Large continental rotations during Vendian and Palaeozoic times: a simple geodynamic explanation

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Calculation of latitudinal plate velocities from palaeomagnetic data has attracted considerable interest in recent years. Palaeomagnetic data from Baltica, Gondwana and Laurentia suggest that plate velocities during the Late Precambrian and Early Phanerozoic exceed those observed for large continental plates today (Torsvik et al. 1992, Meert et al. 1993, Gurnis & Torsvik 1994).

Rotations of large plates have received less attention, and in many traditional palaeo-biogeographic plate reconstructions (e.g. McKerrow et al. 1991), plates are positioned in palaeolatitude but to a large extent treated as 'static' non-rotational blocks. Given the axial dipole field hypothesis, palaeomagnetic declination data provide a unique measure of the angular rotation of a plate and any declination deviation from the present north-south meridian implies rotation of the plate since the time of remanence acquisition. In this account I address the importance of angular rotations recorded for *large* continental plates during the Late Precambrian and Palaeozoic, present a simple geodynamic model and briefly discuss their bearing on palaeogeographic and palaeotectonic modelling.

Apparent polar wander (APW) paths for Baltica ('Europe' from Permian times) and Laurentia ('N. America') were produced for Late Riphean-Early Tertiary and Vendian-Early Tertiary times, respectively. Minimum latitudinal drift velocities and angular rotation rates were subsequently calculated for specific reference

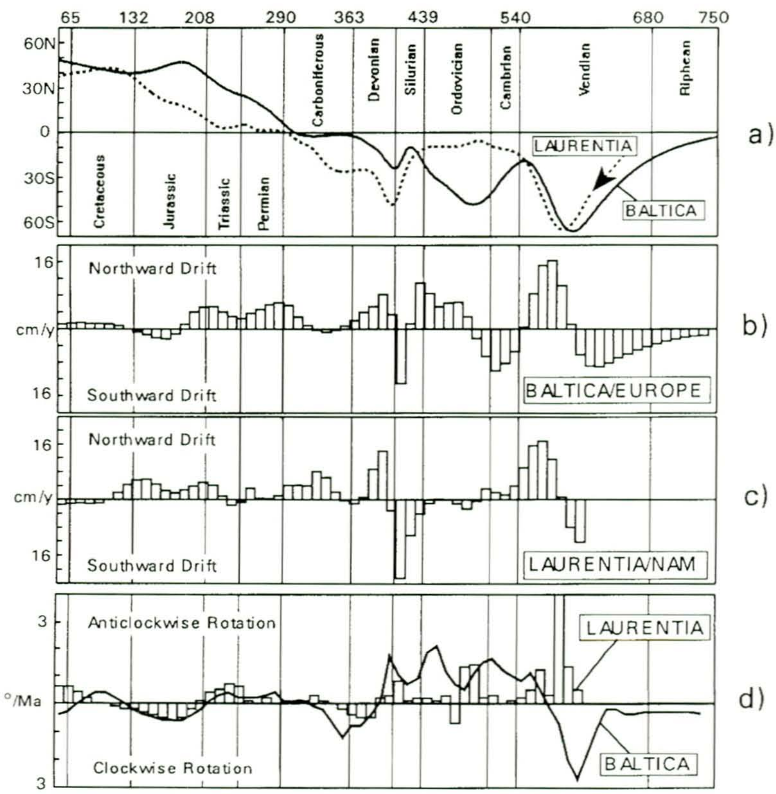

Fig. 1: (A) Latitudinal drift-curve for Baltica-Europe (reference location 60°N, 10°E) and Laurentia-North America (NAM)(reference location 40°N, 270°E). (B) and (C): Latitudinal drift rates for Baltica and Laurentia separated into southward and northward movements. (D) Angular rotation rates separated into clockwise and anticlockwise rotations for Baltica and Laurentia.

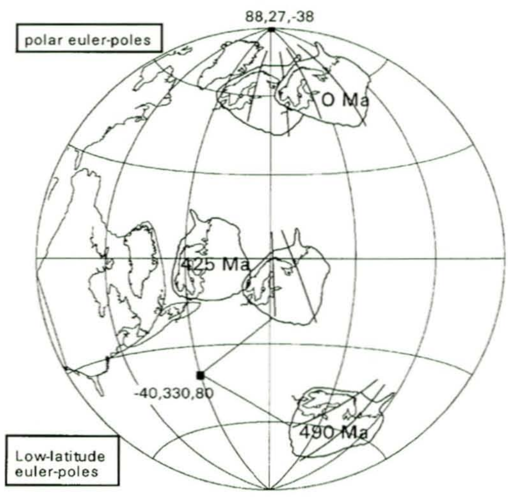

Fig. 2: Example of angular rotation (rotation of a palaeo N-S meridian) with low- and high-latitude Euler-pole geometries. The low-latitude example (Euler pole = 40°S & 330°E; Euler rotation = 80°) aims to explain Baltica's approach towards low latitudes during the Ordovician while undergoing large anticlockwise rotations subsequent to its collision with Laurentia in Mid-Silurian times (c. 425Ma). The high-latitude Euler pole example (Euler pole = 88°N & 27oE; Euler angle = 38°) demonstrates the lack of rotation of the palaeo-N-S meridian for Baltica while keeping Laurentia fixed.

locations on both continents (Fig. 1). High, pre-Mesozoic, latitudinal plate velocities indicated from these APW paths are detailed in Gurnis & Torsvik (1994) and in this account we emphasize the large, up to 4°/Ma, but also long-lasting (tens of Ma) angular rotations in pre-Carboniferous times (Fig. 1). Laurentia showed a large component of anticlockwise rotation, up to 4°/Ma, during Vendian times, coinciding with rapid northward drift (up to 18 cm/yr.). Subsequently, during most of Cambro-Ordovician times, Laurentia remained stationary in low equatorial latitudes and both drift rates and angular rotations were mostly low. Baltica also showed a burst in angular velocity but in a clockwise sense during Vendian times and it is evident that Baltica and Laurentia were separate continental units at this time. A spectacular and long-lasting anticlockwise sense of rotation is seen throughout Cambro-Ordovician times for Baltica. It is further clear that these rotations are linked with periods of large latitudinal movements (Fig. 1).

The movement of a plate on the Earth's surface can be described by a rotation about an Euler pole. The location of the Euler pole in relation to the plate will determine the balance between rotation of the palaeo N-S meridian (i.e. the magnetic declination vector) and latitudinal translation. For example, no angular change in the magnetic meridian would be observed if the Euler pole were located near to the geographic (and magnetic) pole. An example of this is the Euler pole geometry controlling the Tertiary opening of the North Atlantic. Indeed, except for parts of the Indian ridge, the majority of the present-day ocean ridges trend north-south, indicating plate movements with high-latitude Euler poles. Accordingly, only small rotations of plates are observed today. For example, the Eurasian and North American plates rotated little during most of Cenozoic times, except for local block rotations along converging margins. Large rotations of Baltica and Laurentia may partly have resulted from 'in-situ' local rotations dependent on plate boundary conditions (e.g. oblique convergence/asymmetric rifting). However, it is advocated that a controlling pattern of low-latitude Euler poles (Fig. 2) may have been the dominating mechanism during Vendian and Early Palaeozoic times. The predominating ocean during the Early Palaeozoic, Iapetus, had a dis-

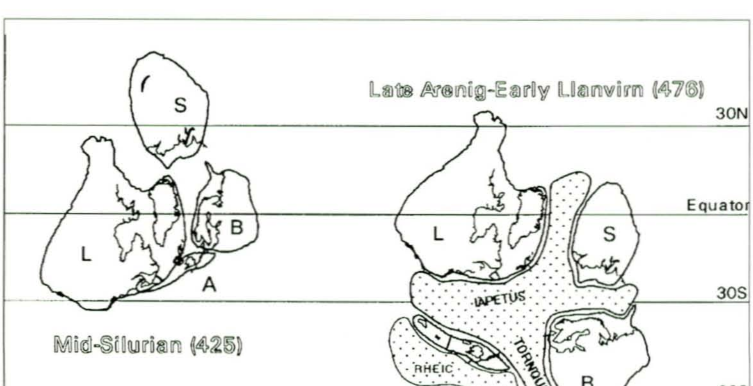

Fig. 3: Palaeoreconstruction of Baltica, Laurentia, Avalonia and Siberia (inverted) which demonstrates that the Scandinavian Caledonides (Baltica) probably faced Siberia during the Early Ordovician and that the same margin collided with a different continent (i.e. Laurentia) in Mid-Silurian times due to anticlockwise rotation of Baltica in the intervening period.

tinct palaeo-N-S closure history. Whilst Laurentia was located in a stable equatorial position, the Iapetus Ocean probably closed by the northerly drift of formerly high-latitude plates (e.g. Baltica & Avalonia) during Ordovician and Early Silurian times. Both Baltica and Avalonia show evidence for large anticlockwise rotations during the Ordovician, the two plates having merged during the Late Ordovician. The two ultimately collided with Laurentia during Early-Mid Silurian times (c. 425 Ma) to produce the Scandian Orogeny. Large and long-lasting pre-collisional rotations probably had low-latitude Euler poles. The first-order correlation between latitudinal movement and rotation (e.g. during the Ordovician for Baltica, Fig. 1) favours such a model.

Large angular rotations and an inverted palaeo-orientation of Baltica during Early Ordovician time (Fig. 3) question traditional theories of orthogonal relationships of Baltica and Laurentia across a single Iapetus Ocean throughout the Caledonide evolution (Stephens & Gee 1985). Torsvik et al. (1994) argue that subduction-related, eclogite-facies metamorphism in Latest Cambrian/Early Ordovician time in the Scandinavian Caledonides occurred in an ocean-continent transition zone that was marginal to Baltica but facing northern Siberia rather than Laurentia. Subsequent anticlockwise rotation and northward drift of Baltica ultimately produced the Scandian collision between Baltica and Laurentia (Fig. 3).

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