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

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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.* 1991*a*, 1992*a*; Perroud *et al.* 1992). Nevertheless, details on the closure history of the Iapetus Ocean and Tornquist Sea (Fig. 1) have remained sketchy due to a sparseness 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.

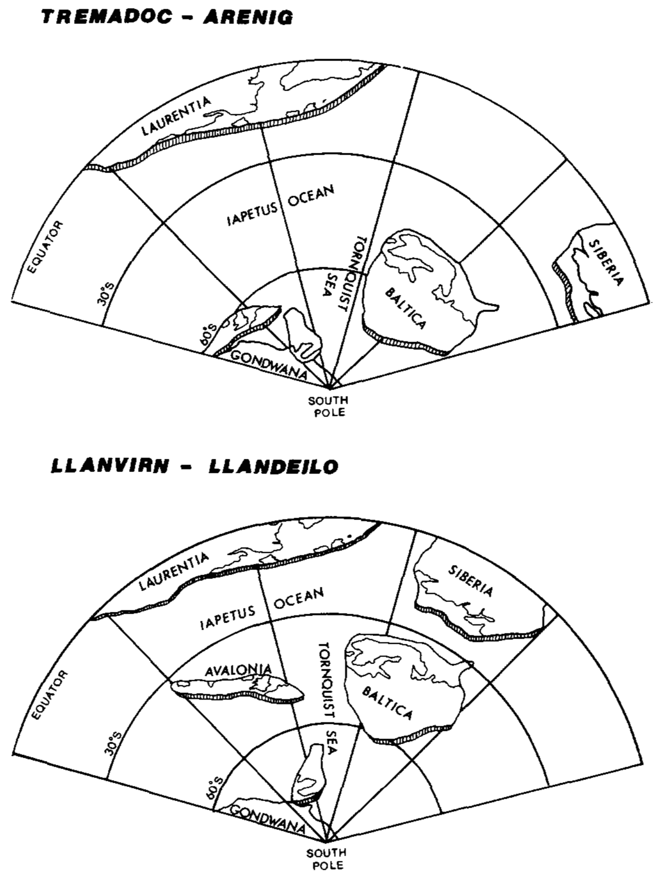

Fig. 1. Continental reconstructions of the Iapetus- and Tornquist-bordering continents in (**A**) Early Ordovician times (Tremadoc–Arenig) and (**B**) Mid-Ordovician times (Llanvirn–Llandeilo). Adapted from Torsvik *et al.* (1992*a*).

Secondly, recently-reported Silurian palaeomagnetic data from Baltica (Douglass 1988; Trench & Torsvik 1991*a*) 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, 1990; 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 1991*b*), 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).

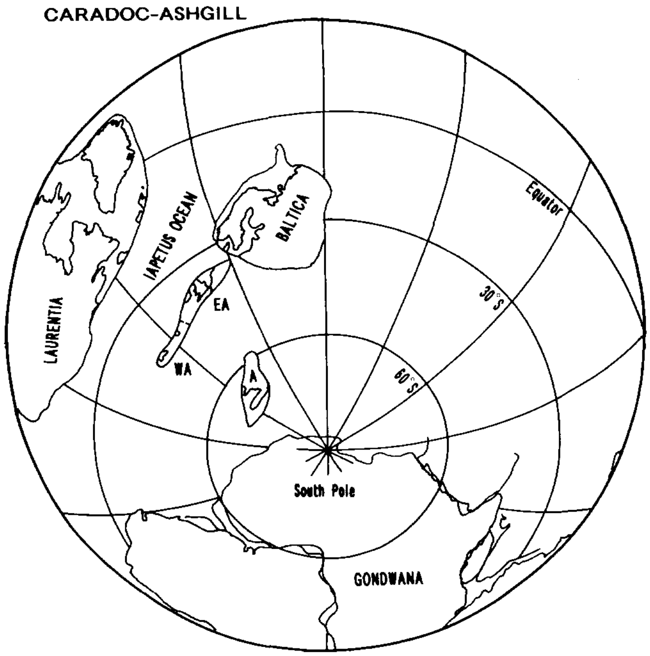

Fig. 2. Continental reconstruction of the Iapetus-bordering continents in Late Ordovician (Caradoc–Ashgill) times (*c.* 450 Ma). Abbreviations are as follows: WA, Western Avalonia; EA, Eastern Avalonia; A, Armorica. Late Ordovician south pole for Gondwana after Kent & Van der Voo (1990). The latitudinal position of southern Britain is consistent with the APWP of Trench & Torsvik (1991*b*) and with new palaeomagnetic data reported by Channell & McCabe (1992) from the Borrowdale Volcanic Group. Baltica positioned using a south pole at c. 1°N, 27°E. Northern Britain and Laurentia reconstructed using a Bullard *et al.* (1965) pre-Atlantic configuration and a south pole at 16°S, 4°E (European co-ordinates).

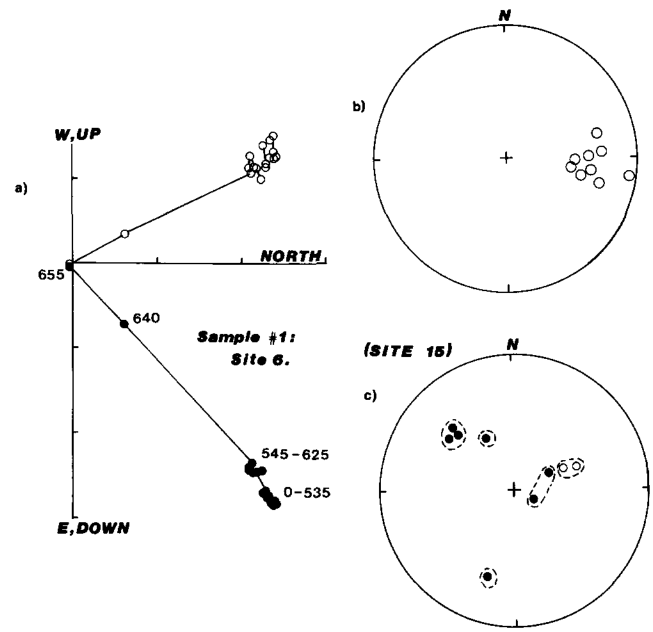

Fig. 3. (A) Orthogonal projection showing incremental thermal demagnetization of a typical palaeomagnetic sample from the East Mendips inlier. Numbers next to data points refer to demagnetization temperatures (°C). Horizontal (Vertical) projection indicated by solid (open) symbols. (B) Characteristic magnetization site mean directions (tilt-corrected) from the East Mendips inlier. Open symbols indicate projection on the upper hemisphere. Equal angle projection. (C) Equal angle projection of characteristic magnetization components revealed by a palaeomagnetic agglomerate test. Closed (Open) symbols are plotted on the lower (upper) hemisphere. Directions obtained from the same clast are encircled in each case.

Palaeomagnetic results. Stepwise-thermal demagnetization identifies a primary, high unblocking temperature ($T_b > 500$ °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.* 1992*b*).

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.* (1992*b*).

(1) Normally-magnetized polarity observed in 9 sites (tilt-corrected mean declination = 095°, mean inclination = −24°, alpha95 = 8.8°; precision parameter, k = 35.2; pole position N13°, 271°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°, mean inclination = −24°, 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° ± 5°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 1991*b*) 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 1991*b*) and indeed, with respect to any published APWP for Britain or Baltica (see Torsvik *et al.* 1990, 1992*a*). 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 Wenlock 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 1991*a*), 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 1991*a*). 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 northward drift-rates, underwent counterclockwise rotation and occupied similar latitudinal positions during Early–Mid-Ordovician (Torsvik *et al.* 1991*a*; 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 Aïr plutons 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 Gilif 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 syntheses 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.

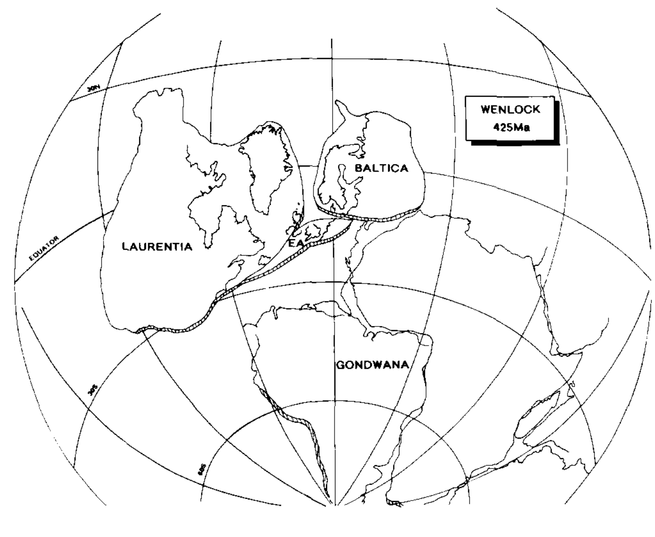

Fig. 4. Continental reconstruction for Wenlock times (425 Ma). Southern Britain (Eastern Avalonia) is positioned using the mean mid-Silurian pole from Baltica given the likelihood of local rotation affecting the East Mendips inlier. The resulting latitude is within the 95% confidence of the inclination determined from the Inlier. The possible rotation of the East Mendips Inlier has not therefore been applied to the entire Avalonian plate. Reconstruction poles: Baltica (20°S, 348°E mean pole of Ringerike Sandstone, Upper Visby, Dacker, Follingbo and Medby Limestones, see Trench & Torsvik 1991*a*), Laurentia (20°S 344°E mean pole of Wabash Reef and Rose Hill Formation rotated into European co-ordinates using Euler rotation parameters as follows, pole 088°N 27°E angle = 37°), Gondwana (43°S, 009°E, Air pole of Hargraves *et al.* 1987). Reconstruction generated using GMAP9 software (Torsvik & Smethurst 1992).

(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 distibution. 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.

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References

BACHTADSE, V. & BRIDEN, J. C. 1991. Palaeomagnetism of Devonian ring complexes from the Bayuda Desert, Sudan—new constraints on the apparent polar wander path for Gondwanaland. *Geophysical Journal International*, **104**, 635–646.

BULLARD, E. C., EVERETT, J. E. & SMITH, A. G. 1965. The fit of the continents around the Atlantic. *Royal Society of London, Philosophical Transactions*, **A258**, 41–51.

CHANNELL, J. E. T. & MCCABE, C. 1992. New palaeomagnetic data from the Borrowdale Volcanic Group (English Lake District): volcano-tectonics and Late Ordovician palaeolatitudes. *Journal of the Geological Society, London*, **149**, 880–881.

——, MCCABE, C., TORSVIK, T. H., TRENCH, A. & WOODCOCK, N. H. 1992. Palaeozoic palaeomagnetic studies in the Welsh Basin—Recent advances. *Geological Magazine*, in press.

COCKS, L. R. M. & FORTEY, R. A. 1982. Faunal evidence for oceanic separations in the Palaeozoic of Britain. *Journal of the Geological Society, London*, **139**, 465–478.

—— & ——1990. Biogeography of Ordovician and Silurian faunas. *In*: MCKERROW, W. S. & SCOTESE, C. R. (eds) *Palaeozoic Palaeogeography and Biogeography*. Geological Society Memoir, **12**, 97–104.

DOUGLASS, D. N. 1988. Palaeomagnetics of Ringerike Old Red Sandstone and related rocks, southern Norway: implications for pre-Carboniferous separation of Baltica and British terranes. *Tectonophysics*, **148**, 11–27.

FRENCH, A. N. & VAN DER VOO, R. 1979. The magnetisation of Rose Hill Formation at the classical site of Graham's fold test. *Journal of Geophysical Research*, **84**, 7688–7696.

HANCOCK, N. J. 1982. Stratigraphy, palaeogeography and structure of the East Mendips Silurian inlier. *Proceedings of the Geologists' Association*, **93**, 247–261.

HARGRAVES, R. B., DAWSON, E. M. & VAN HOUTEN, F. B. 1987. Palaeomagnetism and age of mid Palaeozoic ring complexes in Niger, West Africa, and tectonic implications. *Geophysical Journal of the Royal Astronomical Society*, **90**, 705–729.

HARLAND, W. B., ARMSTRONG, R. L., COX, A. V., CRAIG, L. E., SMITH, A. G. & SMITH, D. G. 1989. *A geologic time scale 1989*. Cambridge University Press.

KENT, D. V. & VAN DER VOO, R. 1990. Palaeozoic palaeogeography from palaeomagnetism of the Atlantic-bordering continents. *In*: MCKERROW, W. S. & SCOTESE, C. R. (eds) *Palaeozoic Palaeogeography and Biogeography*. Geological Society Memoir, **12**, 49–56.

LEE, M. W., PHAROAH, T. C. & SOPER, N. J. 1990. Structural trends in central Britain from images of gravity and aeromagnetic fields. *Journal of the Geological Society, London*, **147**, 241–258.

LEGGETT, J. K., MCKERROW, W. S. & SOPER, N. J. 1983. A model for the crustal evolution of southern Scotland. *Tectonics*, **2**, 187–210.

MCCABE, C., VAN DER VOO, R., WILKINSON, B. H. & DEVANEY, K. 1985. A Middle/Late Silurian palaeomagnetic pole from limestone reefs of the Wabash Formation (Indiana, U-S-A). *Journal of Geophysical Research*, **90**, 2959–2965.

MCCLELLAND, E. A. 1983. Palaeomagnetic studies of fold development and propagation in the Pembrokeshire Old Red Sandstone. *Tectonophysics*, **98**, 131–149.

—— & MCCAIG, A. M. 1988. Palaeomagnetic estimates of rotations in compressional regimes and potential discrimination between thin-skinned and deep crustal deformation. *In*: KISSEL, C. & LAJ, C. (eds) *Palaeomagnetic Rotations and Continental Deformation*. Kluwer Academic Publishers, 365–379.

MCKERROW, W. S. 1988. Wenlock to Givetian deformation in the British Isles and the Canadian Appalachians. *In*: HARRIS, A. L. & FETTES, D. J. (eds) *The Caledonian–Appalachian Orogen*. Geological Society, Special Publication, London, **38**, 405–412.

—— & COCKS, L. R. M. 1986. Oceans, island arcs and olistostromes: the use of fossils in distinguishing sutures, terranes and environments around the Iapetus Ocean. *Journal of the Geological Society, London*, **143**, 185–191.

MILLER, J. D. & KENT, D. V. 1988. Palaeomagnetism of the Silurian-Devonian Andreas redbeds: Evidence for an Early Devonian supercontinent? *Geology*, **16**, 195–198.

MURPHY, F. C. 1987. Evidence for late Ordovician amalgamation of volcanogenic terranes in the Iapetus suture zone, eastern Ireland. *Transactions of the Royal Society of Edinburgh: Earth Sciences*, **78**, 153–167.

PERROUD, H., ROBARDET, M. & BRUTON, D. L. 1992. Palaeomagnetic constraints upon the palaeogeographic position of the Baltic shield in the Ordovician. *Tectonophysics*, **201**, 97–121.

PICKERING, K. T., BASSETT, M. G. & SIVETER, D. J. 1988. Late Ordovician-early Silurian destruction of the Iapetus Ocean: Newfoundland, British Isles and Scandinavia—a discussion. *Transactions of the Royal Society of Edinburgh: Earth Sciences*, **79**, 361–382.

PIPER, J. D. A. 1975. Palaeomagnetism of Silurian lavas of Somerset and Gloucester, England. *Earth and Planetary Science Letters*, **25**, 355–360.

SCHMIDT, P. W., EMBLETON, B. J. J. & PALMER, H. C. 1987. Pre- and post-folding magnetisations from the Early Devonian Snowy River Volcanics and Buchan Caves limestone, Victoria. *Geophysical Journal of the Royal Astronomical Society*, **91**, 155–170.

SOPER, N. J. & HUTTON, D. H. W. 1984. Late Caledonian sinistral displacements in Britain: Implications for a three-plate collision model. *Tectonics*, **3**, 781–794.

—— & WOODCOCK, N. H. 1990. Silurian collision and sediment dispersal patterns in southern Britain. *Geological Magazine*, **127**, 527–542.

——, STRACHAN, R. A., HOLDSWORTH, R. E., GAYER, R. A. & GREILING, R. O. 1992. Sinistral transpression and the Silurian closure of Iapetus. *Journal of the Geological Society, London*, in press.

——, WEBB, B. C. & WOODCOCK, N. H. 1987. Late Caledonian (Acadian) transpression in north west England: timing, geometry, and geotectonic significance. *Proceedings of the Yorkshire Geological Society*, **46**, 175–192.

STEARNS, C., VAN DER VOO, R. & ABRAHAMSEN, N. 1989. A new Siluro-Devonian palaeopole from Early Palaeozoic rocks of the Franklinian Basin, North Greenland fold belt. *Journal of Geophysical Research*, **94**, 10669–10683.

TORSVIK, T. H. 1984. Palaeomagnetism of the Foyers and Strontian granites, Scotland. *Physics of the Earth and Planetary Interiors*, **36**, 163–177.

—— 1985. Magnetic properties of the Lower Old Red Sandstone lavas in the Midland Valley, Scotland; palaeomagnetic and tectonic considerations. *Physics of the Earth and Planetary Interiors*, **39**, 194–207.

—— & SMETHURST, M. A. 1992. *GMAP—Geographic mapping and Palaeoreconstruction package, Release 9*. Baltica Research Report 001.92.

—— & TRENCH, A. 1991. The Ordovician history of the Iapetus Ocean in Britain: new palaeomagnetic constraints. *Journal of the Geological Society, London*, **148**, 423–425.

——, LOVLIE, R. & STORETVEDT, K. M. 1983. Multicomponent magnetisation in the Helmsdale Granite, N Scotland: geotectonic implications. *Tectonophysics*, **98**, 111–129.

——, RYAN, P. D., TRENCH, A. & HARPER, D. A. T. 1991*a*. Cambro-Ordovician palaeogeography of Baltica. *Geology*, **19**, 7–10.

——, SMETHURST, M. A., BRIDEN, J. C. & STURT, B. A. 1990. A review of Palaeozoic palaeomagnetic data from Europe and their palaeogeographical implications. *In*: MCKERROW, W. S. & SCOTESE, C. R. (eds) *Palaeozoic Palaeogeography and Biogeography*. Geological Society Memoir, **12**, 25–41.

——, ——, VAN DER VOO, R., TRENCH, A., ABRAHAMSEN, N. & HALVORSEN, E. 1992*a*. Baltica: A synopsis of Vendian–Permian palaeomagnetic data and their palaeotectonic implications. *Earth Science Reviews*, in press.

——, TRENCH, A. & SMETHURST, M. A. 1991*b*. The British Siluro-Devonian palaeofield, the Great Glen Fault and analytical methods in palaeomagnetism: comments on paper by K. M. Storetvedt *et al*. *Geophysical Journal International*, **105**, 467–473.

——, ——, SVENSSON, I. & WALDERHAUG, H. 1992*b*. Mid-Silurian palaeomagnetic results from southern Britain: Palaeogeographic significance and major revision of the apparent polar wander path for Eastern Avalonia. *Geophysical Journal International*, in press.

TRENCH, A. & TORSVIK, T. H. 1991*a*. The Lower Palaeozoic apparent polar wander for Baltica: palaeomagnetic data from Silurian limestones of Gotland, Sweden. *Geophysical Journal International*, **107**, 373–379.

—— & —— 1991*b*. A revised Palaeozoic apparent polar wander path for Southern Britain (Eastern Avalonia). *Geophysical Journal International*, **104**, 227–233.

——, —— & MCKERROW, W. S. 1992. The palaeogeographic evolution of southern Britain during Early Palaeozoic times: A reconciliation of palaeomagnetic and biogeographic evidence. *Tectonophysics*, **201**, 75–83.

VAN DER VOO, R. 1983. Palaeomagnetic constraints on the assembly of the Old Red continent. *Tectonophysics*, **91**, 271–283.

WOODCOCK, N. H., AWAN, M. A., JOHNSON, T. E., MACKIE, A. H. & SMITH, R. D. A. 1988. Acadian tectonics of Wales during Avalonia/Laurentia convergence. *Tectonics*, **7**, 483–495.

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