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TRANSPRESSIONALLY DRIVEN ROTATION IN THE EXTERNAL VARISCIDES OF SOUTH-WEST BRITAIN

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INTRODUCTION

Although the direction of tectonic transport is a parameter required for many aspects of structural analysis, e.g. the construction of valid balanced cross-sections (Elliott, 1983), it has proved notoriously difficult to determine. This is particularly the case in thin-skinned fold and thrust belts, where large variations in fold and thrust trends make the direction uncertain. We suggest that at least some of this uncertainty is the result of rotation produced by oblique orogenic convergence. Orogenic belts are commonly curvilinear zones reflecting the geometry of the generating convergent plate boundary. Large-scale deflections of the orogen in many instances can be related directly to irregularities in the plate margins inherited from an earlier rift geometry. Only rarely will ocean closure directly reverse the vectors of original opening, and even here locally convergence will be oblique around original irregularities of the margins. The resultant transpression produces significant rotation that can emphasise the original curvilinear geometry, or generate deflections from the trend of the orogen. Orogenic structures are rotated by a combination of block rotation (passive rotation) and stress deflection. Passive rotation can be monitored by changes in the orientation of pre-orogenic structure, or by palaeomagnetic data (Walcott *et al.,* 1981), which, combined with palaeostress analysis, allows an estimate of stress deflection.

In this contribution we analyse the external zones of the dextrally transpressive Variscan orogenic belt of south-western Britain.

VARISCAN NORTHERN MARGIN IN SOUTH-WEST BRITAIN

The Variscan orogen in western and central Europe contains a number of terranes that originated as rifted fragments of North Africa, which were subsequently accreted to the European margin during Late Palaeozoic orogenic convergence (Franke, 1989). An approximately north-westwards convergence is recorded along the northern external

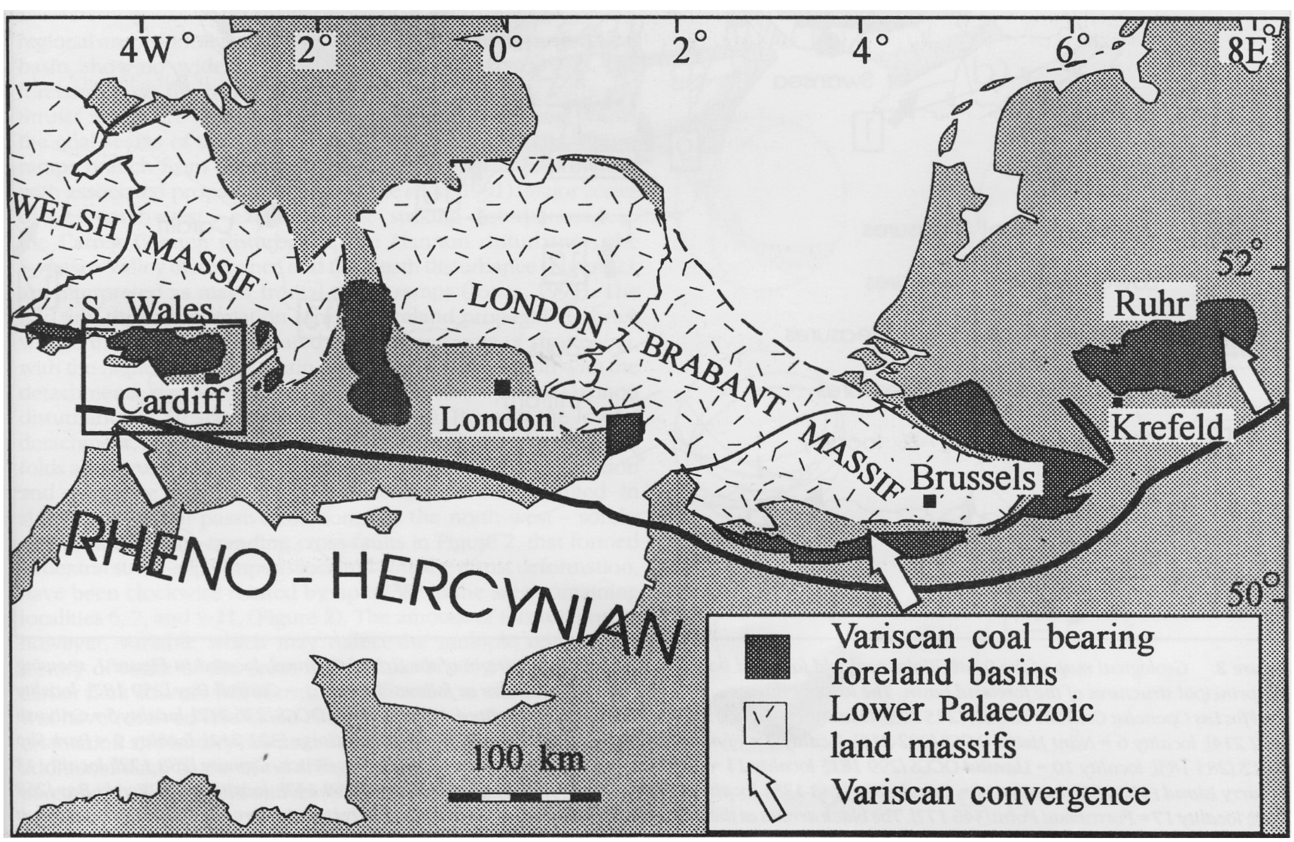

Figure 1. Part of the northern margin of the Variscan orogenic belt in north-western Europe, showing the Welsh and London-Brabant basement massifs and their relationship to the northern margin of the Rheno-Hercynian zone and the coal-bearing foreland basins. The arrows represent the presumed direction of Variscan convergence. Modified from Cole (1993).

Variscan margin to the north of these terranes. The northern margin (Figure 1) consists of a northwards-tapering fold and thrust belt comprising a southerly RhenoHercynian zone of Late Palaeozoic extensional basins above stretched European continental crust, inverted during Variscan convergence, and a northerly belt of coal-bearing foreland basins in which Variscan deformation diminishes northwards.

In the west, the Variscan external zone is buttressed against the east-west-trending, Welsh and London-Brabant basement massifs (see Figure 1), generating a major zone of dextral transpression in south-west Britain (e.g. Coward and McClay, 1983; Andrews, 1993). Four broad Upper Palaeozoic stratigraphic units can be recognised within the zone. Unit 1, in South Wales, consists of a shortened foreland basin with Namurian-Westphalian fill (Gayer and Jones, 1989), overlying, unconformably in south-east Wales, Dinantian platform carbonates, and a thick fluvial Devonian Old Red Sandstone sequence. Unit 2, in north Devon, has Old Red Sandstone fluvial facies interdigitated with marine shelf facies Devonian, which are overlain by Dinantian deep water facies, and which in turn pass up conformably into a turbidite basin fill succession of Namurian to early Westphalian age. Unit 3 develops Devonian shelf facies and intrashelf basins in south Devon and central Cornwall; and unit 4 Devonian flysch-like deposits in south-west Cornwall. The zone is affected by very low grade metamorphism, which generally increases southwards and westwards (Warr and Hecht, 1993). The Lizard complex, in southern Cornwall, represents the incorporation of oceanic basement into the orogen (Gibbons and Thompson, 1991; Le Gal, 1990; Jones, 1994).

The main Variscan thrusts in the zone verge north-north-west, and an oblique convergence is indicated by such features as: rotation of fold hinges towards west-north-west — east-south-east trends; extension parallel to the fold hinges; minor oblique thrusts and folds with transecting cleavages, described by Andrews (1993) from Croyde Bay (Locality 14, Figure 2); and the predominance of major west-north-west — east-south-east dextral strike-slip faults, subparallel to the orogenic front, towards the hinterland in central and southern south-west England (e.g. Coward and Smallwood, 1984; Holdsworth, 1989).

The northern margin of the external zone is represented by two contrasted styles of deformation; the first in the coal-bearing foreland basin and its immediate surrounds (localities 1-13, Figure 2), and the second in the area to the south of the Bristol Channel (localities 14-17, Figure 2). In the first area, palaeomagnetic data from the Old Red Sandstone at locality 5 and from areas north of the Carreg Cennen Disturbance (Figure 2), underlying the regional unconformity beneath

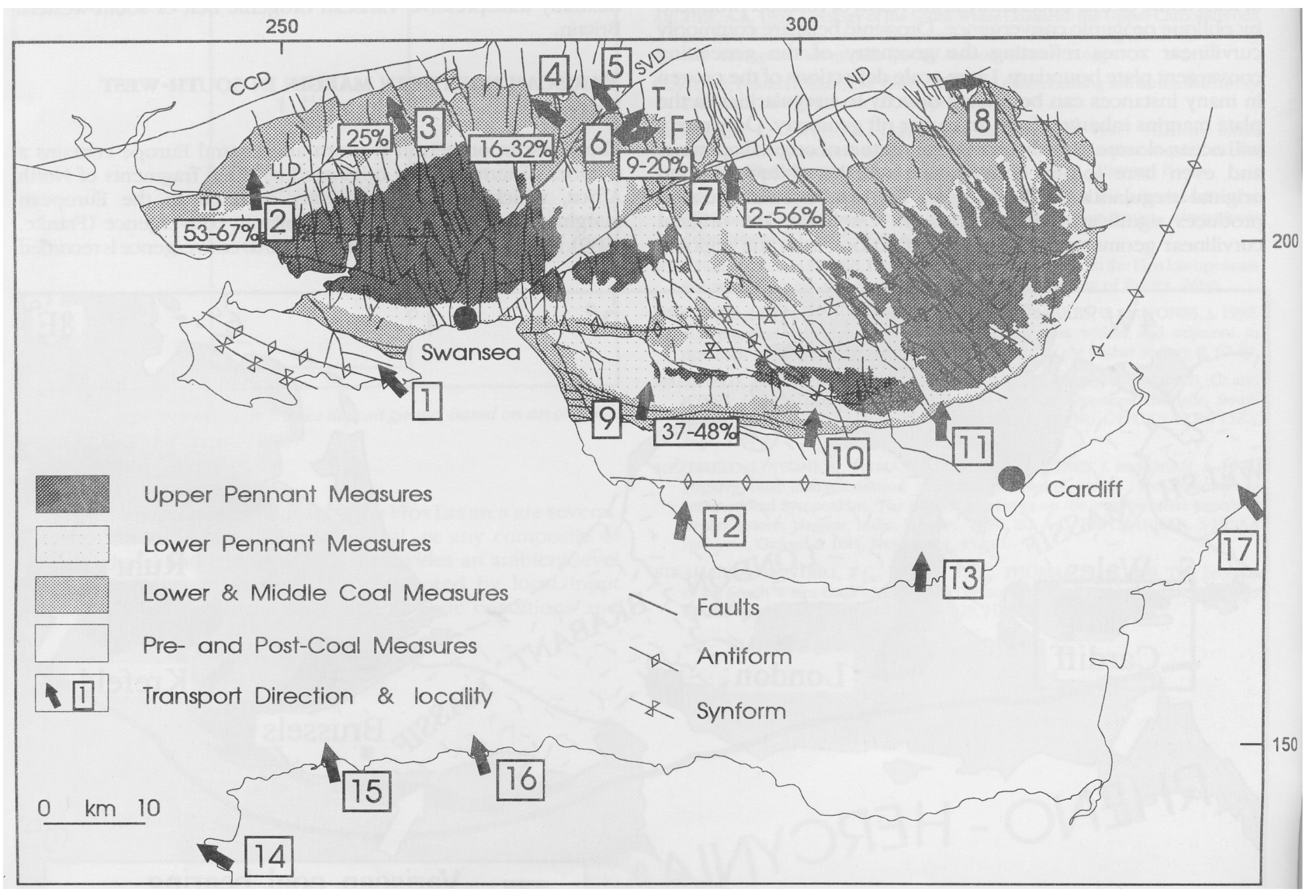

Figure 2. Geological map of the South Wales coalfield foreland basin and the southern margin of the Bristol Channel, located in Figure 1, showing the principal structures of the foreland basin. The locality names and their grid references are as follows: locality 1 = Caswell Bay [259 187]; locality 2 = Ffos Las Opencast Coal Site (OCCS)[245 205]; locality 3 = Gilfach lago OCCS [261 212]; locality 4 = Bryn Henllys OCCS [276 212]; locality 5 = Cribarth [282 214]; locality 6 = Nant Helen OCCS [282 211]; locality 7 = Ffyndaff OCCS [293 205]; locality 8 = Clydach Gorge [321 212]; locality 9 = Park Slip OCCS [285 183]; locality 10 = Llanilid OCCS (299 181]; locality 11 = Taff Gorge (312 182]; locality 12 = Trwyn-y-Witch, Ogmore [288 172]; locality 13 = Barry Island [310 166]; locality 14 = Croyde Bay [243 138]; locality 15 = Wild Pear Beach, Combe Martin [258 14 7]; locality 16 = Woody Bay [268 149]; locality 17 = Portishead Point [346 177]. The black arrows at the numbered localities represent transport directions determined from fold and thrust orientations; at locality 6 separate transport directions are shown for the folds (F) and thrusts (T). Values of percentage shortening, (Jones, 1991, and calculated from data in Miliorizos, (1992), and from our own *data) are shown in boxes at the numbered localities. CCD = Carreg Cennen Disturbance, LLD = Llannon Disturbance, ND = Neath Disturbance, SVD = Swansea Valley Disturbance, TD = Trimsaran Disturbance. Geology based mainly on the Institute of Geological Sciences 1:250000 sheets - Bristol Channel and Lundy.*

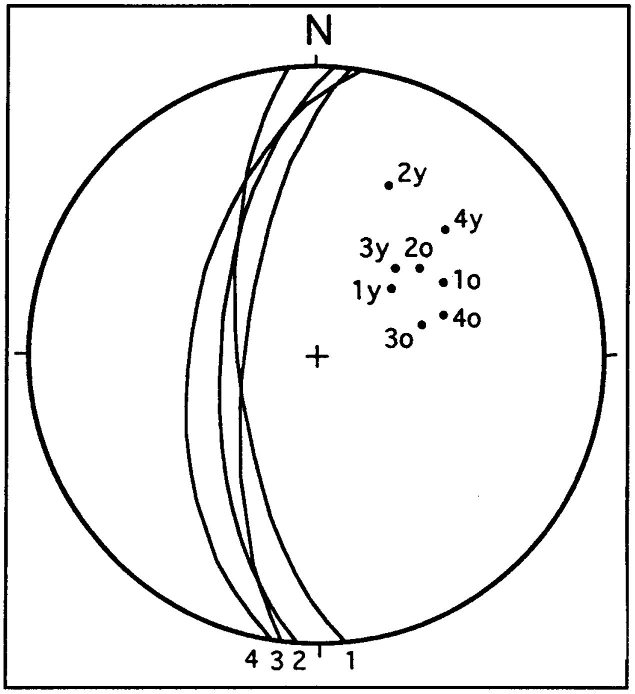

Figure 3. Lower hemisphere stereoplot of structural data from the Old Red Sandstone, Ilfracombe Slates at locality 15, located in Figure 2, showing great circles of numbered antitaxial extensional quartz veins developed sub perpendicular to fold hinges, and poles of the infilling, sigmoidally shaped quartz fibres. A sinistral component of displacement across the veins is indicated by the change from original (o) to younger (y) fibre orientations, and implies a dextral rotation of the fold hinges.

the Namurian-Westphalian foreland basin, show no evidence for rotation (Setiabudidaya, 1991). The foreland basin fill, however, is strongly deformed by folds and thrusts which are associated with extensive detachments within the coal seams of the Lower and Middle Coal Measures. Thrust ramps branch from these detachments, forming imbricate fans, with associated propagation folds (Cole *et al*, 1991). Major zones of west-south-west — east-north-east striking disturbances, e.g. the Carreg Cennen disturbance, the Llannon disturbance, the Swansea Valley disturbance and the Neath disturbance (Figure 2), are interpreted as major frontal thrust ramps (Jones, 1991). The fold and thrust deformation forms a foreland propagating thrust wedge that has accommodated variable amounts of shortening, with the highest levels of strain developed in association with the detachments; e.g. 53-67% shortening associated with the Llannon disturbance at Ffoslas (locality 2, Figure 2). Beneath the lowest detachment, levels of thrust-related shortening are very low. The folds and thrusts above this detachment show variable orientation and vergence (Figure 2). The deformation has resulted in significant dextral passive rotation; e.g. the north-west — southeast to north-south trending cross-faults in Figure 2, that formed as dextral strike-slip ramps associated with the thrust deformation, have been clockwise rotated by up to 38° in the area containing localities 6, 7, and 9-11, (Figure 2). The amount of this rotation is, however, variable which may reflect the multiple reactivation history of some of the cross-faults (Cole *et al.,* 1991). Only the earlier fault strands will record the full rotation; the later phases will have received less or no rotation. A full analysis of the fault orientation and history has not been attempted and would require additional data. In the Same area, the directions of local tectonic transport, based on fold and thrust orientation, have been rotated by up to 90° from the regional Variscan north-west direction (Figure 2). These rotations from the regional trend suggest a thin-skinned deformation of the foreland basin as a result of oblique convergence. Dip-slip thrusting in some parts of the external zone outer margin has quite atypical directions (localities 6 and 8, Figure 2). Similar structural features from Dinantian limestones of the foreland basin floor, cropping out along its southern margin (localities 1, 11-13, Figure 2) suggest that these rocks also underwent a dextral rotation. Palaeomagnetic data from deformed Old Red Sandstone in south-western Wales, along tectonic strike to the west, south of the coalfield in Pembrokeshire (Figure 1), (McClelland Brown, 1983; McClelland, 1987; Setiabudidaya, 1991) indicate a passive dextral rotation of 10°-45°.

In the second area, along the southern margin of the Bristol Channel, oblique thrusts and folds with hinge-parallel extension and dextrally transecting cleavages are developed. At Wild Pear Beach, West of Combe Martin (locality 15, Figure 2) rotated extensional quartz veins indicate up to 11° of dextral rotation (Figure 3).

Measurement of the orientation of faults and their associated slickenside lineations, at localities 6, 11 and 15, has allowed the orientation of the principal palaeostress axes to be determined, using the method of Hardcastle and Hills (1991) (Figure 4). These show that the σ_1 orientations along the northern margin of the coal-bearing foreland basin, are strongly rotated relative to the regional north-westerly Variscan convergence indicated by non-rotated strike-slip thrust ramps in the east and west of the coalfield (Figure 2). The rotation is up to 90° at locality 6 (Figure 2), where the levels of thrust-related shortening are generally less than 35%. Towards the hinterland the amount of rotation is progressively reduced, to about 11° at locality 15, where the levels of shortening are significantly greater (55% at locality 15).

INTERPRETATION

We interpret these data to suggest that in the thinner parts of the thrust wedge of the foreland basin a greater degree of rotation has occurred associated with a small component of pure shear. Whereas in the thicker parts of the wedge towards the hinterland, a greater component of pure shear is developed with a smaller amount of rotation.

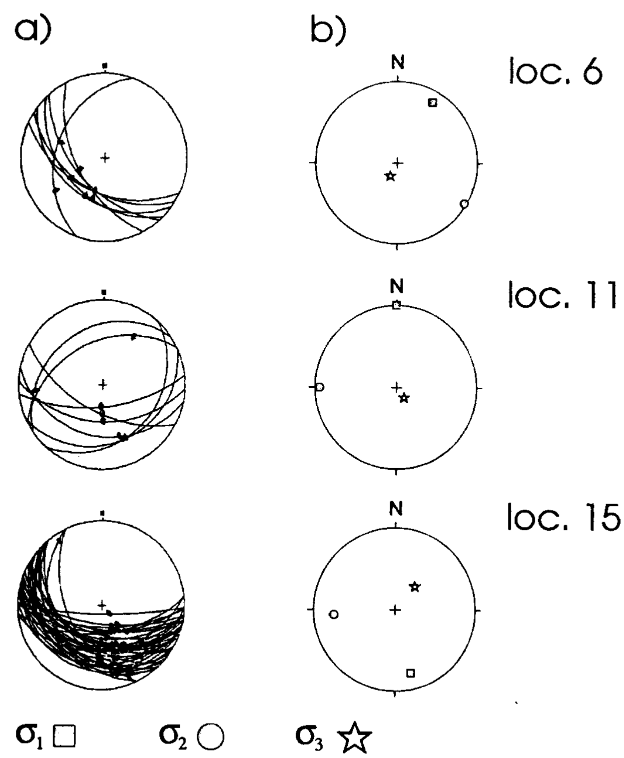

Figure 4. Lower hemisphere stereoplots of: a) great circles of thrusts, showing slip vectors, at three localities located in Figure 2; and b)principal axes of Variscan palaeostress determined from the data in a), following the method of Hardcastle and Hills (1991).

The analysis suggests that oblique convergence deflects the a, stress trajectories from a regional orientation in the hinterland towards a higher angle to the external margin which is assumed to be - 288°-108°, following Andrews (1993). In the thinner, northern, parts of the wedge, however, large and variable rotations occur. Thus the present orientation of σ_1 stress trajectories along the external zones of an obliquely shortened orogen should be treated very carefully when considering regional tectonics. The south-west British Variscides show that various divergent trajectories can be the result of different stages of the same process - transpression along the external orogenic zone.

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