Reports

Paleontologic Technique for Defining Ancient Pole Positions

Abstract. *Taxonomic diversity gradients appear to offer a quantitative paleontologic technique for obtaining ancient positions of the rotational pole of the earth. Statistical analysis of a model based on the taxonomic diversity of Recent planktonic foraminifera shows a close relationship to the latitudinal temperature gradient and, thus permits location of the pole. A similar analysis for Permian orthotetaceid brachiopods suggests a pole near the present position. Available data on diversity fit a present earth model better than one based on Permian paleomagnetic results and thus suggest that it may be necesary to consider a model for the earth's magnetic field which does not require coincidence of the magnetic and rotational poles.*

Data accumulated in the last 10 years in the field of rock magnetism suggest that the earth's magnetic poles and, possibly, the positions of continents may have shifted in the course of geologic time. These data, though inconclusive, have renewed speculation concerning both polar wandering and continental drift. Independent evidence fixing the relative positions of the earth's major surface features during its history is urgently needed as a check on paleomagnetic interpretations. Unfortunately, little of the independent evidence so far adduced appears to provide high resolution or to demand a unique interpretation. We suggest that, given sufficient data and appropriate techniques for handling it, paleontological information can provide both the high resolution and unique interpretation necessary to check paleomagnetic results.

The well-known temperature sensitivity of certain organisms suggested long ago that the distribution of climatically controlled fossils could be used to define ancient climatic zones (*1, 2*). Given sufficient geographic distribution of control points and temperature-dependent organisms closely related to those of the present, this technique does, in fact, work extremely well. Few would care to dispute the impressive floral and faunal evidence of a Tertiary climatic deterioration, for example. However, in dealing with more ancient rocks, control becomes poorer and relationships to existing organisms more obscure, so that a unique interpretation can rarely be secured. An additional difficulty, potentially affecting climatic interpretations, is the distribution of fossil-bearing rocks. For example, the distribution of lower Permian (Sakmarian) rocks, because of their real or apparent absence from the Pacific Ocean Basin and from most of Africa (at least in marine facies), makes it possible to suggest the existence of rotational poles characterized by circles of radius 30° in which no marine fossils occur. These circles center at 0° latitude, 0° longitude, and at 0° latitude, 180° longitude. It appears, therefore, that any plot of the distribution of lower Permian marine organisms will carry with it a strong prejudice based solely upon the distribution of known marine outcrops. Thus, even though a fossil form had no pronounced dependence on temperature, interpretation of its distribution would, nevertheless, give a pole position in the central-eastern Pacific. The most reasonable interpretation of the data for the distribution of Permian organisms is not in agreement with such a pole position, since large areas within this belt, characterized by appropriate facies, are devoid of types believed to be sensitive to temperature (*2*). Nevertheless, data for the distribution of marine fossils alone, because of the limited distribution of marine sediments, can neither exclude nor prove the validity of this interpretation of pole position.

The diversity of taxonomic groups (*3*) as well as the distribution of organisms, is strongly affected by temperature. Thus it appears that a measure of taxonomic diversity for a compact group of organisms could delineate temperature gradients, which could be used to give pole locations. This is possible because both temperature and diversity vary primarily as a function of latitude. In contrast to distribution data, the basic information derived from "taxonomic diversity gradients" is quantitative and varies systematically. Because of this, it can be subjected to statistical analysis in order to reveal the effects due to

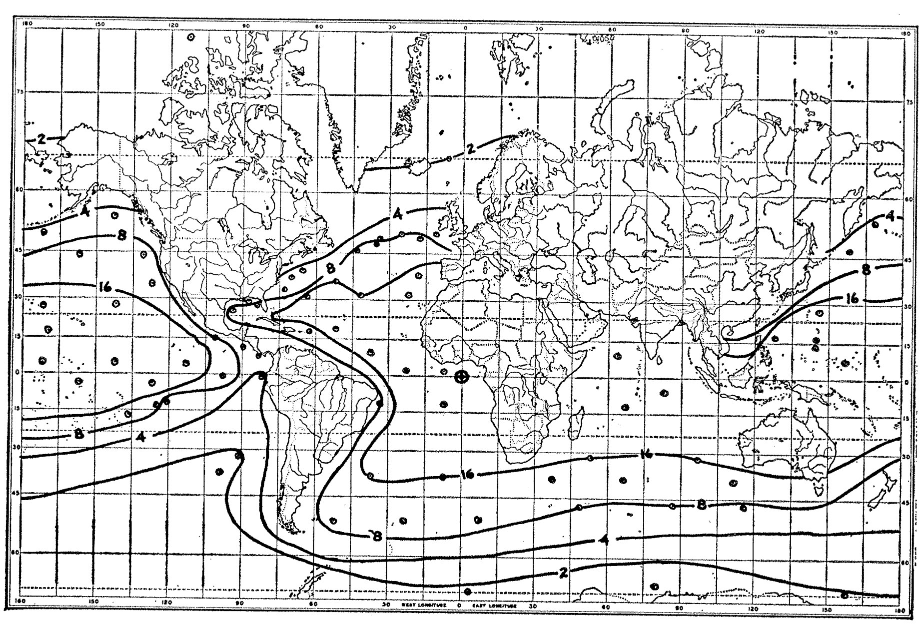


Fig. 1. The distribution and diversity of recent planktonic foraminifera (contoured according to the number of species).

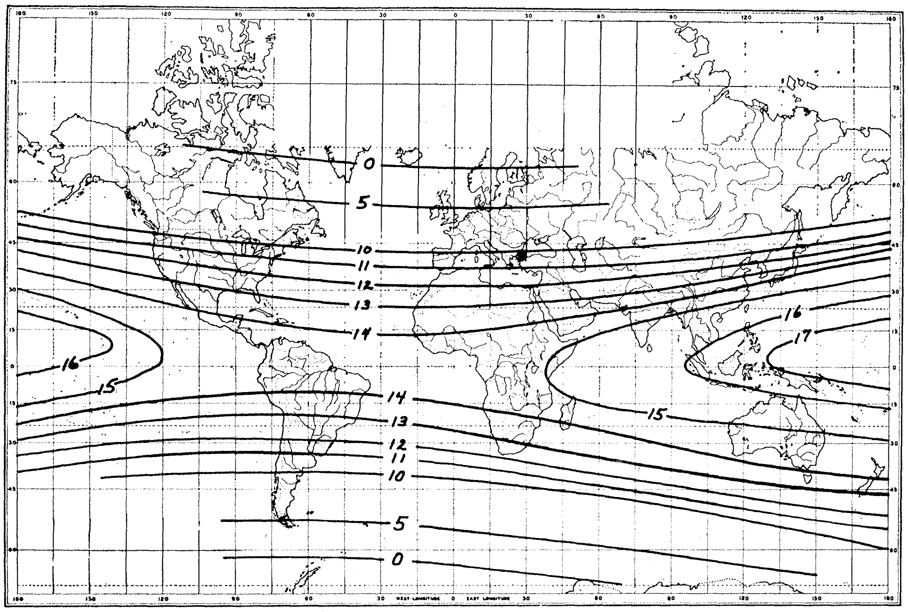


Fig. 2. Quadratic surface fitted to diversity of recent planktonic foraminifera and showing pronounced dependence on the latitudinal temperature gradients.

overall planetary temperature gradient and to separate from it the interference caused by local anomalies.

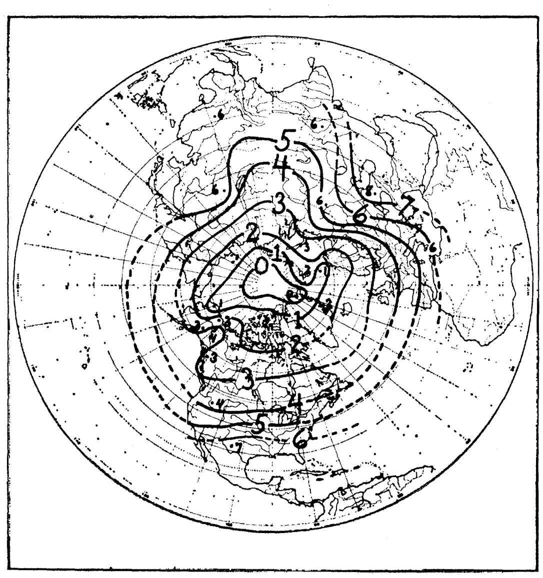
In Fig. 1, the present-day distribution and diversity of planktonic foraminifera in bottom samples, as derived from a general survey of the literature, provides an example of a taxonomic diversity gradient. Planktonic foraminifera were selected because they are widely and involuntarily distributed by ocean currents and thus provide a test of the actual utility of diversity gradients as a reflection of temperature gradients. Contours drawn according to the number of species of planktonic foraminifera present at control stations clearly indicate the presence of an overall diversity gradient but also indicate the presence of anomalies, or "noise." Trend surface analysis of the raw data gives a strong quadratic surface of the form shown in Fig. 2. This surface reveals the portion of the taxonomic diversity which is related to the earth's overall latitudinal temperature gradient. The remaining diversity must be attributed to anomalies caused by ocean currents, faunal province effects, and absence of data. The quadratic surface readily permits the location of the equator with considerable precision despite the fact that the control is strongly influenced by the absence of planktonic foraminifera on all of the continental masses.

Location and analysis of data on a Mercator projection, while convenient for display, is not ideal for subsequent statistical handling. Spatial distortions due to the projection and "edge effects" in the trend program can cause serious difficulty. Ideally, the data should be considered on a spherical surface, and attempts to handle them in this way are now being made.

In an attempt to use diversity gradients as seen in fossil populations, a group of Permian brachiopods (Orthotetaceids) was studied (Fig. 3). Because of the difficulty of obtaining sufficient control, the entire Permian period has been used, so there may be considerable averaging of the slope of the diversity gradient, though it appears unlikely that any large changes in its direction would be expected. The data used were obtained from 22 control stations. Though the data available are as yet insufficient for conclusive results, it appears that in the Northern Hemisphere the Permian diversity gradient for Orthotetaceid brachiopods sloped generally northward toward a pole not far removed from the present rotational pole. The position of the rotational pole, as suggested by the diversity surface, and the position of the magnetic pole inferred from paleomagnetic measurements (*4*) show a large degree of discordance.

To compare more directly the paleontologic and paleomagnetic information, a model of the earth's surface during the Permian, based on continental positions as suggested by paleomagnetic pole locations, has been constructed and is shown in Fig. 4 with the diversity gradients superimposed upon it. Here it was necessary to limit the number of control points even further, since only those points within the stable and undeformed areas of the continents can be considered in this model. It is quite clear that the fit of the diversity data to the paleomagnetic model of the earth is inferior to that of the present-day model. It would appear that in Europe and Asia, the paleomagnetic latitudes and diversity latitudes are almost normal to one another.

From the attention given the method



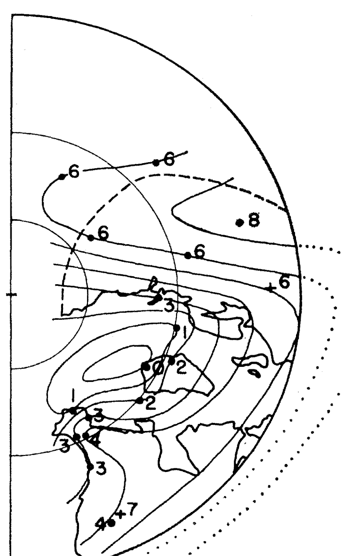


Fig. 3 (left). The diversity of Permian Orthotetaceid brachiopods in the northern hemisphere (contoured according to the number of genera). Fig. 4 (right). Diversity of Permian Orthotetaceid brachiopods on a paleomagnetic model of the earth.

so far, the use of diversity gradients appears promising for the determination of past positions of the rotational pole. More detailed studies of diversity gradients extant among fossil populations should be made for a geologic time interval nearer to the present, in which better control is available. On the basis of the discordance of paleomagnetic and diversity results suggested by the meager Permian data, it appears that the present model for the earth's magnetic field may be inadequate and that it may be necessary to consider a model which does not require coincidence of the rotational and magnetic poles. (*5*).

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References and Notes

1. E. Dacqué, *Grundlagen und Methoden der Paleogeographie* (Fisher, Jena, 1915); R. W. Chaney, *The Succession and Distribution of Cenozoic Floras Around the Northern Pacific Basin* (Univ. of California Press, Berkeley, 1936); J. W. Durham, *Geol. Soc. Am. Bull.* **61**, 1243 (1950).
2. F. G. Stehli, *Am. J. Sci.* **255**, 607 (1957).
3. A. R. Wallace, *Tropical Nature and Other Essays* (Macmillan, New York, 1878); A. G. Fischer, *Evolution* **14**, 64 (1960); F. G. Stehli, "Permian zoogeography and its bearing on climate," *Proc. N.A.T.O. Advanced Study Inst. on Paleoclimate*, in press.
4. A. Cox and R. R. Doell, *Rev. Paleomagnetism Geol. Soc. Am. Bull.* **71**, 645 (1960).
5. Contribution No. 11, Department of Geology, Western Reserve University.
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Tetragonal Zirconium Oxide Prepared under High Pressure

Abstract. *Tetragonal zirconium oxide, stable at room temperature, was synthesized at 15 to 20 kb and 1200° to 1700°C. Rapid quenching produced a mixture of the monoclinic and tetragonal phases. The high-pressure specimens, when heated to 1200°C in air and quenched, reverted to the all-monoclinic form.*

Polymorphism in zirconium oxide has been the subject of considerable investigation since it was first reported by Ruff and Ebert (*1*). Several recent studies of the temperature range and character of the monoclinic-tetragonal phase transformation (*2–4*) as well as the preparation of high-density zirconia under high pressure have been described (*5*).

Monoclinic zirconium oxide powders (spectrographic grade, 99.95 percent pure) were prepressed at room temperature at 1 kbar. The green specimens were placed in a cylindrical device for reactions at high pressure and high temperature and pressed to 15 to 20 kbars at temperatures ranging from 1200° to 1700°C. The samples were held under these conditions up to 1½ hours, and then the specimens were cooled under pressure. The basic design of the apparatus has been previously described (*6*). The specimen cell was modified slightly. In place of the carbon–silicon carbide resistance heaters, ZT (National Carbon) grade graphite or platinum-rhodium (20 percent Rh) heaters were used. Pyrophyllite replaced mica as the outermost insulation, and boron nitride was used between the sample and the heater. This type of cell was very effective in maintaining integrity and temperature under pressure with a minimum of sample contamination. The temperature was measured with a Pt, Pt-Rh (10 percent Rh) thermocouple. Effective sample sizes were approximately 0.6-cm in diameter by 0.6-cm-long cylinders. The specimens made in this manner were white, very hard, with bulk densities close to theoretical.

The high pressure specimens were studied by x-ray diffraction with CuK$_\alpha$ radiation. The tetragonal phase is found as a mixture with the monoclinic phase. The results of emission spectrographic analysis are given in Table 1. The total impurity pickup from the specimen cell materials was less than 0.1 percent during a high pressure run for 10 minutes, and 0.5 percent during a high-pressure run for 90 minutes.

Table 2 shows a comparison of the diffraction patterns before and after the high-pressure treatment. Figure 1 is a micrograph, at × 2000, of the surface of a high-pressure specimen. The surface has been flame-etched with an oxyhydrogen torch for a few seconds. A 2-minute HF etch produced the same results but less definition of microstructure. The specimens were polished with a diamond paste (1 micron), and a large number of pullouts are evident when the surface is viewed under lower power. Under lower magnification, it is also apparent that the darker phase is predominant. The intensity of the x-ray lines shows that the monoclinic phase is the major one present. The white grains are of the tetragonal phase inside the monoclinic matrix. The appearance of cracking of the white grains would appear to support a shear type of mechanism for the transformation. Under the conditions of high temperature and high pressure applied, only the tetragonal phase is present. Upon rapid quenching the monoclinic phase is formed. Since the tetragonal phase is the denser phase and the transformation is slug-

Fig. 1. Micrograph of high pressure zirconium oxide (× 2000). White grains are tetragonal phase in monoclinic matrix.

Table 1. Impurity pickup by ZrO_2 specimens. The ZrO_2 was treated to 20 kb and 1700°C.

Impurity	Impurity (ppm) 10-min pressure	90-min pressure
Si	100	400
B	500	2000
Al	100	150
Fe	100	450
Ca	100	1000

Table 2. X-ray diffraction patterns of ZrO_2 subjected to high pressure.

*d*Å	Before and after (monoclinic) *hkl**	After only (tetragonal) *hkl**
3.69	011	
3.63	110	
3.16	111	
2.93		111
2.84	111	
2.63	002	
2.60	020	
2.54	200	
2.52		002
2.50	102	
2.33	021	
2.21	211	
2.19	$10\bar{2}$	
2.18	121	
2.02	$11\bar{2}$	
1.99	$21\bar{1}$	
1.85	022	
1.82	220	
1.81		200
1.80	122	
1.79		220
1.78	221	
1.69	300, $20\bar{2}$	
1.66	013	
1.64	130	
1.61	311, 310, $21\bar{2}$	
1.59	131	
1.58	222	
1.55		311
1.54	$13\bar{1}$	
1.53		222

* *h*, *k*, and *l* are rotation axes.