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A ~90° Late Silurian–Early Devonian apparent polar wander loop: The latest inertial interchange of planet earth?

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Abstract

Although rates of true polar wander have been small during the last 200 Myr of geological time primarily due to the slow response of the viscous lower mantle, it is possible for the Earth's rotation axis to move rapidly to the equator if mass perturbations within the interior cause the maximum and intermediate inertial axes to cross. Rotation of the silicate Earth is then recorded by a ~90° arcuate sequence of palaeomagnetic poles embracing a time interval of <20 Myr. An apparent polar wander loop (APW) of this length and duration is recorded by Silurian–Devonian palaeomagnetic data from two separated regions (the Caledonides and Gondwana) and is suggested by less well-constrained results from other continental blocks. The Caledonian and Gondwana data appear to identify a short term interchange of the Earth's inertial axes during the interval ~410–390 Ma and yield a conventional continental reconstruction highlighting pending collision between Laurentia and the western margin of Gondwana near the Silurian–Devonian boundary to isolate the Rheic Ocean. This APW loop was accompanied by the extinction of successive oceans and occurred during, or shortly before, continental collisions between Gondwana, Laurentia, Baltica and Siberia to form the bulk of the supercontinent Pangaea. The implied rapid translation of the outer Earth resulting from transient modification of the Earth's figure is therefore most plausibly related to the avalanching of long lithosphere slabs into the lower mantle. The inertial interchange appears to be recorded by contemporaneous sea level changes although more refined stratigraphic data are required to confirm this.

Keywords: Palaeomagnetism; Silurian; Devonian; Caledonides; Gondwana; Inertial Interchange True Polar Wander

1. Introduction

The major feature of the Earth's equilibrium figure is an equatorial hydrostatic bulge with an amplitude of ~20 km resulting from the influence of gravity on the rotating planet. Migration of the spin axis causes the bulge to adjust over ~10^3–10^4 yrs, a time scale of asthenosphere adjustment specifically identified from post-glacial rebound [1]. On much longer time scales density heterogeneities in the mantle rise and fall by buoyancy and perturb the non-hydrostatic inertia tensor of the Earth. This causes the lithospheric shell to migrate relative the spin axis forcing positive mass anomalies towards the equator in order to realign the maximum principal inertia axis (I_{max}) with the rotation axis [2]. The spin axis and hydrostatic bulge remain fixed in a celestial reference frame while the lithospheric shell is deformed through the equatorial bulge as though it were moving through a standing wave [3–5].

True Polar Wander (TPW), is recognised palaeomagnetically as a component of apparent polar wander (APW) common to all plates which contrasts with

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diverse motions resulting from plate tectonics [6–8]. Knowledge of the oceanic elements and the quality of the continental palaeomagnetic record allow the TPW contribution to APW to be reliably resolved back to the Jurassic [8]. It is more difficult to recognise during earlier epochs due to the absence of preserved ocean crust. Relatively small amounts of TPW identified during the past 200 Myr total some 30° [8] and are comparable to TPW inferred from modelling studies using density and rheological properties of the Earth's interior [7]. Since the viscosity of the lower mantle is the most important factor controlling TPW, this presumably reflects the sluggish rate of change of the Earth's internal density structure [9].

However, much more rapid TPW may be possible if density perturbations cause the Earth's principal inertia axes to interchange [10]. When the maximum principal axis (I_{max}) becomes less than the intermediate axis (I_{int}) the entire silicate Earth could rotate rapidly over the liquid outer core by 90° to align the new I_{max} with the spin axis and produce Inertial Interchange True Polar Wander (IITPW). If the interchange between I_{max} and I_{int} is merely transient, successive rotations in the opposite sense result and define a ~90° APW loop. Since continental blocks furthest from I_{min} undergo the largest latitudinal movement, the pole to the great circle defines the I_{min} axis [11]. The interval required for inertial interchange depends on the time periods taken for (i) the non-hydrostatic mass anomaly to develop and (ii) the resulting rotational bulge to readjust to the changing rotation axis. The present day viscosity structure of the Earth has been used to argue for the duration between 3 and 20 Myr [12].

Although IITPW has long been acknowledged to be a likely feature of Earth dynamics [4,13] it has only recently been invoked to explain extraordinary APW. Kirschvink et al. [10] proposed that rapid motions of major continental blocks during the Early–Middle Cambrian times resulted from IITPW. This interpretation is controversial [14] and Meert [15] argues that Cambrian continental motions were non-synchronous and nowhere approached the ~90° motions required by IITPW. However a later time interval near the Lower–Upper Palaeozoic boundary has already been identified as a possible interval of TPW by Van der Voo [16] who suggested that APW paths recognised in Laurentia, Baltica and Gondwana were identical loops recording ~75° of TPW (Fig. 1). I show here that the expanded palaeomagnetic database supports this interpretation; furthermore since this event can now be shown to incorporate ~90° of polar motion constrained to a narrow timeframe, it actually appears to record IITPW.

2. Silurian–Devonian apparent polar wander: the record in the Caledonides

The sequence of events leading to the welding of Laurasia and formation of the northern wing of Pangea was initiated in Late Ordovician times by collision of Baltica and Laurentia in the Grampian orogeny [17]. Succeeding orogenesis included the collision of Western Avalonia with Laurentia (Taconic Orogeny), Siluro-Devonian (Acadian) Orogeny linked to the "soft" collision with Gondwana [18], and a lengthy regime (at least Late Silurian to Carboniferous) of major strike slip between Laurasia, Avalonia and Gondwana [19]. Rock suites produced during these events include Early Silurian to Devonian granite and alkaline intrusions and basaltic–andesitic volcanic suites, with emplacement accompanied, and followed, by Late Silurian through Late Devonian molasse sedimentation. Widespread palaeomagnetic investigations of these suites, particularly within the British Isles, provide the most temporally concentrated Palaeozoic dataset. Fig. 2 (inset) shows the tectonic framework embracing the bulk of these results. Palaeomagnetic data from rocks emplaced during the Late Ordovician subduction identify subsequent rotations between the blocks of this tectonic collage [20] although tectonic boundaries established during the

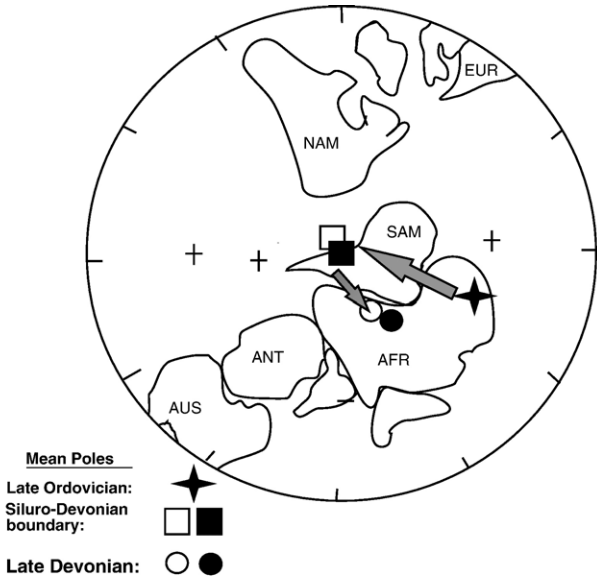

Fig. 1. A continental reconstruction in North American coordinates derived by superimposing Late Ordovician to Devonian APW paths from Gondwana and Laurentia after [16]; mean Late Ordovician palaeomagnetic poles have been fixed to yield this reconstruction. This was the first suggestion that APW paths of the continental blocks included a common component of motion resulting from TPW during Silurian and Devonian times.