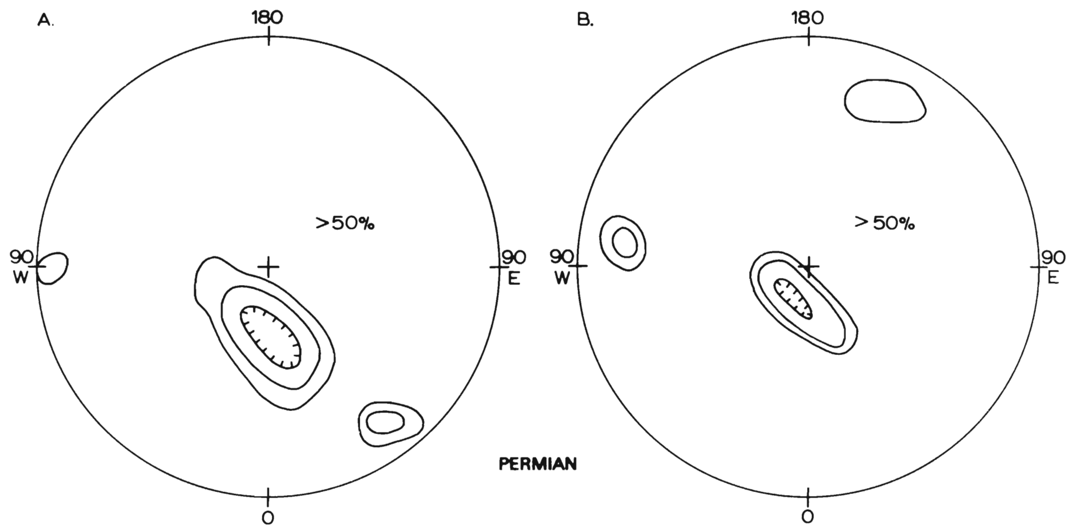
ANALYSIS OF PERMIAN DATA

In text-figs. 4 and 5 the Permian brachiopod diversity data and Permian palaeomagnetic latitudes for the same 27 localities are analysed on present-day and the proposed Permian geographic coordinates respectively. Neither set of data fits either frame of reference particularly well but both behave rather similarly on the two sets of coordinates suggesting that they may be comparable palaeolatitude indicators plotted on incorrect continental configurations. This is equivalent to saying that the axial dipole assumption of palaeomagnetism may well be valid. The brachiopod data fit the present-day coordinates better in that the geographic pole falls within the 10 per cent 'confidence limit'. This is equivalent to the point made previously by Stehli (1970). However, it must be admitted, in the light of the size of the 'cones of confidence', that neither fit is very satisfactory. The Permian palaeomagnetic latitudes fit only marginally better on the Permian reconstruction than on present-day coordinates. This is a rather surprising result although the fit to the Permian coordinates is aggravated by the large number of localities in south-east Asia as discussed below.

Text-figs. 4A and 5A illustrate a second deficiency of the method of analysis in that the minima in the sums of squares of residuals grid at approximately 55° N.,



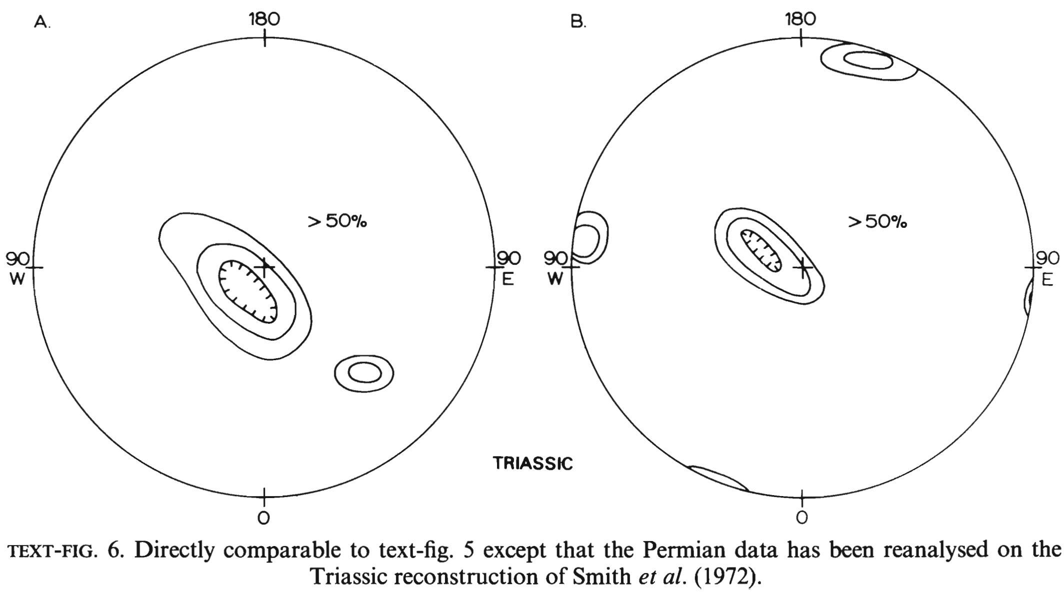
TEXT-FIG. 4. Contoured plots of sums of squares of residuals for an array of trial north poles fitted to (*a*) Permian brachiopod ratios and (*b*) Permian palaeomagnetic latitudes plotted at the 27 localities indicated by solid circles in text-fig. 1. The contours join points 10, 30, and 50% higher than the minimum value. The 10% contour is pecked towards the minimum.



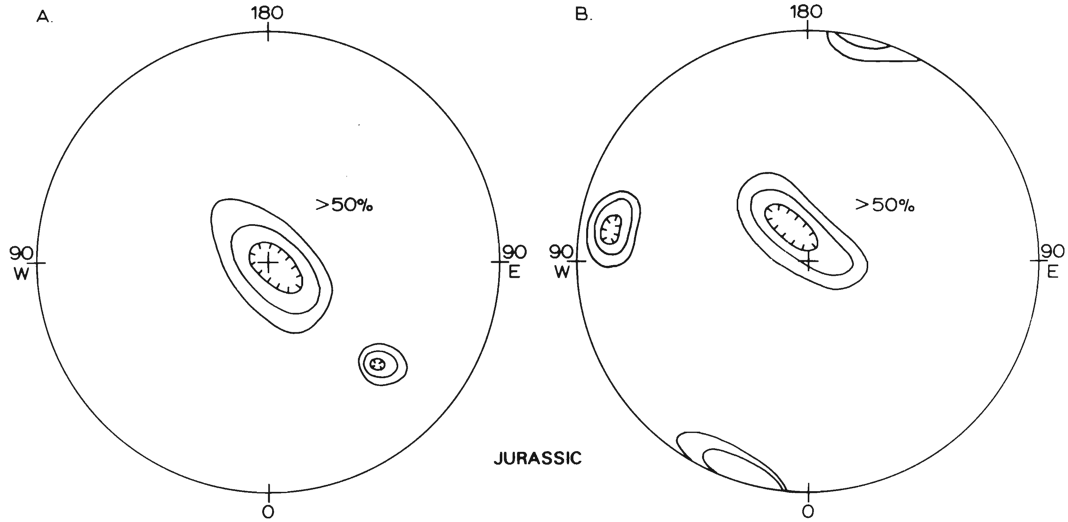
TEXT-FIG. 5. Contoured plots of sums of squares of residuals for an array of trial north poles fitted to (*a*) Permian brachiopod ratios and (*b*) Permian palaeomagnetic latitudes plotted on the Permian reconstruction of Smith *et al.* (1972). Conventions as for text-fig. 4.

15° E. and 15° N., 35° E. respectively are spurious as are those noted previously at approximately 90° from the main minima. In this case the false minima arise from the fact that the quadratic function in latitude fitted to the latitude-dependent data does not necessarily vary monotonically from the equator to the poles. Only if k_2 and k_3 have the same sign does the function have one turning-point, i.e. at the equator. If k_2 and k_3 are of opposite sign the function has three turning-points, one at the equator and the other two symmetrically disposed about it. Thus if k_2 is positive and k_3 negative, low values are fitted at the poles, high values at intermediate latitudes, and at intervening minimum at the equator. If k_2 is negative and k_3 positive, as in these cases, the function fits high values at the poles, low values at intermediate latitudes, and a maximum at the equator. This feature recurs on all plots involving Permian brachiopod data and it is noteworthy that in every case the spurious pole is being fitted in the vicinity of station 5 which has the highest diversity ratio (see Table 2). This problem is accentuated by a further unsatisfactory feature of the function fitted; the fact that it is discontinuous at the poles.

Since the required minima in text-figs. 4 and 5 lie on either side of the geographic pole with respect to the present-day and Permian continental distributions, they suggest that the Permian diversity and palaeomagnetic data might fit a continental configuration with respect to the pole which is intermediate between that of the present day and that proposed for the Permian by Smith *et al.* (1972). With this in mind both sets of data were plotted and reanalysed on the proposed palaeogeographies for the Triassic and Jurassic which are, of course, intermediate in this way. The results are shown in text-figs. 6 and 7. Since the reconstruction of the continents into a single land mass is the same on the Permian and Triassic palaeogeographic maps, one can be derived from the other by rotating the single supercontinent about a pole at approximately 5° S., 110° E. by a little more than 20°. Thus the residuals plot for the Triassic frame of reference can be obtained from the



TEXT-FIG. 6. Directly comparable to text-fig. 5 except that the Permian data has been reanalysed on the Triassic reconstruction of Smith *et al.* (1972).



TEXT-FIG. 7. Directly comparable to text-fig. 5 except that the Permian data has been reanalysed on the Jurassic reconstruction of Smith *et al.* (1972).

Permian plot in this way. It will be seen that in the case of the brachiopod data the minimum residuals are obtained nearer the pole when the data are analysed on Triassic rather than Permian coordinates. The difference between the Triassic and the Jurassic palaeogeography is more subtle since by this time the northern continents have begun to separate from the southern continents (Smith *et al.* 1972).

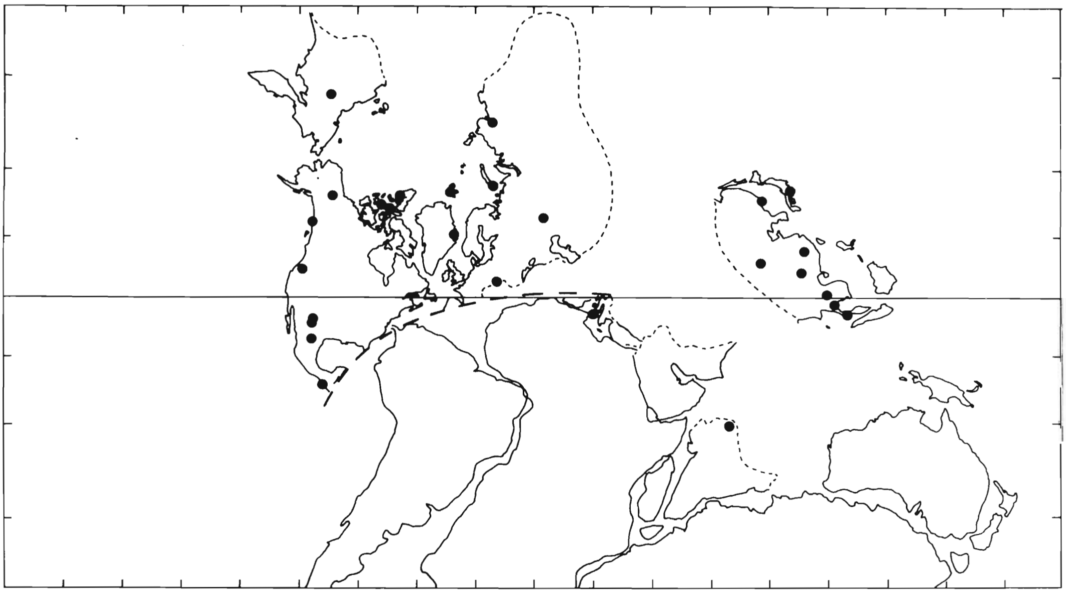
Of the four world geographies considered so far (present-day, Permian, Triassic, and Jurassic), the assigned Permian palaeomagnetic latitudes at the 27 Permian brachiopod localities do not fit any of them particularly well and in all cases there is mis-match of 10–20° between the predicted palaeogeographic and palaeomagnetic poles. The brachiopod diversity data, however, give a better fit on the Jurassic palaeogeography; the predicted and palaeogeographic poles are approximately coincident and the 'cone of confidence' is as small as, or smaller than, any other obtained. This extended analysis of the Permian diversity data demonstrates that these data do indeed cast doubt on Permian palaeogeographic reconstructions based on palaeomagnetism as Stehli has suggested, but does not substantiate his conclusion that the diversity data favour the present distribution of the continents with respect to each other and the pole in Permian time. Here it has been shown that the diversity data are more compatible with a Jurassic reconstruction of the continents which assumes relative movements between the continents since that time and involves latitudinal changes.

ALTERNATIVE PERMIAN RECONSTRUCTION

As noted above in discussing text-figs. 4 and 5 there is a suggestion in the foregoing analysis that the axial dipole assumption of palaeomagnetism is valid (since the palaeontologic and magnetic data behave similarly on the various reconstructions) but that the data are being analysed on inappropriate palaeogeographies.

Even in the case of the Jurassic palaeogeography, which would appear to be the most appropriate, the 'goodness of fit' is still very poor. The palaeomagnetic data used in assigning palaeolatitudes to the Permian reconstruction has been summarized by Smith *et al.* (1972). It will be noted that in contrast to the distribution of Permian brachiopod localities used in the above analysis (text-fig. 1), these authors have utilized no palaeomagnetic results from south-east Asia in positioning their Permian reconstruction latitudinally. Initial palaeomagnetic results from south-east Asia (Irving 1964, McElhinny 1969) suggest that it was not part of Pangaea in Permian time but formed a separate land mass situated in lower latitudes than those indicated by the Permian palaeogeography assumed above.

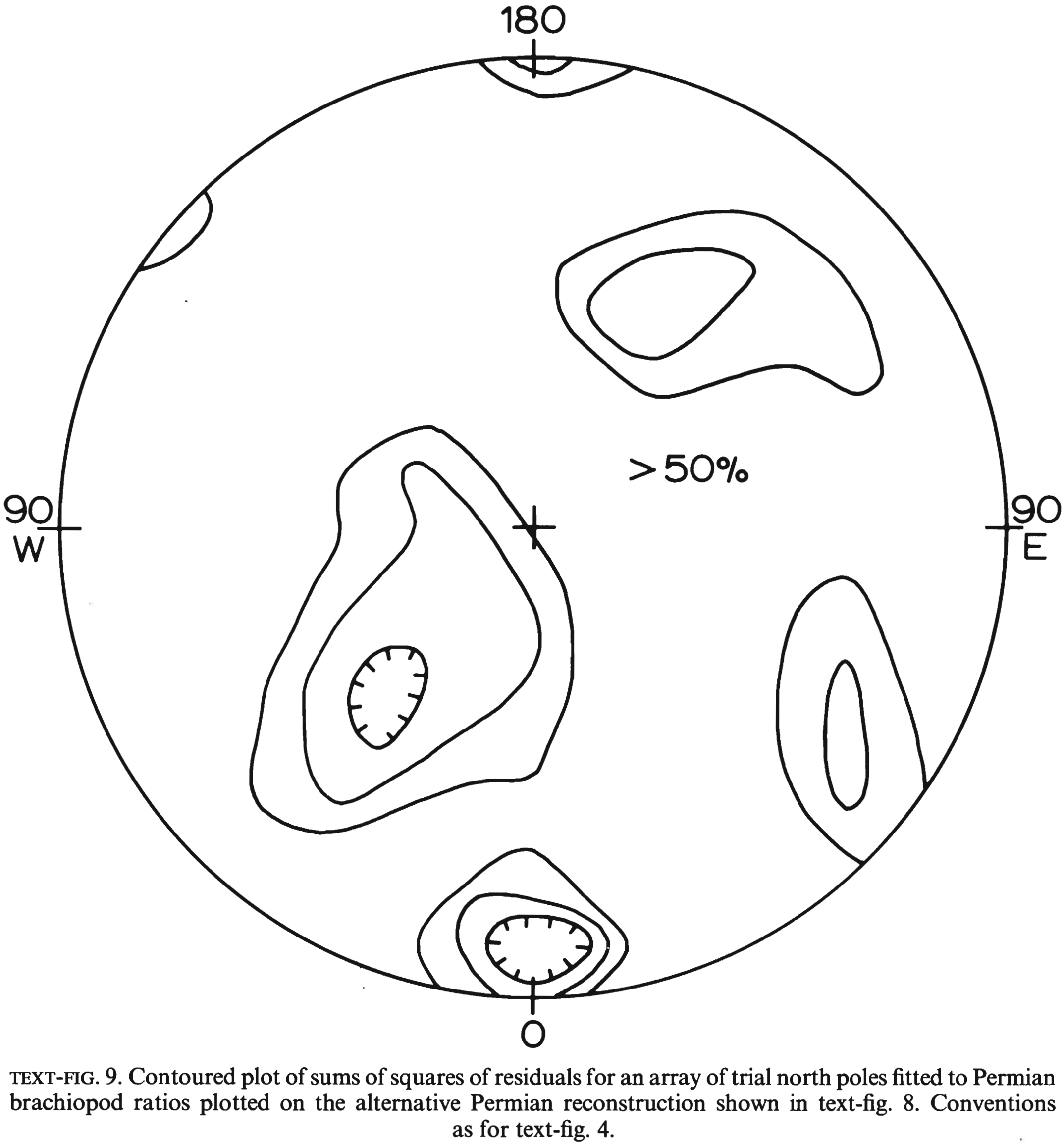
As a further test of the axial dipole field assumption, and in order to investigate the effect of assuming a Permian reconstruction based essentially on the palaeomagnetic results alone, an 'alternative' Permian palaeogeographic reconstruction has been considered (see text-fig. 8). In this the reassembly and latitudinal and



TEXT-FIG. 8. Alternative Permian palaeogeographic reconstruction based on palaeomagnetic results. The palaeomagnetic pole position assumed for North America and eastern Siberia is 41° N., 116° E., for Eurasia is 43° N., 162° E., and for south-east Asia is 18° E., 162° W. The position of the Gondwanic continents is unchanged from that given by Smith *et al.* (1972). Solid circles indicate Permian brachiopod localities.

longitudinal positioning of the southern continents is unchanged from that given by Smith *et al.* (1972) but in accepting the palaeomagnetic results for the northern continents at face value it was thought necessary to introduce a 'Tethyan shear zone' as suggested previously by Van Hilten (1964) and Irving (1967), and to reposition south-east Asia as described above. It also seemed more appropriate from a geological point of view to include eastern Siberia with North America although there is no palaeomagnetic control on this. It would be fair to say that most authors, more recently, have argued against the concept of a Tethyan shear zone (e.g. Creer 1971, Zijderveld *et al.* 1970). The palaeomagnetic latitudes for each of the Permian brachiopod localities shown in text-figs. 1 and 8, and assumed in the above analysis, were derived from this reconstruction.

The result of analysing the Permian brachiopod data on this alternative Permian reconstruction is shown in text-fig. 9. This figure is not quite so different from text-fig. 5A (brachiopod data on the Permian reconstruction) as it might at first appear, for in preserving the longitude grid with respect to the southern continents the longitude of most of the data points, which are on the northern continents, has been



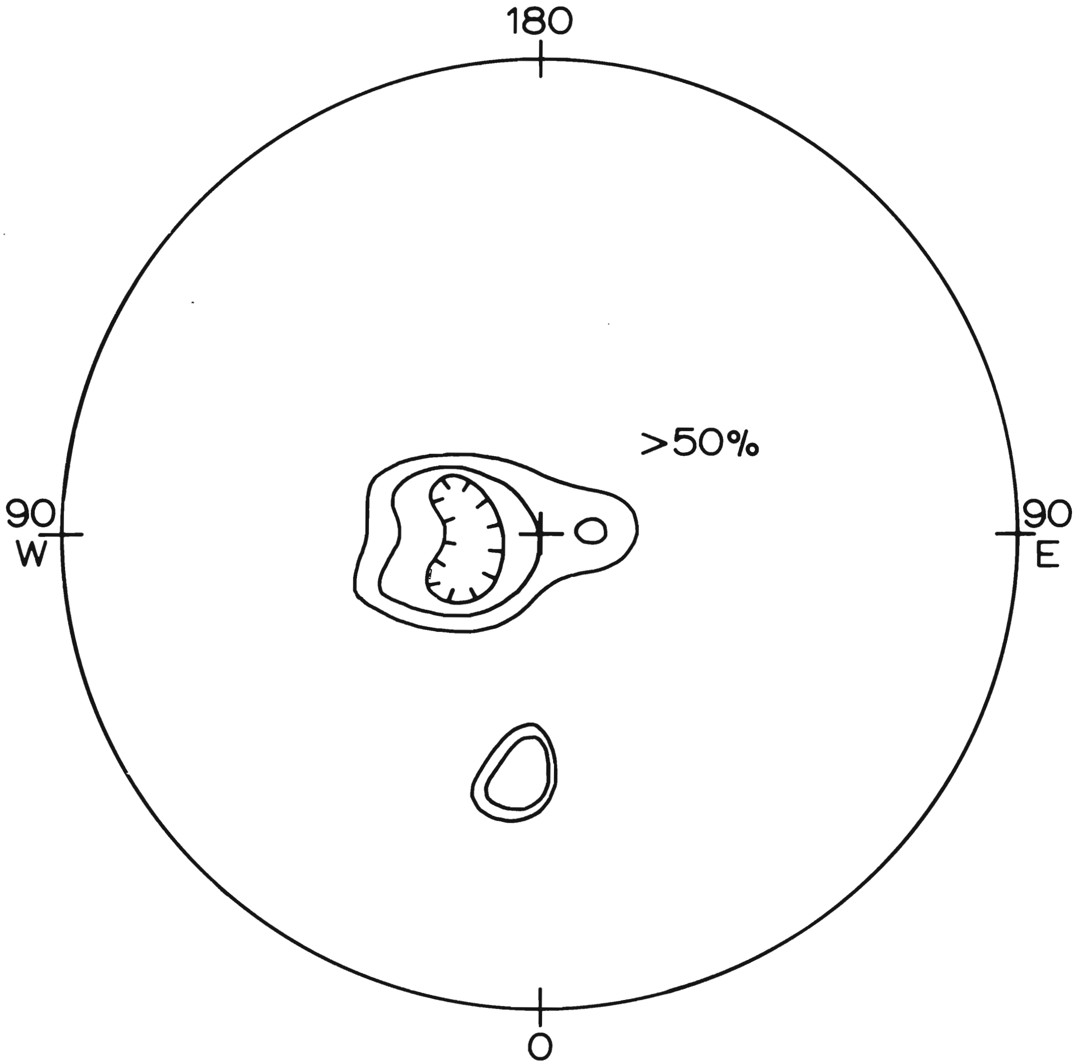
TEXT-FIG. 9. Contoured plot of sums of squares of residuals for an array of trial north poles fitted to Permian brachiopod ratios plotted on the alternative Permian reconstruction shown in text-fig. 8. Conventions as for text-fig. 4.

displaced through 40–50° to the west. However, it is clear that the fit of the data to these alternative Permian coordinates is very poor and this was perhaps predictable in that, in general, the alternative reconstruction, rather than being intermediate between the Permian reconstruction and present-day geography is even further removed from it. Had the 'cone of confidence' in text-fig. 9 been smaller than that in text-fig. 5A it would have suggested that the Permian magnetic field was dipolar but non-axial, i.e. that the reconstruction was correct but the palaeolatitudes wrong. However, the alternative reconstruction was obtained by making the axial dipole assumption and the implication of the above analysis therefore is that either the earth's magnetic field was non-dipolar in Permian time or at least had large non-dipole components, as suggested previously by Briden *et al.* (1970). In either case it would cast considerable doubt on the validity of using palaeomagnetically derived palaeolatitudes on Permian reconstructions. It is tempting to speculate that the postulated large non-dipole components of the geomagnetic field in Permian time correlate with the absence of field reversals during this period, which coincides with part of the Kiaman (reversed) Magnetic Internal (Irving and Parry 1963). This is perhaps consistent with the suggestion of Lilley (1970) that the stability of the dipolar component of the earth's magnetic field is dependent on there being considerable departures from the perfect rotational symmetry of an axial dipole field, i.e. decay and possible reversal of the dipole field are more likely to occur when the field has a high degree of axial symmetry. If this empirical relationship is correct one might anticipate similar problems with palaeomagnetic results pertaining to Mid-Cretaceous and Early Jurassic time in that these episodes are also thought to be intervals of single (in these cases 'normal') magnetic polarity (McElhinny and Burek 1971).

RESERVATIONS

To say that it is not difficult to criticize the above analysis is to indulge in the art of classic understatement. Clearly it all hinges on the validity of the brachiopod diversity data as palaeolatitude indicators. To what extent, for example, are they distorted by the 'continentality' of the probable Permian reconstruction and the strong development of boreal and tethyan provinces? An obvious criticism of both the palaeontologic and palaeomagnetic data is that the sequences sampled at different localities may be of a different and even non-overlapping time ranges. This could be a serious disadvantage as regards the diversity data because of the large climatic variations within the Permian period; it might conceivably be an advantage as regards the palaeomagnetic data since it might tend to average out the non-dipole components. This essential difference between the Permian data and the present-day diversity data, which apply to an 'instant' in geologic time, may well account in part for the larger cones of confidence obtained when analysing the Permian diversity data.

The Permian palaeomagnetic data comes off rather poorly in the above analysis and one feels intuitively that this must be due to the rather unfortunate distribution of Permian localities, there being none in the present Southern Hemisphere and eight in south-east Asia. Clearly it is not appropriate to consider the palaeomagnetic results in much greater detail here but in order to allay this criticism in part the 61 Permian palaeomagnetic results plotted by Smith *et al.* (1972) have been analysed on the Permian reconstruction by the above technique. The result, shown in text-fig. 10, should be compared with text-fig. 5B. It confirms that the Permian palaeomagnetic inclinations do not fit the Permian reconstruction particularly well as suspected on the basis of the more limited and less reliable palaeomagnetic data—the fitted pole is 10–15° from the palaeogeographic pole and the 'cone of confidence' is rather large.



TEXT-FIG. 10. Contoured plot of sums of squares of residuals for an array of trial north poles fitted to 61 Permian palaeomagnetic inclinations given by Smith *et al.* (1972), and analysed on their Permian reconstruction.

CONCLUSIONS

If it is valid to consider the brachiopod diversity ratios given by Stehli (1970) as latitude-dependent parameters the following conclusions may be drawn from the foregoing discussion:

1. there is no suggestion from the above analysis that the Permian magnetic field was dipolar but non-axial;
2. however, there is an indication that there were large non-dipole components of the field in Permian time. These may be such as to cast serious doubt on the validity of the Permian reconstruction presented by Smith *et al.* (1972) and/or the palaeolatitudes assigned to it;
3. the Permian diversity data do not support the alternative Permian palaeogeography suggested here (text-fig. 8) but, if anything, suggest that the Triassic or Jurassic reconstruction may be a more appropriate frame of reference on which to plot Permian data.

For all its limitations and assumptions I hope that the above analysis has illustrated the potential value of studies of organic diversity in contributing to our understanding of the configuration of the continents in the past and in checking the underlying assumptions of palaeomagnetism. Although appreciating the difficulties involved in assembling data of this type I hope that this small and provocative contribution will spur some palaeontologists on to further this type of study.

Acknowledgements. I thank Professor F. G. Stehli for details of the present-day and Permian localities at which he has assigned diversity ratios; R. A. Duncan for his generosity in providing me with a print-out of his computer programme and a preprint of his paper on rotational pole determination; Dr. R. L. Parker for details and a print-out of his SUPERMAP computer programme which was used in making the reconstruction shown in text-fig. 8; and Drs. J. C. Briden and A. G. Smith for useful discussions and details of the palaeomagnetic results they used in positioning their Permian reconstruction latitudinally. Thanks are also due to Dr. J. R. Cann for critically reading the manuscript and to my wife for draughting the diagrams.

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DISCUSSION

J. C. Briden and A. Gilbert Smith. Most of the brachiopod data used in Dr. Vine's analysis come from areas whose Permian positions are not well known because the majority of them have been affected by Mesozoic and/or Tertiary orogenesis. Tectonic arguments suggest that areas such as Sicily could not have had positions that were markedly different from those on the Permian map. However, there are few known tectonic constraints on the positions of much of south-east Asia, Japan, and parts of Siberia during Permian time. For convenience only, they have been drawn on our map in their present-day positions relative to the rest of Asia. The peculiarities noted by Dr. Vine are therefore not surprising.

The difference between Dr. Vine's mean palaeomagnetic pole, derived from all Permian data, and ours based on the same data (Vine, text-fig. 10) stems solely from the different weightings used in our respective averaging methods.

It is possible that in Permian time the distribution of land and sea could have modified the climatic belts so as to make them oblique to palaeolatitude lines. If they were oblique, then 'diversity gradient poles' would probably differ systematically from geographic poles.

Obviously, we need more data. In particular we need palaeomagnetic measurements in the same areas as those in which the brachiopod studies have been made. Until these and other information are available it will be possible to interpret the Permian anomalies in a variety of ways.