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Comment on "Palaeomagnetic results from volcanic rocks of the Shelve Inlier, Wales: evidence for a wide Late Ordovician Iapetus Ocean in Britain" by C. McCabe and J.E.T. Channell

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1. Introduction

In a recent paper, McCabe and Channell [1] report a Late Ordovician palaeomagnetic pole from the Shelve Inlier, Wales, and argue for a Iapetus Ocean of 30 degrees latitudinal width between Laurentia and Southern Britain in *Late* Ordovician times. They further suggest that Southern Britain lay in "high" latitudes adjacent to the northern margin of Gondwana at this time.

Unlike McCabe and Channell we contend a "primary" Llanvirn (*Mid*-Ordovician) remanence age for the Shelve volcanics. Additionally, several important points regarding the palaeomagnetism of Southern Britain may have been overlooked by McCabe and Channell. In particular, re-examination of a previous palaeomagnetic study of the Shelve Inlier [2] reveals a dual polarity remanence, which passes a fold test at 95% confidence, and indicates temperature southerly palaeolatitudes of 32S ± 8.

2. Palaeomagnetic research in the Shelve Inlier

The review of previous palaeomagnetic work from the Shelve Inlier by McCabe and Channell does not fully evaluate earlier data. A previous study of the area [2] revealed predominantly shallow inclination data rather than steep results as suggested by McCabe and Channell [1]. The 6 sites (of 58) which did show steep inclinations were reported in "in-situ" co-ordinates [2] and should not be compared with the "structurally corrected" data of the later work.

New thoughts on the structural history of the Shelve inlier can reconcile the contrasting results however. Following Blyth [3], Piper [2] considered the dolerite and andesite intrusions of the Shelve inlier to post-date tectonism and therefore did not structurally correct the remanence data. In fact, many of these intrusions are pre-orogenic [4]. Structural correction of the andesites and dolerites brings them into reasonable agreement with the newly available data [1] (Fig. 1, Table 1), passing the fold test at 95% confidence level [5]. The two studies *do* therefore yield comparable results, but this requires a revised structural interpretation rather than a direct comparison of "in-situ" and "structurally corrected" datasets.

We observe that whilst the positively inclined (reversed polarity) andesite and dolerite sites closely correspond with the mean result of McCabe and Channell, the negatively inclined (normal polarity) data are significantly shallower (Fig. 1b, d, Table 1) and result in a lower palaeolatitude for the combined polarities (32S $\pm$ 8). As the positively inclined data from the earlier study [2] agree with those obtained by detailed stepwise demagnetisation [1], it is likely that the shallower negative inclinations are significant. Omission of negatively inclined directions during data analyses might therefore produce bias towards higher palaeolatitudes.

McCabe and Channell [1] assigned a *Late* Ordovician age to their pole suggesting the single polarity of their data to support remagnetisation. Their reported "single polarity" contradicts the previous study [2] in which both polarities (con-

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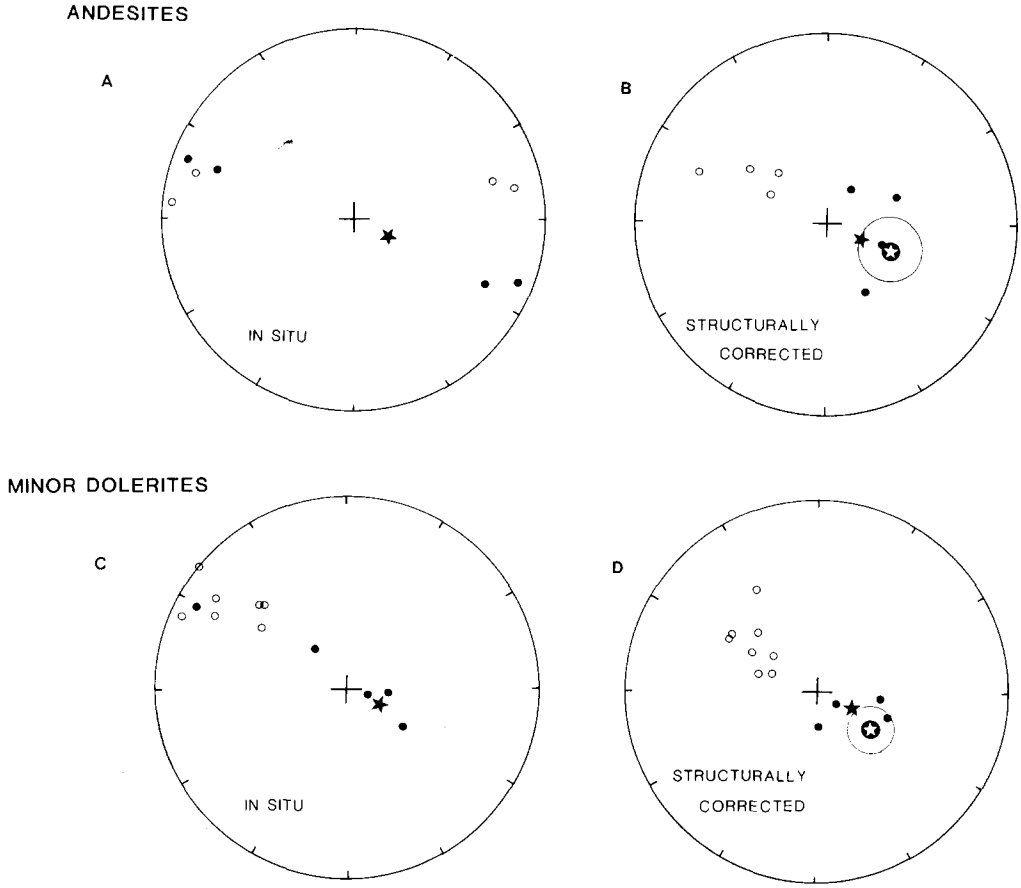

Fig. 1. In situ (a,c) site mean data of Piper [2] recalculated to account tectonic deformation (b,d). Structural corrections interpolated from [11]. Star represents mean direction from Shelve Volcanics [1]. Encircled star and encompassing 95% confidence limit gives mean of both polarity data (recalculated after [4]).

sistent within individual sites) are observed (Fig. 1a–d). Indeed, dual polarity data were previously mentioned by McCabe and Channell but were subsequently omitted perhaps due to poor data quality [cf. 6 and 1]?

We note that 45% of the samples collected by McCabe and Channell were rejected from their statistical analyses, excluding an undisclosed number from their pilot study. If these authors rejected negatively-inclined results at this stage [6], they may have biased the overall mean direction towards high palaeolatitudes.

We conclude that:

(1) Arguments for *Late* Ordovician remagnetisation [1] based on a supposedly single remanence-polarity are not tenable.

(2) The Shelve volcanics record a "primary" *Mid*-Ordovician remanence and the dolerites/andesites a "primary" *Mid–Late* Ordovician remanence age; and,

(3) If McCabe and Channell rejected normal polarity data, then their data analysis may contain a bias towards "high" inclination results. Hence, the estimate of the width of the *Late* Ordovician Iapetus Ocean (based on *Mid*-Ordovician data) may then be too large.

3. Builth Wells–Llandrindod Wells Ordovician inlier

McCabe and Channell [1] choose to play-down the significance of a pole from the Builth Wells inlier [7] which suggests a narrower (ca. 15 degree latitudinal width) Iapetus Ocean yet claim "it is nonetheless quite clear that a wide *Late* Ordovician ocean separated Laurentia and southern Bri-

TABLE 1
Statistical details of "in situ" and "corrected" data calculated from Piper [2] for Andesites and Minor Dolerites of the Shelve Inlier.

N	Dec.	Inc.	*k*	%95	Lat.(°)	Long.(°)	*d*P	*d*M
Andesites								
In situ, opposite polarity sites inverted								
8	100	2	18.0	13.4	5.3S	78.2E	6.7	13.4
Corrected, opposite polarity sites inverted								
8	112	51	10.6	17.9	12.9N	51.0E	16.4	24.2
Minor dolerites								
In situ, opposite polarity sites inverted								
12	122	33	5.1	21.4	3.5S	50.9E	13.8	24.3
Corrected, opposite polarity sites inverted								
12	124	52	18.3	10.4	8.1N	41.9E	9.7	14.2
Combined results								
Reversed polarity (positively inclined)								
8	107	63	12.3	16.4	25.4N	46.1E	20.3	25.8
Normal polarity (negatively inclined)								
12	304	−44	26.1	8.7	2.2N	45.3E	6.8	10.9
Both polarities (negative directions inverted								
20	119	52	14.6	8.8	10.3N	45.5E	8.2	12.0

No reliable attitude data are available for the Corndon Hill or Snead intrusions which have been omitted from recalculation. Site 33 (dolerite) was omitted due to its large 95% confidence cone (> 30 degrees). Dec. = declination, Inc = inclination, N = no. of sites, k = precision parameter, %95 = cone of 95% confidence, Lat., Long., = pole latitude and longitudes, dP and dM = 95% confidence limits on the location of the palaeomagnetic pole.

tain". We recount below why this claim may be incorrect.

McCabe and Channell dispute the validity of a statistically positive "felsite agglomerate test" from the Builth inlier ($N = 6$, $R = 3.67$, $R_0 = 3.85$, [7]) and argue "the age of the Builth magnetisation to be unconstrained". The "felsite agglomerate" actually comprises ignimbrite and lahar deposits [8], each containing large clasts which may have been sampled for palaeomagnetic analyses [7]. Given the contrasting emplacement temperatures of these volcanic facies, uncontrolled sampling might then produce the observed remanence distribution (fig. 4 of [7]). However, a statistically positive conglomerate test, ($N = 5$, $R = 2.2$, $R_0 = 3.50$), from a "beach-facies" basal conglomerate which overlies the Builth Wells (Llanelwedd) volcanics resolves any uncertainty and substantiates a primary origin for the Builth remanence [9]. We also note that the Builth Wells pole does not resemble any younger segment of the Southern British APWP [10].

The Builth Wells result *should not* therefore be ignored when reconstructing the Ordovician of Europe. In fact, several factors suggest a greater reliability than for the Shelve result. Notably, the published demagnetisation data is of equal or better quality (cf. fig. 1 of [7] and fig. 3 of [1]), and no samples were rejected in the calculation of a final mean. Whilst we do not attach particular significance to these later observations, we opine that the Builth Wells pole [7] cannot be considered subordinate, or dismissed, compared to that from the Shelve inlier as implied by McCabe and Channell [1].

4. Closing remarks

Tectonic reconstructions of Lower Palaeozoic Europe are intrinsically complex. It is an oversimplification to base a tectonic interpretation on a single palaeomagnetic pole to the exclusion of equally reliable data.

A reliable movement history for Southern Bri-

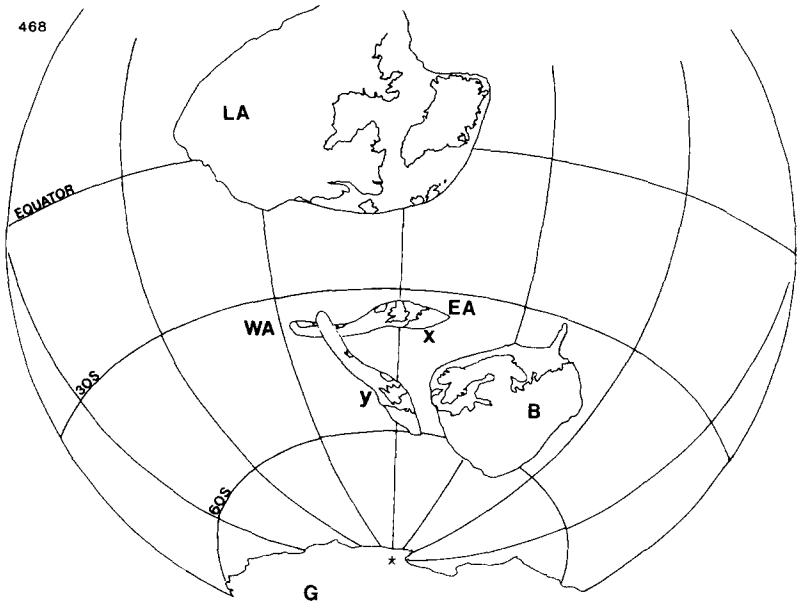

Fig. 2. Ordovician (Llanvirn-Llandeilo) palaeoreconstruction for the Iapetus bordering continents. Contrasting positions of Eastern Avalonia (Southern Britain) are based on the Builth Wells volcanics/fitted cubic spline pole (labelled *x*, poles listed in [10]) and Shelve inlier pole (labelled *y*). Laurentia, Baltica and Gondwana positioned using data listed in [10,12]. *LA* = Laurentia, *B* = Baltica, *G* = Gondwana, *WA* = Western Avalonia, *EA* = Eastern Avalonia.

tain based on palaeomagnetic data is not yet unambigously resolved. The existing data discrepancies within Southern Britain are minimised when the potential for high inclination bias in the Shelve inlier statistical analysis is recognised however. Palaeomagnetic results from the Builth Wells Volcanics (35S ± 4.4 [7]) and Shelve andesites\ dolerites (32S ± 8, recalculated from [2]) now agree. The unbiased, *Mid*-Ordovician, Shelve volcanics palaeolatitude may be significantly shallower than the 51S ± 7 reported by McCabe and Channell.

We welcome the new data [1], as it has refocussed our attention on the problems involved in reconstructing Southern Britain's drift history during Ordovician times. A *Mid*-Ordovician reconstruction for the Iapetus bordering continents incorporating the present palaeomagnetic database is shown in Fig. 2. We note the following points:

(1) Southern Britain occupied mid-southerly latitudes (not "high latitudes near the northern margin of Gondwana" [1]). Present uncertainties in its location reflect a *maximum* discrepancy of 16 degrees of latitude between the published studies from the Builth Wells and Shelve Inliers.

(2) Separation of Southern Britain and Baltica across the Tornquist's Sea was reduced by this time as both plates lay in moderate southerly latitudes [cf.10].

(3) Palaeomagnetic data indicate that Southern Britain was separated from Laurentia *and* from Gondwana by mid-Ordovician times. Southern Britain did not therefore "move northward *with* Gondwana during the Silurian [1]".

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