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Paleomagnetic results from the Lower Devonian Llandstadwell Formation, Dyfed, Wales

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Abstract

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A paleomagnetic investigation of the Lower Devonian Llandstadwell Formation in southwest Wales has yielded a characteristic direction (declination = 196°, inclination = − 5°) that passes a fold test. Comparison of the corresponding virtual geomagnetic pole (334° E, 39° S) to previously published poles for Great Britain indicates that the magnetization is secondary and likely to be of Carboniferous age. No evidence for post-Hercynian rotation of Pembrokeshire is indicated by our data.

Introduction

With the ever-increasing interest in the complex histories of fold and thrust belts, paleomagnetism has become an important method used to document the scale, timing and sense of rotations that may have occurred within these belts. In such tectonic zones, furthermore, the classic fold test (Graham, 1949; McElhinny, 1964; and McFadden and Jones, 1981) can be used to constrain the ages of the magnetizations carried by the rocks. Once the age of the magnetization has been established, the observed magnetic directions can be compared to predicted directions calculated from established Apparent Polar Wander Paths. The results of these comparisons are then used to document the amount and sense of rotations. Several paleomagnetic studies have been concerned with deformational processes themselves involving folding (McClelland Brown, 1983) or the effect of strain on rock magnetism (Kligfield et al., 1983; Lowrie et al., 1986). These studies use the magnetic results to gain insight into the progressive deformation of the rocks.

The earliest studies of the Old Red Sandstone in Pembrokeshire (Creer, 1957, 1962; Chamalaun and Creer, 1964; Chamalaun, 1964) were aimed at providing Devonian data for the Apparent Polar Wander Path for Great Britain. Thermal demagnetization revealed two components of magnetization: a small, high-temperature component that passed the fold test and was interpreted to be Devonian in age and a large low-temperature component of magnetization that was inferred to be of Hercynian age.

More recently McClelland Brown (1983) reexamined the Old Red Sandstone and used pre- and synfolding components of magnetization to constrain the geometry of the folds at various stages of deformation and to document a 40° clockwise rotation of Pembrokeshire since the Hercynian orogeny. In this report, we present results obtained from additional samples in a fold that lies within the same thrust sheet as one of the folds

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studied by McClelland Brown. No rotation of this part of Pembrokeshire is indicated by our data. This suggests that any rotations that might have occurred in Pembrokeshire are of a localized nature and do not represent a simple large-scale block rotation. In addition, a positive fold test indicates that our rocks were remagnetized prior to folding, not during folding.

Regional geology

In Pembrokeshire, southwest Wales, the Hercynian Fold Belt truncates the paratectonic or nonmetamorphic Caledonides. The Precambrian and Paleozoic rocks of this region form part of the outer margin of the Hercynian fold belt and were folded and faulted in the Permo-Carboniferous. Many of the outcrops consist of Devonian and Carboniferous sediments (Fig. 1).

Hancock et al. (1982) divided the region into two zones on the basis of structural assemblages (Fig. 1). The southern Zone I contains evenly spaced WNW trending folds and faults. The northern Zone II contains folds with a WSW trend. The southern zone was further subdivided into three subzones. Zone Ia is characterized by gently plunging, large amplitude folds. The large folds of Zone Ib plunge more steeply and are complicated by parasitic folds. The folds in Zone Ic are smaller, noncylindrical folds with abundant minor décollement surfaces.

The stratigraphy of the Lower Old Red Sandstone near Milford Haven has been described in detail by Allen et al. (1981). For our study we sampled the Lower Devonian Llandstadwell Formation, the oldest member of the wholly fluviatile Cosheston Group. Lithologically, the Llandstadwell Formation consists of upward-fining sequences of interbedded conglomerates, sandstones and siltstones. These sediments have been interpreted to be braided stream deposits (Allen et al., 1981). Fossil plants from our study area indicate a Siegenian age for the sediments (Thomas, 1978).

Sampling and laboratory treatment

For our study we sampled a well-exposed southeasterly plunging fold in a roadside quarry near Milford Haven, South Wales (open star in Fig. 1). Thirty-nine samples from six sites, three on each limb of the fold, were collected with a portable gasoline powered drill and oriented with a magnetic compass. We are reporting here on the thermal demagnetization of the 39 samples. Natural Remanent Magnetization (NRM) characteristics were measured using a ScT cryogenic magnetometer or a Schonstedt SSM-1A spinner magnetometer located at the University of Michigan.

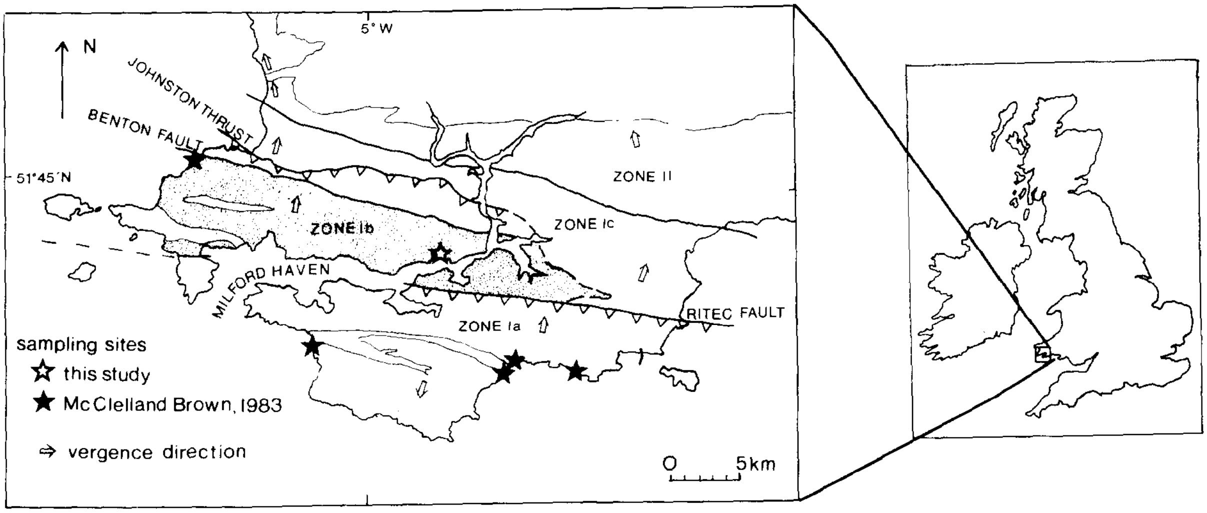

Fig. 1. Map of the structural zones in Southwest Wales (after Hancock et al., 1982) showing paleomagnetic sampling localities and direction of fold vergence.

Samples were stored and treated in a magnetic field free room to minimize the effects of viscous magnetizations. To isolate characteristic components of the NRM, stepwise thermal demagnetization procedures were used. Pilot studies showed that chemical (Henry, 1979) and alternating field demagnetization methods did not successfully isolate magnetic components. After visual inspection of orthogonal demagnetization trajectories, magnetic directions were determined by principal component analysis (Kirschvink, 1980). Only those results that we interpreted as characteristic were used in calculating mean directions. A virtual geomagnetic pole was calculated from the site means in order to compare our data with published Paleozoic data from Great Britain.

Results and discussion

Two characteristic behaviors were observed upon thermal demagnetization. The more strongly magnetized samples yielded univectorial Zijderveld diagrams such as that shown in Fig. 2a. Blocking temperatures ranged from 200° to 590°C suggesting that magnetite may be the magnetic carrier. The more weakly magnetized samples yielded multicomponent demagnetization trajectories such as that in Fig. 2b. A characteristic direction, with blocking temperatures ranging from 200° up to 600°C was observed in all these samples. Although there is some evidence of a high blocking temperature component, we do not feel that thermal demagnetization adequately resolved this component. No consistent direction was observed at temperatures above 600°C, and many samples were unstable at these temperatures. For the more weakly magnetized samples then, the lower blocking temperature component was used for our analysis. Note that this direction matches the direction observed in the more strongly magnetized, univectorial samples.

The characteristic directions for 38 of the 39

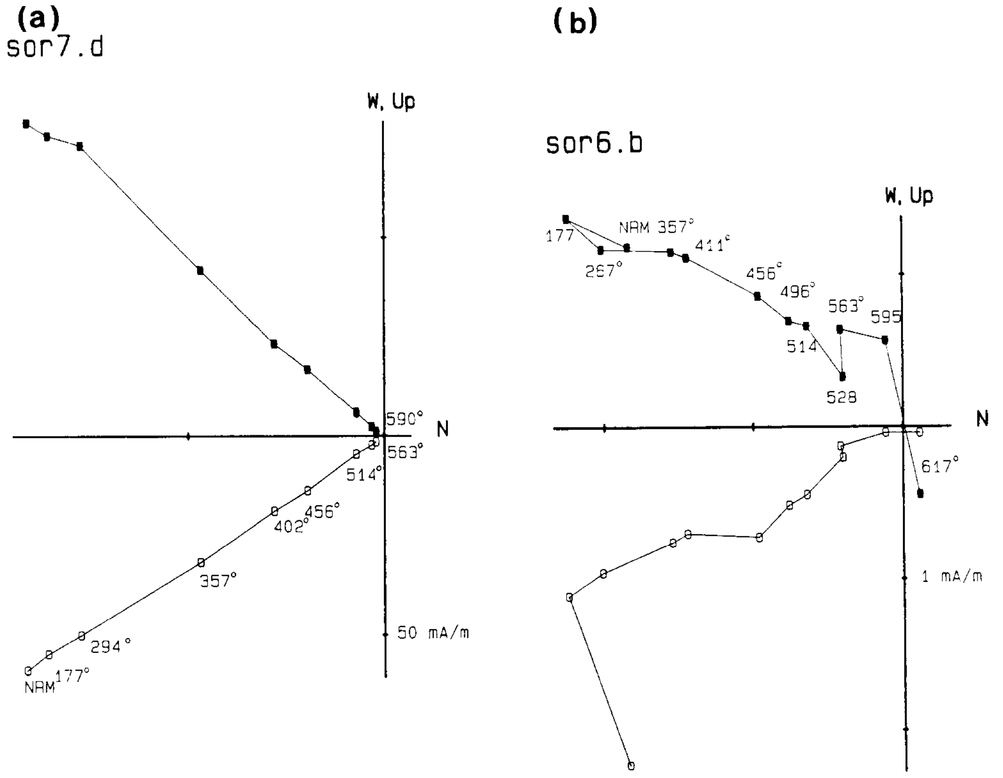

Fig. 2. Typical thermal demagnetization diagrams of samples of the Llandstadwell Formation. a. A strongly magnetized, univectorial sample, b. A more weakly magnetized sample. Solid symbols represent projections on the horizontal plane, and open symbols projection on the vertical plane.

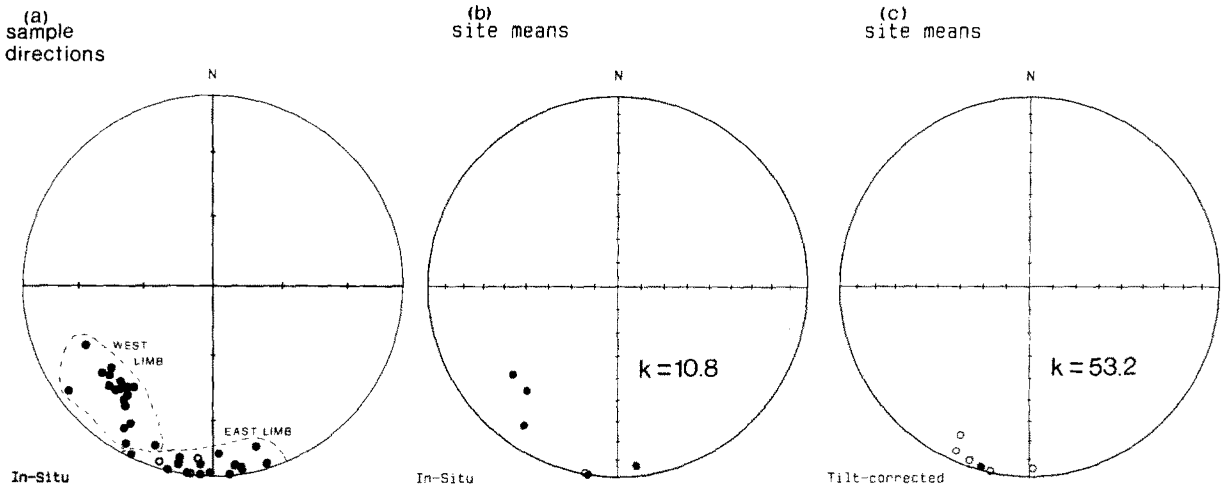

Fig. 3. Equal-area projections of the characteristic directions of the Llandstadwell Formation. a. In situ sample directions. b. Site means, in situ, with corresponding Fisher precision parameter. c. Unfolded and unplunged site means with the corresponding Fisher precision parameter. Solid circles are positive inclinations plotted on the lower hemisphere and open circles are negative (upper hemisphere) inclinations.

samples and the corresponding site means are shown in Fig. 3 and listed in Table 1. One of the samples yielded an uncharacteristic direction and was not included in the results. In field coordinates, the data for each limb plot in separate fields on the stereonet. The data pass a McElhinny fold test at 99% confidence limit. With respect to the tilt correction, unplunging the fold was necessary in order to reduce the dispersion of the site means. The fold axis (bearing/plunge = 121/40) that was used for the plunge correction was measured in the field. In addition, stepwise unfolding of the data yields the highest precision parameter with 100% unfolding, thus confirming a pre-folding age for the magnetization.

In Fig. 4 the calculated virtual geomagnetic pole for the Lower Devonian Llandstadwell Formation is shown with Briden and Duff's (1981) Apparent Polar Wander Path for the Middle Paleozoic of Europe. The pole for the Llandstad-

TABLE 1

Paleomagnetic site means

Site	S/D	n/N	in situ D/I	k	α_{95}	D/I unfolded	D/I unfolded and unplunged
1	79/58	6/6	230/ 29	101	6.7	219/ −6	204/ −6
2	71/45	6/6	214/ 13	41	10.6	215/ −15	205/ −15
3	69/55	7/7	221/ 28	340	3.3	210/ −4	199/ −4
4	5/36	6/6	190/ −1	44	10.2	189/ −1	192/ −1
5	11/20	5/6	189/ 0	96	7.9	189/ 0	193/ 0
6	8/41	8/8	174/ 6	85	6.0	174/ −5	179/ −5

Mean of site means

	D/I	k	α_{95}
In situ	202/ 13	11	21.3
Unfolded	200/ −5	18	19.2
Unfolded and unplunged	196/ −5	53	9.3

S/D are the strike and dip of the beds; n/N is the ratio of samples used in calculations to samples analysed; D/I are the declination and inclination after demagnetization; k and α_{95} are the statistical parameters associated with the means.

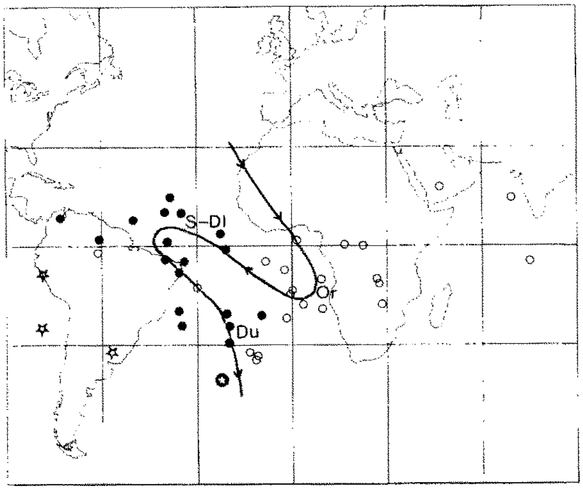

Fig. 4. Lower Paleozoic Apparent Polar Wander Path for Europe (after Briden and Duff, 1981). Ordovician poles are shown by open circles, Silurian and Devonian poles by closed circles, poles calculated from magnetic directions cited by McClelland Brown (1983) by open stars and the pole for the Llandstadwell Formation (this study) by the encircled star.

well Formation does not plot near the published Silurian and Devonian poles. Rather, the pole is located near poles of Carboniferous age, despite the positive fold test. We conclude that the magnetization carried by the Llandstadwell Formation represents a remagnetization that occurred just prior to the folding of the rocks.

There are two major differences between our results and those of McClelland Brown (1983). Our data do not support the concept of a 40° clockwise rotation of the entire Zone Ib in Pembrokeshire as was suggested by McClelland Brown (1983). In addition, our fold test indicates that within zone Ib the timing of the remagnetization with respect to the folding is not the same. Whereas our results indicate that the remagnetization is pre-folding, McClelland Brown's test suggests a synfolding remagnetization.

Our sampling locality is on the same thrust sheet as one of the folds studied by McClelland Brown. If the paleomagnetic results from both studies are reliable, then any rotations that may have occurred in Pembrokeshire are of a very localized nature. The reliability of our data is supported by the fact that the corresponding virtual geomagnetic pole falls on Briden and Duff's Apparent Polar Wander Path for Great Britain as described above. The paleomagnetic directions from the two folds published by McClelland Brown are rotated with respect to our directions. The 40° of clockwise rotation indicated by her data was argued to be supported by the 40° difference in vergence between Zone I and Zone II of Hancock et al. (1982). However, there is no geologic evidence to support a large rotation within Zone Ib, as is suggested by the difference in paleomagnetic directions in the two studies. In detail, the two folds studied by McClelland Brown yield slightly different results, but McClelland Brown concludes that the remagnetization occurred in discrete episodes during deformation; thus she was able to use the paleomagnetic results to constrain the geometry of the folds during fold development. It would be interesting to see if samples from Zone II support the regional rotation indicated by the difference in regional vergence. If not, then the paleomagnetic results indicate that the deformational history of the Hercynian fold belt in Southwest Wales involves large rotations within single thrust sheets and that the remagnetization of the rocks occurred in very discrete episodes during deformation.

Conclusions

This paleomagnetic study of the Lower Devonian Llandstadwell Formation has yielded a characteristic direction that passes a fold test. Comparison of the corresponding virtual geomagnetic pole with published Paleozoic poles for Great Britain suggests that the magnetization is secondary and likely to be of Carboniferous age. Presumably this remagnetization is related to chemical or thermal processes of the Hercynian orogeny.

Our results do not agree with previously published results from similar-aged rocks from Pembrokeshire. A study by McClelland Brown (1983) yielded two components of magnetization, a pre-folding direction thought to be Devonian and a synfolding magnetization. The latter indicated a 40° clockwise rotation of Pembrokeshire since the Hercynian orogeny. No rotation of Pembrokeshire is indicated by our data and in our study the remagnetization appears to be pre-folding. If the results from both studies are reliable then Pembrokeshire has had a complex deformational history with respect to the timing of folding and acquisition of magnetization. Even within the same thrust sheet, the sequence of folding and remagnetization does not appear to be the same. In addition, a considerable amount of localized rotation seems to have occurred.

Acknowledgements

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