The closure of the Iapetus Ocean and Tornquist Sea: new palaeomagnetic constraints

A. TRENCH and T. H. TORSVIK

Journal of the Geological Society 1992; v. 149; p. 867-870
doi: 10.1144/gsjgs.149.6.0867

Notes
The closure of the Iapetus Ocean and Tornquist Sea: new palaeomagnetic constraints

A. TRENCH & T. H. TORSVIK
1Department of Geology, University of Western Australia, Nedlands, Perth, WA 6009, Australia
2Geological Survey of Norway, PB 3006 Lade, N-7002 Trondheim, Norway

Early Wenlock volcanic rocks from the East Mendips inlier, SW England, yield primary palaeomagnetic directions which indicate that southern Britain (Eastern Avalonia) occupied a palaeolatitude of 13 ± 5°S in Mid-Silurian (430 Ma) times.

When combined with coeval data from Laurentia, the southern Laurentian margin (Scottish terranes), and Baltica, the collective data indicate that: (1) the British and Scandinavian sectors of the Iapetus Ocean were closed, to within the limits of the palaeomagnetic resolution, by the Early Wenlock; (2) Acadian deformation across Britain, which culminated in Early Devonian time, post-dated initial docking of Eastern Avalonia and Laurentia; (3) a previous palaeomagnetic requirement for the Tornquist Sea to remain open into Mid-Silurian times is removed, thereby reconciling palaeomagnetic and biogeographical constraints upon the convergence of southern Britain and Baltica.

Recently-acquired palaeomagnetic data from southern Britain and Baltica have facilitated more reliable reconstructions of the early Palaeozoic palaeogeography of Northern Europe (Fig. 1). Palaeomagnetic data now record the progressive drift of southern Britain across the Iapetus Ocean during Ordovician times (Torsvik & Trench 1991; Channell et al. 1992) and a predominant northward drift and counterclockwise rotation of Baltica from Cambrian to Devonian times (Torsvik et al. 1991a, 1992a; Perrout et al. 1992). Nevertheless, details on the closure history of the Iapetus Ocean and Tornquist Sea (Fig. 1) have remained sketchy due to a paucity of coeval Late Ordovician–Mid-Silurian data from the bordering continents. These palaeomagnetic uncertainties permit competing geological models.

In this contribution, we address two outstanding problems relating to the closure of the Iapetus Ocean and Tornquist Sea. First, the destruction of the Iapetus Ocean across Britain (i.e. the collision of Eastern Avalonia with Laurentia) has been suggested on geological and palaeomagnetic grounds to have occurred in Late Ordovician (Murphy 1987; Pickering et al. 1988), Silurian (Soper & Woodcock 1990; Soper et al. 1992) or Early Devonian times (Leggett et al. 1983; Soper & Hutton 1984; Torsvik 1985; Soper et al. 1987; McKerrow 1988; Woodcock et al. 1988). Palaeomagnetic data have yet to provide a definitive solution to this problem as the only Silurian results from southern Britain, Upper Llandovery and Lower Wenlock volcanic rocks of the Mendips (Piper 1975), were derived using alternating field demagnetization and limited analytical techniques. Recent studies in the Welsh Basin (summarized by Channell et al. 1992) have shown that these analytical methods, which were common practice in the 1970s, are unlikely to have completely resolved multi-component magnetizations within lower Palaeozoic rocks.

Secondly, recently-reported Silurian palaeomagnetic data from Baltica (Douglass 1988; Trench & Torsvik 1991a) imply oceanic separation from southern Britain in the order of 1000–1500 km in post-Wenlock times. This apparent separation post-dated Ordovician times when Baltica and southern Britain drifted northward through comparable latitudes (Fig. 2). Mid-Silurian separation of Baltica and southern Britain also contradicts biogeographical evidence indicating Late Ordovician proximity of these continents (Cocks & Fortey 1982, 1996; McKerrow & Cocks 1986). The palaeomagnetic estimate of separation was achieved by comparing the new Baltica data with the existing southern British data (summarized by Trench & Torsvik 1991b), within which the Silurian pole (Piper 1975) requires revision using modern analytical methods.

To address these uncertainties, 11 palaeomagnetic sites were sampled within a 250 m sequence of early Wenlock (c. 430 Ma; Harland et al. 1989; M. riccartonensis Zone, Hancock 1982) andesitic lavas exposed within Matthew’s and Moon’s Hill Quarries of the East Mendips Silurian inlier, SW England (Hancock 1982). The sequence strikes approximately E–W and dips steeply northward (45°–90°), and tectonism and low-grade metamorphism is associated with the Hercynian orogeny (Hancock 1982).

Fig. 1. Continental reconstructions of the Iapetus- and Tornquist-bordering continents in (A) Early Ordovician times (Tremadoc–Arenig) and (B) Mid-Ordovician times (Llanvirn–Llandeilo). Adapted from Torsvik et al. (1992a).
Palaeomagnetic results. Stepwise-thermal demagnetization identifies a primary, high unblocking temperature ($T_0 > 500 \, ^\circ C$), characteristic magnetization (ChRM; Fig. 3a). Lower unblocking temperature magnetizations of Hercynian and Recent origin are occasionally present, and the presence of multi-component magnetizations at some sites explains the disparity between the present study and that of Piper (1975). The significance of the lower unblocking temperature components, their relationship to Hercynian deformation, and their marked influence on the previous pole determination are developed elsewhere (Torsvik et al. 1992b).

The properties of the high unblocking temperature characteristic magnetizations are summarized below. These attributes of the characteristic magnetization data are discussed in detail by Torsvik et al. (1992b).

1. Normally-magnetized polarity observed in 9 sites (tilt-corrected mean declination = $095^\circ$, mean inclination = $-24^\circ$, alpha95 = $8.8^\circ$; precision parameter, k = 35.2; pole position N13^\circ, 271^\circ E, & dp/dm = 5/9).

2. Clasts from intra-formational bedded agglomerates (2 sites) reveal high unblocking temperature magnetizations which are directionally-consistent within, but differ between individual boulders (Fig. 3b). These magnetizations show equivalent unblocking temperatures to the characteristic magnetization.

3. The characteristic magnetization is better grouped following tilt correction but this improvement is not statistically significant at the 95% confidence level (in-situ mean declination = $064^\circ$, mean inclination = $-24^\circ$, alpha 95 = 9.5°; precision parameter, k = 30.4).

4. Unblocking temperature spectra and thermomagnetic analyses, revealing Curie-temperatures around 580 and 680 °C, suggest that magnetite and hematite are the characteristic magnetization carriers.

Tectonic considerations. Positive agglomerate tests validate the primary nature of the ChRM from the East Mendips inlier. The mean inclination from the remaining 9 sites therefore establishes a palaeolatitude of $13^\circ \pm 5^\circ S$ for southern Britain in early Wenlock time. This latitude is significantly lower than that predicted by the reference apparent polar wander path (APWP) for southern Britain (26°S, Trench & Torsvik 1991b) and that obtained by Piper (1975) based upon more limited sampling and demagnetization (29°S).

The mean characteristic magnetization pole from the inlier is anomalous with respect to the previously defined APWP from southern Britain (Trench & Torsvik 1991b) and indeed, with respect to any published APWP for Britain or Baltica (see Torsvik et al. 1990, 1992a). The declination of 095° suggests substantial clockwise rotation in the order of 70°–80° but a precise estimate is not possible given the lack of a stable Wen-
lock reference direction for southern Britain. We tentatively link rotation to early Hercynian tectonism on northward-directed thrusts. Indeed, thrusting of the Silurian and Upper Old Red Sandstone succession is recognized in the vicinity of Moon’s Hill Quarry (Hancock 1982). The latter structures are also apparent in the regional gravity dataset from southern Britain (Lee et al. 1990) and may have induced clockwise structural rotation in SW Wales (McClelland 1983; McClelland & McCaig 1988). Further palaeomagnetic studies are required to determine whether the East Mendips rotation is of local or regional extent.

When comparison is made with coeval palaeomagnetic data from the southern Laurentian margin (Scottish Newer granites, Torsvik et al. 1983; Torsvik 1984), Laurentia (Rose Hill Formation, French & Van der Voo 1979; Wabash Reef limestones, McCabe et al. 1985) and Baltica (Ringerike redbeds, Douglass 1988; Gotland limestones, Trench & Torsvik 1991a), the palaeogeographical significance of the new data is apparent. A continental reconstruction using these datasets is shown in Fig. 4.

It is evident that the oceanic separation across Britain and between Laurentia/Baltica which was apparent in Ordovician times (Figs 1 & 2) was removed prior to Early Wenlock time (Fig. 4). The Iapetus Ocean was therefore closed, within palaeomagnetic resolution, prior to the Acadian Orogeny which peaked in Emsian times (Soper et al. 1987; McKerrow 1988).

We also note that the new data remove the palaeomagnetic requirement for latitudinal separation between Baltica and southern Britain in Wenlock times (see Trench & Torsvik 1991a). This ‘separation’ conflicted with faunal evidence indicating Late Ordovician closure of the intervening Tornquist Sea (Cocks & Fortey 1982, 1990). Baltica and southern Britain therefore shared comparable northerly drift rates, underwent counterclockwise rotation and occupied similar latitudinal positions during Early–Mid-Ordovician (Torsvik et al. 1991a; Trench et al. 1992) and Early–Mid-Silurian time. Whilst this does not preclude palaeo-longitudinal separation of these continents, it strongly favours their proximity prior to Avalonia-Laurentia collision. In Fig. 4, Gondwana is positioned using an Early Silurian south pole obtained by Hargraves et al. (1987) from the Air pluto in Niger. This pole plots off Southern Africa and is in agreement with a pole from the Siluro-Devonian Snowy River Volcanics of Eastern Australia (Schmidt et al. 1987). We note however that these results contradict Mid-Devonian palaeomagnetic data from the Gilf Hills, Sudan, which place the south pole in northern Africa at this time (Bachtadse & Briden 1991). Assuming present-day maximum drift rates to be applicable to the Palaeozoic, the magnetic age of one or other of these pole positions must be in error. If the former Gondwana poles are correct, then a supercontinent, comprising Laurentia, the British terranes, Baltica and Gondwana existed by Wenlock times. Previous synthesis have suggested accretion of these continents in Siluro-Devonian times (Van der Voo 1983; Miller & Kent 1988; Stearns et al. 1989) given the then available data from Baltica and southern Britain.

Conclusions. (1) Primary palaeomagnetic data from the East Mendips Inlier, SW England, place southern Britain (Eastern Avalonia) at a latitude of 13 ± 5°S in early Wenlock times (c. 430 Ma).

(2) Palaeomagnetic data no longer require an oceanic separation between southern Britain and Baltica in Silurian times. Palaeomagnetic and biogeographical data bearing on the closure of the Tornquist Sea are therefore reconciled.

An anonymous reviewer and M. A. Smethurst commented on earlier versions of this manuscript. N. J. Soper contributed useful editorial suggestions. J. Channell, C. McCabe, and W. S. McKerrow are thanked for discussions on the Early Palaeozoic palaeomagnetism and geology of southern Britain. The authors are also grateful to the managerial staff of John Wainwright & Son Ltd., Moon’s Hill Quarry, for organizing pit access. I. Svensson performed laboratory experiments.

Fig. 4. Continental reconstruction for Wenlock times (425 Ma). Southern Britain (Eastern Avalonia) is positioned using the mean mid-Silurian pole from Baltica given the likelihood of local rotation affecting the East Mendips Inlier. The resulting latitude is within the 95% confidence of the inclination determined from the Inlier. The possible rotation of the East Mendips Inlier has not therefore been applied to the entire Avalonian plate.


(3) Comparable latitudinal positions for Eastern Avalonia and Baltica throughout Ordovician to mid-Silurian time (see Figs 1, 2 & 4) favours their amalgamation prior to the collision of Avalonia with Laurentia. The possibility of palaeolongitudinal separation is not precluded however. Both continents underwent predominantly counterclockwise rotation during this time interval.

(4) By mid-Silurian time, Baltica, northern Britain and southern Britain had assumed a relative geography at near equatorial latitudes that resembles their present-day geographical distribution. Latitudinal separation across the British and Scandinavian sectors of Iapetus was therefore no longer significant by early Wenlock times. A mid-Silurian supercontinent, which comprised Laurentia, Baltica, the British terranes and possibly Gondwana was therefore assembled by Wenlock times (assuming a mid-Silurian south pole relative to Gondwana to lie offshore SW Africa).

(5) Acadian deformation across Britain, which took place in Devonian times, therefore post-dated initial docking of Eastern Avalonia and Laurentia.
A.T. thanks the University of Western Australia for facilitating academic leave in Trondheim during April/May 1992.

References


