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Express Letter

True polar wander during the middle Paleozoic?

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Abstract

True polar wander would be recognized paleomagnetically as identical apparent polar wander paths for all surface elements. The apparent polar wander paths for the Late Ordovician–Late Devonian interval for Laurentia, Baltica and Gondwana have nearly identical looping shapes that can be brought into superposition. The paths of these continents are well documented, but even the less well known paths of South China and Siberia reveal similar lengths. The resulting reconstruction places the northern Andean margin of South America opposite the Appalachian margin of Laurentia, with Baltica and Laurentia adjoined in the fit of Bullard and colleagues. Siberia and South China would be to the north of Africa, if their paleopoles are taken at face value. For middle Paleozoic time, there is of course no information about oceanic domains, but it is interesting that all continental elements, insofar as is known, appear to have similar apparent polar wander tracks that can be plausibly superimposed without causing overlap in the positions of the continents. Albeit speculatively, because of the lack of information about the oceanic elements, it is suggested in this study that true polar wander may have occurred with a cumulative magnitude of about 75° during a 75 Ma interval, and may have been of greater magnitude than the apparent polar wander due to relative motions during the middle Paleozoic. This middle Paleozoic rate of true polar wander appears to have been an order of magnitude greater than the average rate during the late Mesozoic and Tertiary.

1. Introduction

When Earth's inertia tensor contains non-zero off-diagonal elements with respect to a coordinate system fixed to the rotation axis, its body reorients itself in order to reduce the off-diagonal components to zero by bringing its maximum principal moment of inertia into alignment with the rotation axis [1–3]. This shift in the position of the main body of the Earth with respect to the rotation axis is called true polar wander (TPW). If the assumption of a geocentric, co-axial geomagnetic dipole field is granted, TPW would manifest itself paleomagnetically in apparent polar wander paths (APWP's) of all surface elements that are similar [4–6], provided that the magnitude of the TPW is much greater than that of the relative plate motions. TPW can also be identified with respect to other frames of reference, such as the hotspot framework [7–9,30]. Studies for Cretaceous and later times have revealed minor TPW of the order of a few tenths of degrees per million years [5,10–12], although some fast rates have been postulated for intervals of short duration [9,30].

For TPW determinations, knowledge is needed about the movements of the surface elements

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Table 1
South paleopoles from the major continents

Continent	Late Ordovician (~ 450 Ma)	Siluro-Devonian (~ 408 Ma)	Late Devonian (~ 372 Ma)	Reference
North America	−16/324	− 3/277	−28/291	[13]
Baltica	−10/ 10	− 3/315	−27/329	[13,14]
Gondwana (Africa Coord.)	25/356	−30/356	−11/ 11	[13]
Siberia	22/310	−20/322 *	**	[13]
South China	39/ 56	**	9/ 10	[16]
North China	29/311	**	−34/ 49	[31]

* Pole position is estimated as between the mean Silurian and the mean Early Devonian pole. ** No paleopole position given because of suspicions about remagnetizations [13] or lack of data [16,31]. Paleopoles of Baltica can be rotated into North American coordinates using the parameters of Bullard et al. [15]; paleopoles in North American coordinates have been rotated into African coordinates in Fig. 1 about an Euler pole at 14.6°N, 324.3°E, angle 115.2° counterclockwise.

(plates) with respect to the reference framework (hotspots or dipole axis). For paleomagnetically determined TPW this includes the oceanic elements [5–6] and this *a priori* precludes a rigorous application of the analysis methods to pre-Cretaceous times. However, even without knowledge about oceanic APWP's for early Mesozoic or older intervals, it is possible to assess whether TPW is a possibility, and this paper intends to explore this possibility for the middle Paleozoic.

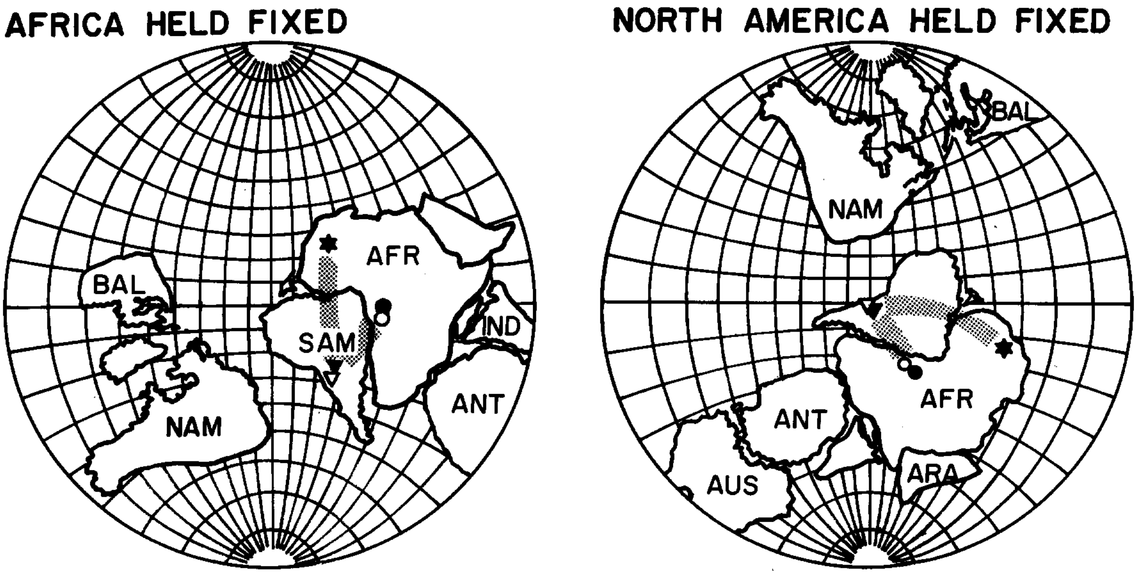

Fig. 1. Continental reconstructions in African and North American coordinates with the Late Ordovician-Silurian-Devonian apparent polar wander paths of Gondwana and Laurentia superimposed (for rotation parameters and paleopole data, see Table 1). The mean Late Ordovician paleopoles of Laurentia and Gondwana have been made to coincide (★). Siluro-Devonian boundary poles (△ ▲) and Late Devonian paleopoles (○ ●) are shown for Gondwana as open symbols and for Laurentia as closed symbols. Baltica's paleopoles (not shown) are nearly identical to Laurentia's after closing the present-day Atlantic Ocean. Data from Siberia and South China are not shown because of their scarcity (see Table 1), but these continents would be placed to the north and northeast of Africa's north coast in African coordinates.

2. Middle Paleozoic apparent polar wander for the major continents

Mean paleopoles for the Late Ordovician–Late Devonian interval (approximately 450–370 Ma) of the major continents are summarized as south poles in Table 1. Between the Late Ordovician and the Siluro-Devonian boundary all APWP's show approximately 50° of change. For Laurentia [13] this shift implies a counterclockwise rotation and southward movement. For Baltica [14], including the southern British Isles, the pole shift is nearly identical to that of Laurentia when the Atlantic Ocean is closed with the parameters of Bullard et al. [15]. During the Devonian, the pole moves in the opposite direction with respect to both continents held fixed and shifts by about 25°. With respect to Africa held fixed, the Gondwana APWP also shows two tracks [13] nearly identical in length to those of Laurentia and Baltica: from the Late Ordovician to the Siluro-Devonian boundary the south pole moves from Morocco to northern Chile, followed by an approximate backtracking towards a Late Devonian paleopole position near western Zaire. In Fig. 1, the APWP's for these three continents have been superimposed and are shown in African and North American present-day coordinates.

Only three other major Paleozoic continents, now incorporated into Asia, have existed and therefore need to be examined. The APWP's of South China and North China are based on scant paleopole information [16,31], but they show similar or even greater magnitudes of pole shifts between Ordovician and Devonian times (Table 1). For Siberia, several paleopoles are available, but suspicions remain about possible remagnetizations of the Devonian rocks [13] that render a rigorous analysis impossible. Even so, it is noteworthy that Siberia too appears to have had a similar magnitude of pole shift (Table 1). The APWP's of smaller displaced terranes (e.g., Avalon, Armorica, Iran, Indo-China and Tarim) are too incompletely known to be included in the analysis.

Not only are the APWP's of Table 1 and Fig. 1 of the same length and overall shape, their temporal calibration along the tracks is very similar when taking stratigraphic and geochronological data into account. The only exception to this has been, until recently, the age of the paleopole from the Aïr Ring Complexes in Niger [17], which was based on $^{40}Ar/^{39}Ar$ ages of about 435 Ma. The paleopole location of these complexes, off the coast of southern Chile (to the south of the apex of the common APWP of Fig. 1), and the Early–Middle Silurian age of the paleopole, does not agree with the age of about 405 Ma for this apex as predicted from paleopoles for Australia, Laurentia and Baltica. However, the age of about 435 Ma may not be representative of the complexes: recent Rb-Sr isochron data for several complexes yield 407 ± 8 Ma [18,32], which agrees well with the predictions from the other continents.

A condition for an interpretation of the common APWP of Fig. 1 in terms of TPW is that the paleopole determinations must represent a geocentric, co-axial dipole field (i.e., that the rotation axis and the dipole axis of the Earth were roughly coincident). While this condition can only be tested in approximate ways, paleolatitudes estimated from sedimentary facies agree well with paleomagnetic studies for North America [13,19] and with the Ordovician–Silurian APWP track of Gondwana [13,20]. For Devonian–Early Carboniferous time, the Gondwana paleofacies analysis of Scotese and Barrett [20] yields paleopole estimates that deviate from the APWP loop [13,21] of Fig. 1 through central Africa, but these authors did not take Late Devonian and Early Carboniferous glacial relicts in western Africa [22,23] into account.

3. Discussion

The APWP's of all continents, insofar as is known, show tracks with similar lengths for the Late Ordovician–Late Devonian interval. When these APWP's are superimposed, paleoreconstructions are obtained (Fig. 1) that are very similar to recent proposals in which Laurentia rifts off from the Andean margin of South America in the earliest Paleozoic, followed by a drift pattern of Laurentia in a progressively clockwise pattern around South America [24–26]. The North America–Gondwana reconstruction of Fig. 1 is different from conventional middle Paleozoic maps [e.g., 13,23] only in terms of relative longitudes: the conventional maps typically had the Appalachian margin of Laurentia facing the northwest African margin, because it is these two margins that eventually collided in the Carboniferous. If Siberia and South China are included in the reconstruction, they would be placed to the north and northeast of the present-day north coast of Africa, but note that there are large uncertainties in their paleopoles. That a reconstruction without continental overlap is obtained is encouraging, and suggests the possibility that all continents drifted in unison with respect to the pole in this interval. It cannot be ascertained whether the oceanic areas of the middle Paleozoic world joined in this common drift, but if they did, TPW did occur. Yet, even without knowledge about the movements of middle Paleozoic oceans, TPW is a distinct possibility.

Even if TPW occurred, it is clear from the middle Paleozoic evolution of many continental margins that relative movements between them must also have occurred. Thus, I am not arguing for a single middle Paleozoic supercontinent. The latest Ordovician–Late Devonian interval is the time of the Caledonian and Acadian orogenies in the North Atlantic domain: Continent–continent convergence and collision and displaced terrane accretion are likely to have caused these orogenies. Hence, the postulate of TPW for this time does not imply that APW due to relative motions is not a constituent of the pole paths, but only suggests that TPW may have been of larger magnitude than APW.

It may be of interest to speculate on the causes of such TPW with rates of about 1°/m.y. (for a duration of 75 m.y.), but the lack of knowledge about mass distributions and anomalies in the middle Paleozoic Earth prevents this. Continental and oceanic lithospheric plates do not themselves provide sufficient density contrasts on a spherical Earth [27], but hotspots and subduction zones do [28]. Deglaciation of large ice caps may also have a significant effect on the moment of the inertia tensor, and there were widespread Late Ordovician glaciations in Africa. Anderson [29] has argued that supercontinent assemblies cause pent-up heat in the underlying mantle, which in turn causes geoid highs. The density anomalies producing these geoid highs "control the location of the rotation axis" [29] and tend to move to the equator. Supercontinents, then, would tend to flee the polar regions. It is difficult to assess whether this mechanism could apply to the middle Paleozoic, because, as already mentioned, the reconstruction of Fig. 1 is not thought to represent a supercontinent. However, for the Late Carboniferous–Late Triassic interval, when almost all the continents were assembled and drifted in unison (TPW?), Pangea's center of mass appears indeed to have moved towards the equator.

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