Model of the World Plate Tectonics since the Early Palaeozoic

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The pattern of palaeomagnetic curves with particular regard to the lower Palaeozoic epochs which was revised by a suitable choice of polarity of data for the individual continents is given. The investigated distribution of the continental blocks for the individual geological epochs agrees with all the palaeontological and geological facts. The comparison of the model of continental drift with the occurrence of orogenic events and some palaeontological conclusions was carried out.

1. Introduction

Thanks to the efforts of hundreds of specialists abundant material and data on palaeomagnetic poles for the individual geological epochs were accumulated through intensive palaeomagnetic research over several decades (RUNCORN, 1960; IRVING *et al.*, 1976; KHRAMOV, 1974; McELHINNY, 1973; CREER, 1970, and others). Nevertheless, the interpretations of the results obtained, in particular as regards the Lower and Middle Palaeozoic, were not fully successful and generated a great deal of doubt about the validity of the obtained palaeomagnetic poles, so that specialists from various fields, particularly some geologists, are still not fully convinced of the validity of some palaeomagnetic results.

According to TEICHERT and MEYERHOFF (1972) “the evidence disproves the widely held and widely believed concepts of a Pangaea, Laurasia, and Gondwanaland with a vast continental interior covered with continental deposits.”

MEYERHOFF (1970): “Today evaporites are deposited in two belts 10°–50° north and 10°–38° south of the equator. The results show that ancient evaporites were deposited as far north as 83°N and as far south as 39°S. However, palaeomagnetic studies have not helped to explain the presence of evaporites at high latitudes; they only make explanation more difficult. For example, if Irving’s latitudes are used, the latitudinal spread of evaporites is from 80°N to 71°S.

The spread of “reliable” poles on each continent is wider than the Atlantic Ocean where drift is supposed to have taken place. How, then, can the method be used to determine relative motions between continents?”

According to MEYERHOFF (1970), Martin also doubted the reliability of palaeomagnetic data for Africa and wrote that the placing of a Devonian pole on Africa is contradicted by the extensive development of Devonian coral reefs in West Africa and the

presence of Devonian evaporites in Ghana and North Africa.

According to MEYERHOFF (1970), "several palaeomagneticians arrived at conclusions which are unsupported by modern meteorology, climatology, physical oceanography, and plant geology.

This concerns also the distribution of late Palaeozoic glacial centres and middle Palaeozoic to Tertiary coal deposits. Those who advocate drift and/or polar wandering must provide a satisfactory explanation for these tillite and coal distributions to prove that new concepts of global tectonics are valid".

I think we should not ignore these and other comments but we should look for their explanation because only a positive discussion can improve our understanding with geologists.

2. Palaeomagnetic Polar Wandering Curves

The known curves for individual continents are given in Fig. 1a, b. We can see a big deviation of the Ordovician pole for North America and England as well as a big distance between the Ordovician and Silurian pole for Australia. Further (Fig. 2), the comparison of Ordovician results for North America (RUNCORN, 1960), Czechoslovakia (BUCHA, 1961, 1969), and Siberia (KHRAMOV, 1974) are given. The declinations for all three regions (130° – 145°) do not differ considerably, the dip is between $+25^{\circ}$ for North America to -25° for Czechoslovakia and -10° for Siberia. The Ordovician pole positions for North America, Europe, and Siberia were determined (Fig. 3a). After rotating, and shifting North America and Europe in such a way that all three poles coincided (see Figs. 3a, b, c) we can consider such a configuration as given in Fig. 3c to have existed in the past. When we rotate it in order to make the Ordovician paleopole coincide with the present geographic pole we obtain also the original orientation in the Ordovician (Fig. 3d). Our data from Czechoslovakia (BUCHA, 1961, 1969) showed a comparatively unusual pattern

Fig. 1. Palaeomagnetic curves expressing the apparent wandering of the north pole for the interval between the Cambrian and the present: a) ●— for Czechoslovakia (BUCHA, 1961), ○···· for Siberia (KHRAMOV, 1974), △----- for North America, ■— England, b) ○----- Africa, ■— Australia, □----- South America (McELHINNY, 1973).

Fig. 2. Plot of directions of magnetization of the Ordovician rocks from North America (Runcorn, 1960)—left-hand side, Czechoslovakia (BUCHA, 1961, 1969)—in the middle, Siberia (KHRAMOV, 1974)—right-hand side.

Fig. 3. Schematic configuration of the continental plates (North America, Europe, Asia) and the position of Ordovician poles. a) recent configuration, b) when identifying the North American with the European pole, c) when identifying the North American and European pole with the Asian (Siberian) pole, d) after identifying the joint Ordovician paleopole with the present geographical pole and after a simultaneous rotation of all the three continental plates. The data given in Fig. 2 were used to express the pole positions for North America, Europe (Czechoslovakia), Asia (Siberia) in the Ordovician.

in that they displayed the opposite direction to some of the curves then known for Europe and North America. For this reason we checked some of the results which were decisive for the pattern of the curve, particularly as regards the Lower Ordovician and the Cambrian (BUCHA, 1969). It was found that with an exception of a few smaller deviations, the original pattern of the curve remained unchanged, i.e. for the Cambrian it passes through Central America towards the east, then through South Africa into the Indian Ocean (Lower Ordovician), and from here towards Japan (Silurian) and then to the north (Fig. 4).

Our results from the territory of Czechoslovakia (BUCHA, 1961, 1965, 1969) indicated a possibility of showing that there existed a single ancient continent, the Pangaea, in the Lower Palaeozoic, including the Asian and North American continents in the overall configuration of all continents. However, one must bear in mind that the palaeomagnetic (averaged) poles representing the position of the geographic poles, are two in number and that the occurrence of reverse polarity, so frequent in the history of the geomagnetic field, prompts one to be careful in deciding which of the poles to adopt in constructing the palaeomagnetic curves of the individual blocks.

As regards the curve derived for Australia (Fig. 4), we considered all the early Palaeozoic data (McELHINNY, 1973) separately, i.e. early, middle, late Cambrian, early, late Ordovician, and not just the mean value; in this way, the big spread of Cambrian and Ordovician poles as objected by Meyerhoff can be reduced considerably. It is known that the Cambrian and Ordovician represent a time interval of more than 160 million years and therefore, it does not seem very probable that Australia and North America would have remained "put" in a single place over this long span of time. Then, the palaeomagnetic polar-wandering curve of the North Pole for Australia proceeds similarly to the cs curve, only slightly more to the north across present Africa (Cambrian–Ordovician) towards Siberia (Silurian) and then to the north. We consider the poles for the Cambrian and Ordovician to be north, so that the "polar-wandering" curve has a quite different pattern and is longer in the early Palaeozoic. However, in this connection the distance between the Ordovician and Silurian poles is shorter than in the connection given earlier.

The curve for Siberia, constructed from Soviet data (KHRAMOV, 1974) is then presented (Fig. 4).

The polar-wandering curve for North America (Fig. 4) displays an even longer trajectory than the European curve, determined by Czechoslovak palaeomagnetic data. Among other reasons, this is also due to the continent departing by 40° from Europe and Africa over the past 150 million years as a result of the relatively large speed of wandering of both Americas in the past.

Also the curve for England showing a similar pattern to the curve for North America is given (Fig. 4).

The set of curves for the 6 continental blocks (Fig. 4) indicates (BUCHA, 1975a, b) that they differ completely from the curves, hitherto published (Fig. 1). The Cambrian and Ordovician poles, located in the region of the present Atlantic and Africa were also considered as north for the southern continents (Australia, Africa), i.e. again with a polarity opposite to that employed by other authors. Moreover, it is evident that the distances between Cambrian and Silurian poles for Australia, Europe, Africa were shorter than those considered earlier.

The palaeomagnetic curves as given here have approximately the shape of spirals, converging on today's North Pole. The pattern of the African curve where Silurian values were not available—these should be considered tentative and should be shifted in such a way that Carboniferous pole coincided with the recent pole. It is interesting that none of the curves passes through the region of the present Mediterranean and North Africa, so that one may assume that this region is located approximately in the common centre of

Fig. 4. Set of new palaeomagnetic curves, expressing the apparent wandering of the north palaeomagnetic (geographic) pole for the interval between the Cambrian and the recent for Czechoslovakia, Australia, USSR (Siberia), North America, Africa, England: C—Cambrian, O—Ordovician, S—Silurian, D—Devonian, C—Carboniferous, P—Permian. Cambrian and Ordovician poles were taken with opposite polarity for Australia, North America, Africa and England to those given by McELHINNY (1973).

the whole set of curves mentioned (30°N , 30°E). This fact seems to be important for the further interpretation of the results obtained.

3. Palaeomagnetic Model of the Continental Drift since the Cambrian

In order to obtain an idea of the overall arrangement of the continental blocks and of their development in the course of the drift over the Earth's surface, the present shapes of the continents were not divided into more parts than the number of present continents. It is known, for example, that the European continent was divided into two or more parts (north and south), and that the Asian continent could similarly have been divided into several parts (north, east, south).

It was considered that the common centre of the curves was located in the present northeastern Africa and individual continents were gradually displaced by rotating them around this centre for all 12 periods since the Cambrian to the present (BUCHA, 1975a, b).

This distribution of the continents, determined for 12 intervals of time since the Cambrian to the present, expresses their configuration on the present Earth's surface as determined from the palaeomagnetic data in the present geographic network (Fig. 5).

It should be pointed out that this is a tentative rough configuration of the continents constructed by means of a graphical method of transformation, the more so because for some continents data from all geological epochs considered were not available; more accurate results are expected when computational methods are applied.

Figure 5 shows a similar angular velocity but different rates of motion of the continents; the most marked difference is between North America and Europe. Whereas North America moved 25,000 km over 600 million years, i.e. approximately 4–6 cm per year, Europe rotated with a velocity of 1–2 cm per year (approx. 9,000 km over 600 million years), Asia (Siberia) with a velocity of 2 cm per year. These data agree with the rate of the seafloor spreading determined by other methods.

It seems that the original ancient continent was located eccentrically in the region between the North Pole and the equator, and it, therefore, displayed a tendency to move towards the equator as a result of Eötvös's force. Because of this the Coriolis force began to act on the continent, westwards in the Northern Hemisphere; the ancient continent began to rotate clockwise. Its parts more remote from the centre of rotation (30°N , 30°E) had a tendency to move faster than the parts closer to the centre, and the continent gradually began to disintegrate, as can be seen in Fig. 5.

The continental drift is conditioned by the existence of the asthenosphere extending from a depth of 80 to 300 km in the Earth's mantle and characterized as a low velocity channel of seismic waves. The temperature of the mass here reaches almost the melting point and its viscosity is from two to three orders lower than that of the ambient layers. This magnitude (approx. 10^{21} poise) makes the mass behave as a rigid liquid towards the longterm acting forces. The lithospheric continental blocks, which display horizontal movements of several cm per year as a result of the above mentioned forces float on the asthenosphere.

Fig. 5. Schematic configuration of the continental plates on the Earth's surface in the present geographic network: ϵ_l —lower Cambrian, ϵ_m —middle Cambrian, ϵ_u —upper Cambrian, O_l —lower Ordovician, O_u —upper Ordovician, S_l —lower Silurian, D_l —lower Devonian, C —Carboniferous, P —Permian, J —Jurassic, C_r —Cretaceous. The arrows indicate the direction of motion of the individual continents and * denotes the approximate common centre of rotation around which most of the continents rotated. The distribution of ancient evaporites for individual geological periods is marked as white areas and dotted curves (MEYERHOFF, 1970).

4. Continental Drift and Orogenic Processes

The proposed system of development of tectonic blocks allows one to express certain ideas of the possible causes of the orogenes on the Earth's surface. We know that the orogenic processes in the individual geological periods displayed different intensities over the past 600 million years as can be seen from Fig. 6.

Fig. 6. Reversals of the polarity of the Earth's magnetic field and orogenic events measured as percent regression from a smooth curve passed through the peaks of marine transgression (DAMON, 1971).

The comparison of the model of continental drift (Fig. 5) with the occurrence of orogenesis (Fig. 6) implies the following conclusions (BUCHA, 1975b).

In the Cambrian and Ordovician, the Pangaea gradually opened up and the "southern" continents were shifted into the region of the present Pacific Ocean. No significant collisions between the continents occurred at the time so that the orogenic activity during these periods was also relatively low.

During the Upper Ordovician and the Silurian North America collided with Europe and this was reflected in the strong Caledonian folding.

At the end of the Devonian and in the Carboniferous the southern continents approached the Eurasian block, Europe collided with Africa from the south and tectonic processes carried on as a result of the faster shift of North America along Europe from its western side. Figure 5 implies that the southern continents and North America moved together between the Cambrian and Permian. The result of the extensive collisions between the Lower Carboniferous and the Upper Permian was the intense Hercynian folding, the creation of the Ural and other orogeneses.

In the Upper Devonian North America collided with the north-eastern part of the Asian continent and this was responsible for the considerable deceleration of the motion of North America and of the southern continents, and also affected the intense Hercynian orogenesis, terminated in the Lower Triassic. These extensive tectonic processes also apparently had a decisive effect on the disintegration of the southern plate into several smaller tectonic units and, together with other forces (Eötvös and Coriolis) caused Africa, India and Australia to shift from the South Pole towards the north-east at a relatively high speed after the separation.

No very significant collisions between the continental blocks occurred during the Mesozoic and, therefore, also the orogenic activity was relatively low.

After the approach and collision of moving Africa and India with the slowly rotating Eurasian continent at the end of the Cretaceous and the beginning of the Tertiary, the very marked Alpine, Caucasian and Himalayan foldings took place along the whole Tethys zone.

5. Comparison of the Proposed Palaeomagnetic Model with Palaeontological Data since the Cambrian

The proposal for the model of the dynamic system of the world-wide plate tectonics and of its developments, presented here and in BUCHA (1975a, b) agrees with all palaeontological facts about the occurrence of warm climate (coral reefs, evaporites, coal deposits) and about the glaciations.

According to PALMER (1972), the present distribution of Cambrian trilobite fauna is inconsistent with a static concept of world geography during Phanerozoic time (Fig. 7). During the Cambrian, Mexico and its faunas of European affinities are at the high latitude end, typical American faunas across the United States are in the intermediate latitudes, and Alaska is in lower latitudes (Fig. 8). This complies with our model of tectonic blocks in the Cambrian (see the position of North America in Fig. 5).

Now to the objection of MEYERHOFF and TEICHERT (1971) that the new global

Fig. 7. Map of the continental plates showing occurrences of fossiliferous Cambrian rocks and distribution of restricted shelf margin-open ocean regions (PALMER, 1972).

Fig. 8. North America showing relationship of paleolatitudes to distribution of restricted shelf faunas and shelf margin-open ocean faunas in the Cambrian (PALMER, 1972).

tectonics fails completely to explain the distribution of late Palaeozoic glacial centers and middle Palaeozoic coal deposits.

Our model shows that the southern continents were not always at the same place during the Carboniferous and Permian, but moved from the South Pole to the northwest (see Figs. 5 and 9). At that time the Antarctica moved from the South Pole, together with the whole Gondwanaland by approximately 30° northwards. Further one has to take into consideration that the configuration of the southern continents was different than that given by MEYERHOFF (1970), particularly as regards the position of the Antarctica. That's why the South Pole was not in the centre of the Gondwanaland either but on its border (see Fig. 9); this means that the major glacial centres in the Carboniferous were not too far inland and enough moisture could have reached them (Fig. 9).

Coal deposits could not originate on the territory of Antarctica and Australia during

Fig. 9. Distribution of glacial centers in the Carboniferous (MEYERHOFF, 1970).

Fig. 10. Distribution of coal basins. C—in the Carboniferous, P—in the Permian (MEYERHOFF, 1970).

the Carboniferous because both these continents were near the South Pole at that time (Fig. 10). On the other hand, in the Permian, after the shift of both continents towards the equator, favourable conditions for coal deposits were created—in the Permian both continents had average geographical latitude of 45° – 60° S. Glacial centres originated mainly in the Carboniferous. The Carboniferous continental glaciation and the Permian mountain glaciation could be mingled and intermixed.

The distribution of receptaculitids indicating the position of the tropical belt in the (Lower) Palaeozoic (Fig. 11) conflicts according to NITECKI (1972) with the prevailing palaeogeographic interpretation of the position of the equator and the poles relative to

Fig. 11. The geographic distribution of receptaculitids. The assumed position of the palaeo-equator is indicated by the heavy line (NITECKI, 1972).

the continents during the Palaeozoic.

Our model can also explain all these conclusions (compare Fig. 5 with Figs. 7 and 11) because the continents of Australia, Northern Asia, the Antarctica, the western part of North and South America and Europe were either on the equator or close to it during the Lower and Middle Palaeozoic.

According to TEICHERT and MEYERHOFF (1972) "the evidence disproves the widely held and widely believed concepts of a Pangaea, Laurasia and Gondwanaland. The few faunal-realm studies which have been made show clearly that Asia has been connected to North America via the Bering Strait, and probably via the Novaya Zemlya-Lomonosov Ridge and Spitzbergen-Greenland, since the late Devonian. The conclusion is demonstrated by the fact that the faunal realms of Europe grade eastward and northward into those of northwestern Asia and North America".

In considering our configuration of continents in the Devonian (Fig. 5) we can see that it complies with Meyerhoff's and Teichert's conclusions. Our model shows that Pangaea existed in the Cambrian (and also in the Precambrian); it disproves, however, the concept of Laurasia and Gondwanaland, as presented in some older palaeomagnetic models.

The direction of motion of the individual continents towards the pole near Hawaii in our model complies with Jeffreys' conclusions.

Our model also explains the ancient distribution of evaporites by the gradually changing configuration of the continents as given in Fig. 5. This correlation of our model with the evaporite data shows that their distribution corresponds to the belts along the equator for all geological periods as given by MEYERHOFF (1970).

Thus, we can see that this interpretation of the palaeomagnetic data, (Fig. 5), can answer and explain practically all palaeontological and palaeoclimatological data.

There are not enough palaeomagnetic data for the Ordovician and Silurian which seem to be decisive for the definite course of the polar wandering curves, mainly for Europe, South and North America, Africa and the Antarctica. Palaeomagneticians should concentrate their efforts on this important question, the solution of which could help considerably in explaining the configuration of the continents in these geological periods in more detail.

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