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The deformational history of the area north-west of the Bodmin Moor granite, north Cornwall.

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Inland mapping and structural studies on the coastline of north Cornwall have revealed a complex series of deformational events ranging from early ductile phases of folding through to brittle thrusting, to extensional and strikeslip faulting. Downward SE facing F1 folds were overprinted by localised ductile shearing towards the NW which subsequently led to brittle fracturing and major thrusting. The thrust system is dominated by lateral ramps, the overall transport direction being towards the NW. A subsequent extensional phase of faulting in the north of the area and a series of E-W dextral strike-slip faults have been identified. These and other late fault trends can be linked with phases of mineralisation and igneous activity suggesting a late Variscan age.

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Introduction

The Variscan structure of north Cornwall is generally accepted to have evolved as part of the Rhenohercynian thin-skinned foreland thrust belt (Shackleton, Ries and Coward 1982). Stratigraphic and K/Ar dating show deformation to have been diachronous across south-west England, migrating NNW towards the foreland (Dodson and Rex 1971; Selwood and Thomas 1986b). Complications arose in the understanding of the regional pattern when folds formed by the first deformation were found to face towards the south between Polzeath and the southern margin of the Culm basin. This phase was found to oppose north facing folds south of Polzeath giving rise to a facing confrontation zone (Gauss 1967, 1973; Roberts and Sanderson 1971; Shackleton et al. 1982). Subsequent tectonic modelling of north Cornwall featured an overall transport direction towards the south as a series of overfolds (Hobson and Sanderson 1975; Rattey and Sanderson 1982). However, adjacent inland mapping in central south-west England by workers at the University of Exeter recognised a series of stratigraphic successions separated by fairly flat-lying thrusts, with the overall transport direction towards the north (Selwood and Thomas 1986b; Isaac et al. 1982). Consequently in the last few years attention has returned to the critical north Cornish coastal section (Selwood and Thomas 1986a; Pamplin et al. 1987, Andrew et al. 1988). Fresh studies have also been undertaken on the confrontation of structural styles in south-west Devon (Seago and Chapman 1988).

This paper is based on the mapping at 1:10,000 scale of an area of $50km^2$ situated midway between the facing confrontation zone to the south and the southern margin of the Culm basin to the north (Fig. 1). The area is bounded to the east by the Bodmin Moor granite and to the west by 6km of coastline from Tregardock Beach, southwards to Portgaverne (Fig. 2). It forms part of a NERC/University of Exeter contract to revise the BGS 1:50,000 Camelford and Trevose Head sheet (335/336).

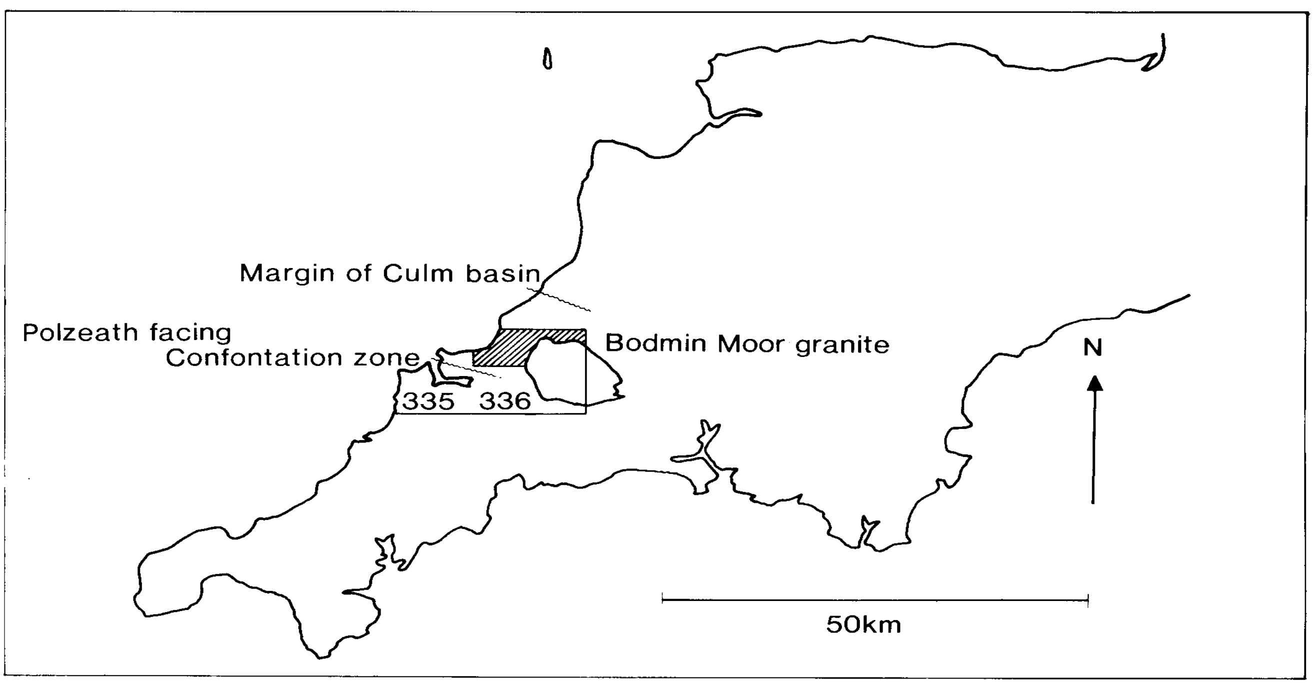

Figure I. Location of the area of study which is being remapped as part of the BGS Camelford and Trevose Head sheet *(335/336).*

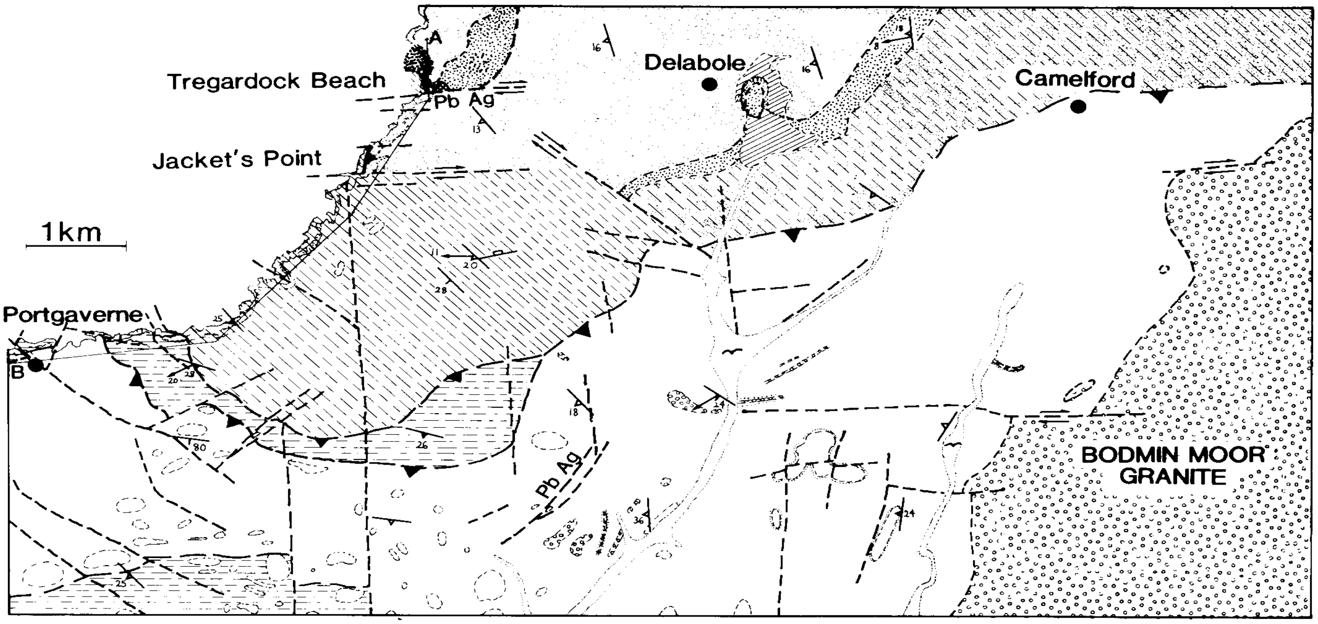

Figure 2. Geological map of the area to the north-west of the Bodmin Moor granite (see Fig. 3 for key). The cross-section A-B is shown in Fig. 5.

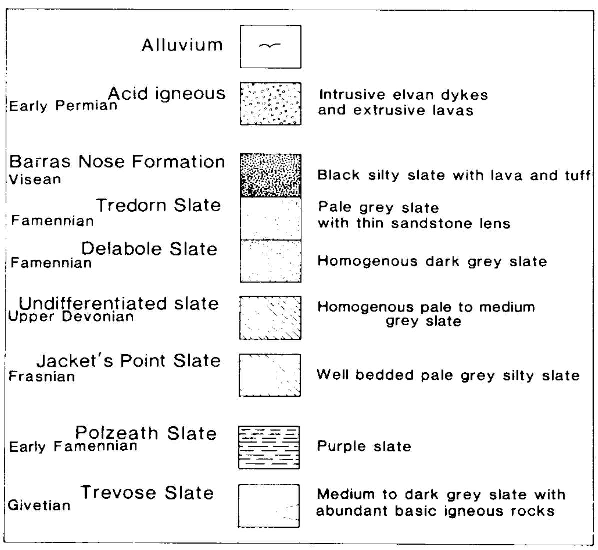

Figure 3. The generalised stratigraphic succession of the area.

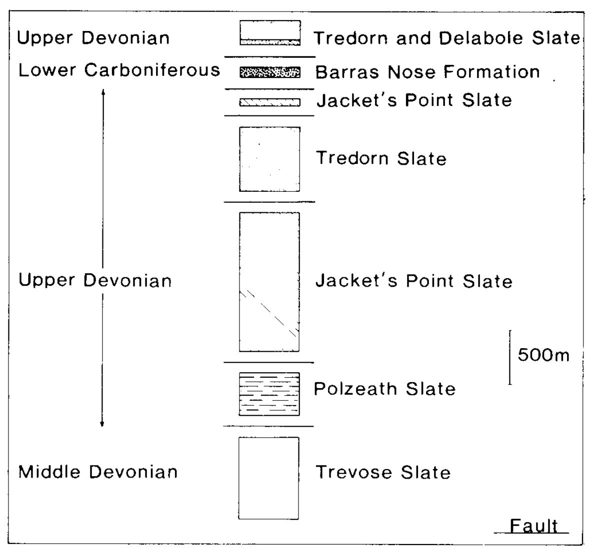

Figure 4. The structural/stratigraphic sequence of the coastline

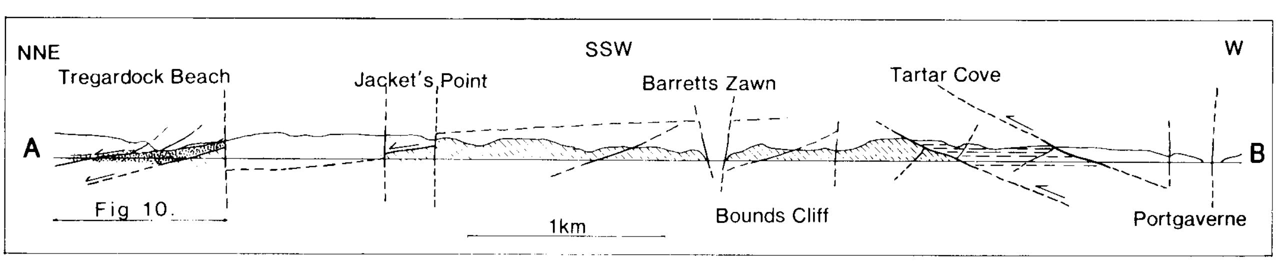

Figure 5. A cross section of the coastal exposure between Tregardock Beach and Portgaverne.

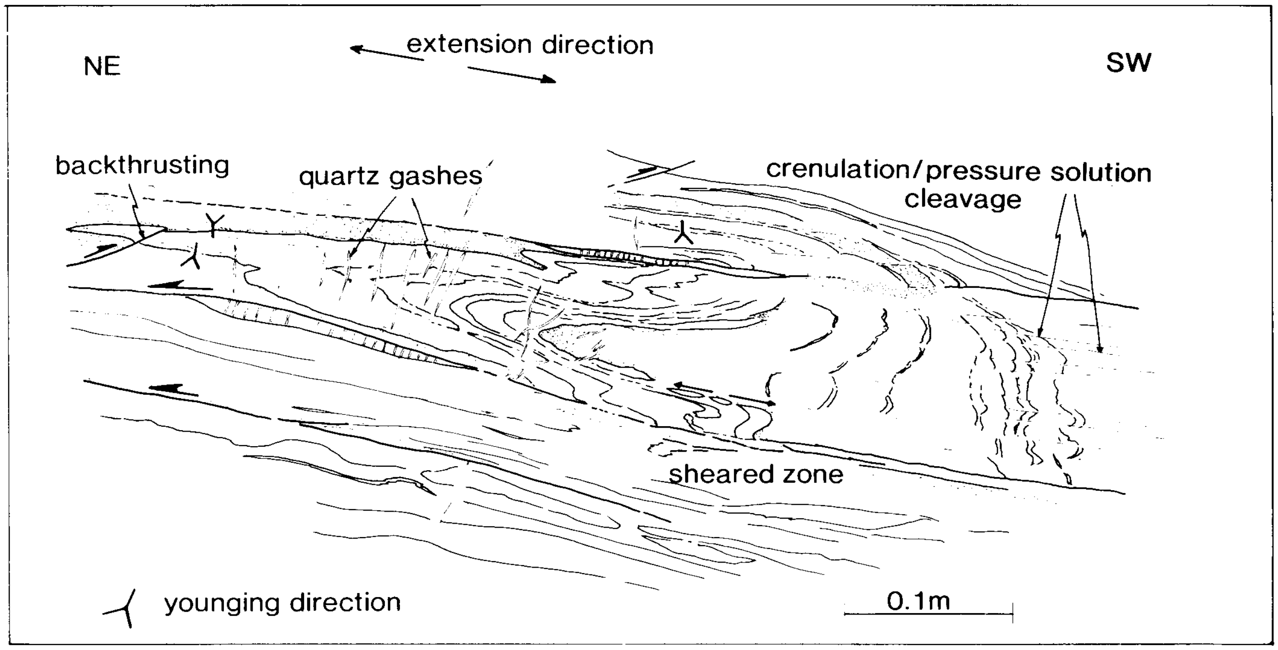

Figure 6. A tight downward south-facing fold with pressure solution and crenulation effects in the core, found in the arenaceous Lower Carboniferous slate at Tregardock Beach.

The nature of the stratigraphy

Fig. 3 shows the stratigraphic sequence of the area which consists predominantly of pale to dark grey argillaceous slate throughout the Middle Devonian to Lower Carboniferous. These include important basic extrusive igneous rocks in the dark grey Middle Devonian Trevose Slate and Lower Carboniferous Barras Nose Formation. In addition a newly recognised suite of acid igneous rocks of probable Permian age has been identified which follow a linear NE-SW trend, parallel to the margin of the granite. The coastal exposure is illustrated by a structural/stratigraphic column (Fig. 4) and a cross section (Fig. 5). These show a dominantly fault-bounded series of stratigraphic units, now over 3km in structural thickness. At Tartar Cove, Polzeath and Trevose, slate of the Pentire Succession (Gauss and House 1972) have been thrust northwestward onto the paler grey slate of the Tintagel Succession (Selwood and Thomas 1986b).

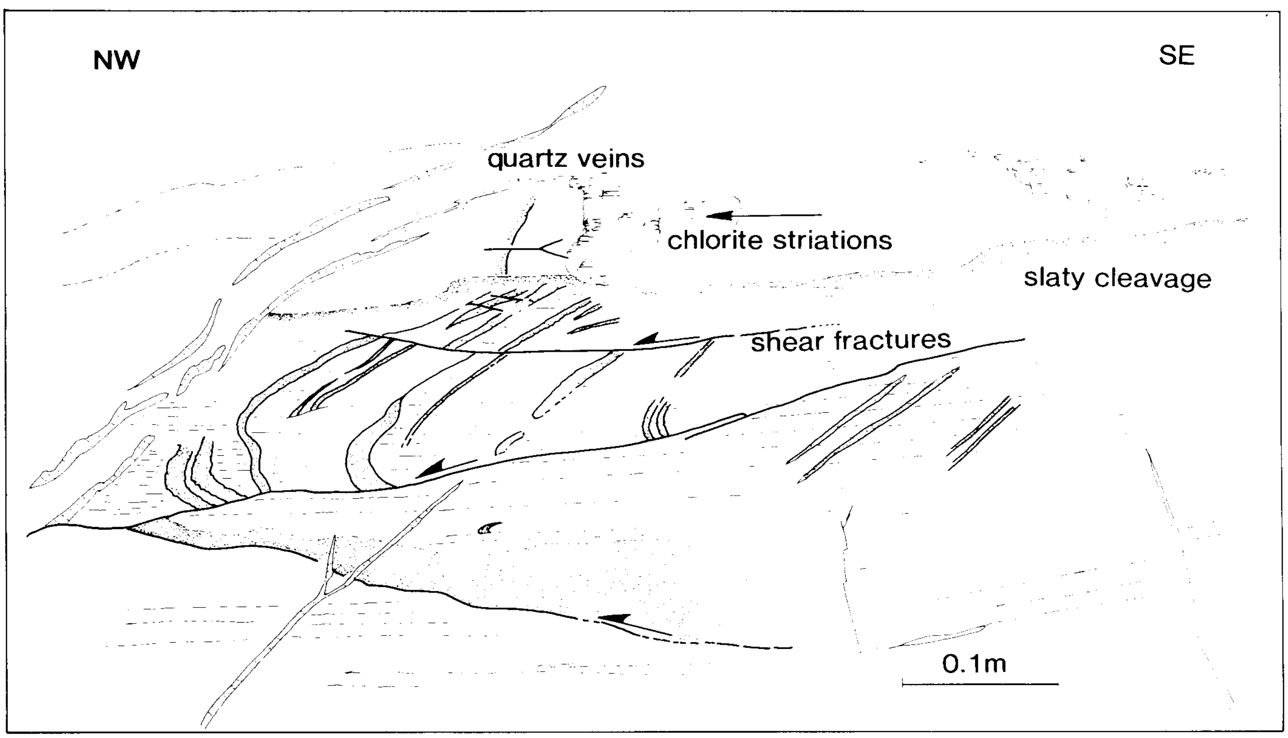

Figure 7. F2 fold at Jacket's Point, the fold vergence, facing direction and chlorite striations all indicate a transport direction towards the north-west.

This boundary forms a major structure with a marked lateral ramp geometry which can be traced inland eastwards from Portgaverne and then northeastward towards Camelford (Fig. 2).

An outline of the deformational sequence

The first deformation (DI)

This was a ductile folding event which gave rise to the dominant gently dipping slaty cleavage throughout the area. This cleavage which dips gently towards the south-west is observed to be axial planar to mesoscopic F1 folds that are usually tight to isoclinal and face gently downwards towards the south-east. Local crenulation and pressure solution effects can be observed in the cores of tight F1 folds developed in more arenaceous Lower Carboniferous slate at Tregardock Beach (Fig. 6).

Using way-up criteria, cleavage-bedding geometry and fold vergence the position on major fold structures can be identified. Up to 1 km of overturned beds in a lower limb is seen in the Upper Devonian between Tregardock Beach and Jacket's Point. An upper limb is seen at Tregardock Beach in the Lower Carboniferous and u hinge region represented in the Middle Devonian at Portgaverne. The cleavage changes from being anticlockwise of bedding on the rightway-up limb to clockwise of bedding on the overturned limb when viewed from the west.

The second deformation (D2)

This consisted of a thrusting and shear folding event directed towards the north-west. On a large scale it produced major south dipping thrust faults, emplacing older strata upon younger as well as thrust-repeating stratigraphic units. Early ductile shearing towards the north-west along S1 cleavage planes was locally intense enough to form north-west verging shear folds which face either towards the north-west or south-east depending on the initial way up of the bed (Fig. 7). Local refolding may be expected where F1 and F2 folds coincide.

At Jacket's Point these structures are seen to be cut by a series of low angle fractures (Fig. 7). These fractures fit into a brittle shear system similar to those produced in shear box experiments on layered clays (Tchalenko 1968). Riedel, thrust and Riedelconjugate shears can be recognised indicating shear towards the north-west (Fig. 8). The principal planes of displacement show thrust fault geometries at the base of the cliff, which separate Tredorn from Jacket's Point Slate lithologies. Kink bands occur in the Riedel conjugate position; these were zones of disruption and fracturing which allowed the channelling of Fe- and Mnprecipitating solutions to pass through. At Tregardock Beach D2 thrusts can be seen to transect F1 folds in a spectacular way, cutting through both hinge and limb regions (Fig. 9). In terms of their strain ellipses, D1 and D2 are coaxial with each other. The first was a downward ductile shear towards the south-east, followed by a complete reversal of shear direction towards the north-west. The extension and shortening directions were the same for both deformations, as shown by later extensional quartz veins truncating earlier ductile extensional structures.

The third deformation (D3)

D3 consists of an extensional phase of faulting developed in the north of the area and is best studied at Tregardock Beach. Here it is responsible for the gently northward dipping faults that repeat Upper Devonian and Lower Carboniferous rocks (Fig. 10). Fault lineation data suggest movement downwards towards the northwest, cutting downsequence across well developed D1 and D2 structures, in the Lower Carboniferous slate. Because the main fault emplaces Upper Devonian onto Lower Carboniferous rocks it has previously been considered to be a tilted thrust fault similar to those outlined by Wilson (1951) in the Tintagel area to the north. At Tregardock Beach these faults with extensional geometries truncate south-dipping faults in their footwall.

Late faulting episodes

Some five major trends of faults have been mapped in the area (Fig. 2), the most significant of which are a series of E-W dextral strike-slip faults with displacements of up to a kilometre.

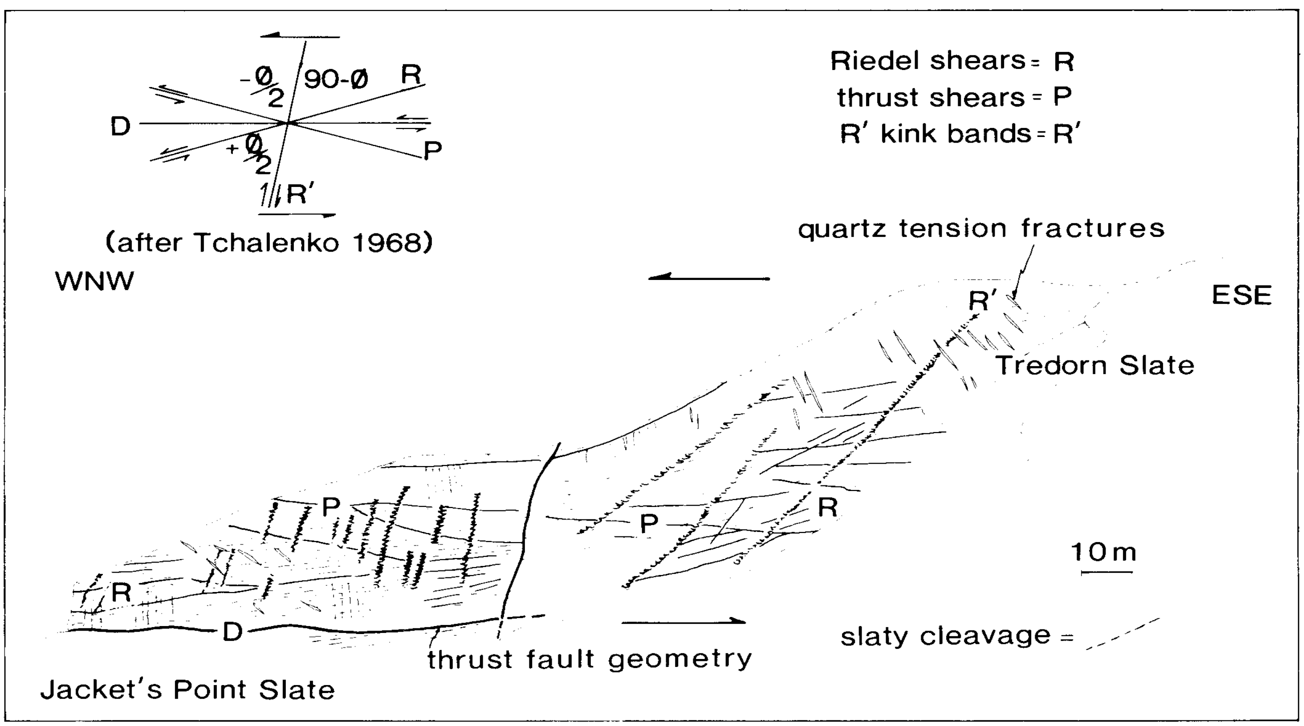

Figure 8. D2 brittle shear fracture geometries at Jacket's Point.

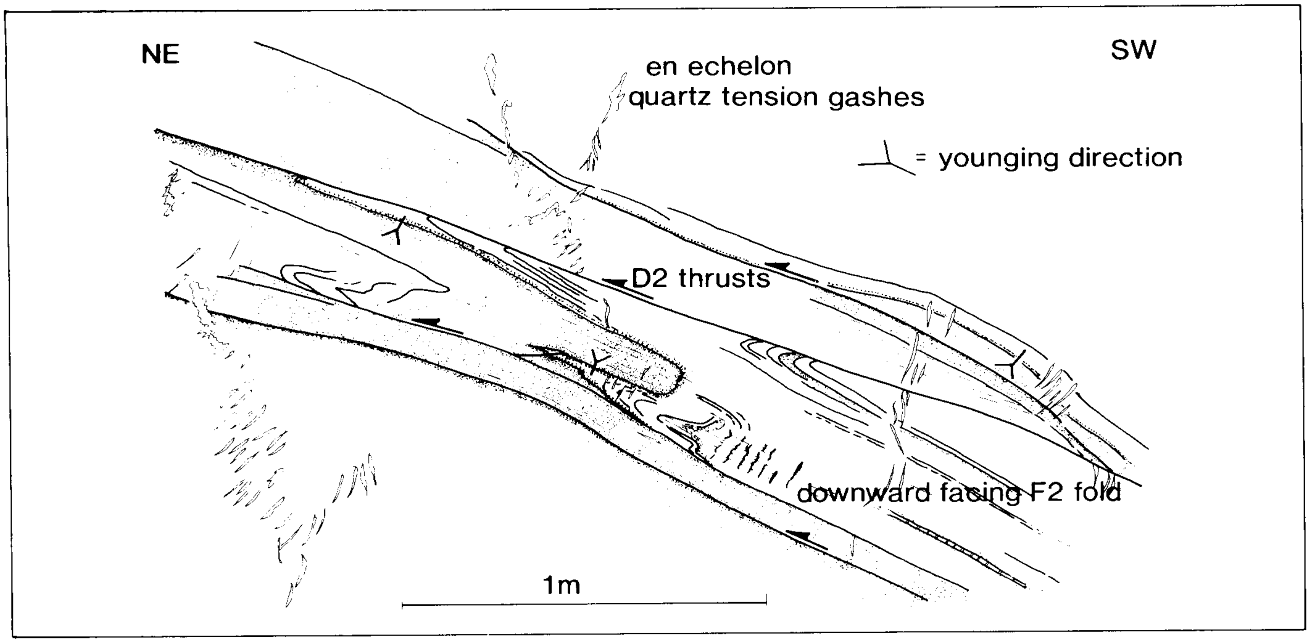

Figure 9. T2 thrusts transecting F1 folds at Tregardock Beach.

Previously believed to be normal or reverse faults, their lateral movements have resulted in significant differences in early structure across these boundaries; for example at Jacket's Point where the facing of F1 folds is seemingly rotated across the steep E-W fault, which juxtaposed overturned Jacket's Point and Tredorn Slates to the north against Jacket's Point Slate to the south.

Such fault movements can be dated as late Variscan as they postdate the granite intrusion but are syn- or pre-lamprophyre dyke emplacement (probably late Carboniferous to early Permian in age) seen parallel to the E-W fault at Tregardock Beach. The E-W, N-S and NE-SW faults are associated with Pb and Ag galena mineralisation, and early Permian igneous activity occurred along E-W and NE-SW trends. The latest movements seem to have occurred along NW-SE trends which may have been reactivated during Tertiary movements.

Conclusions

The Middle Devonian to Lower Carboniferous slates of the area north-west of the Bodmin Moor granite have undergone a diverse range of deformational episodes. Two phases of ductile shearing are recognised, the first a major shearing towards the south-east which produced downward facing folds with S1 slaty cleavage development. This was followed by a reversal of the shear direction towards the north-west, the strain being taken up locally by slip along S1 planes. Deformation became progressively more brittle leading to major thrusting towards the north-west, causing major transection of the F1 folds. It therefore follows that large scale F1 folds cannot be fully mapped out until later displacements are removed. The major thrust crossing the area from east of Portgaverne to Camelford varies in strike from E-W to NE-SW (Fig. 2). It has a marked lateral ramp geometry, emplacing Middle and Upper Devonian Trevose and Polzeath Slate onto Upper Devonian Slate. This is the most likely

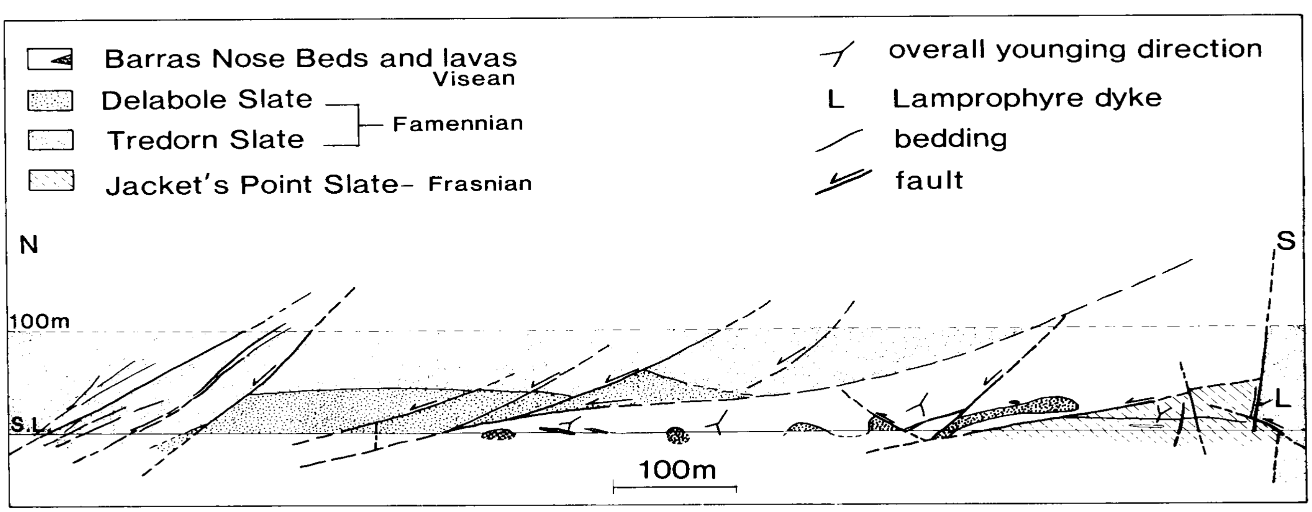

Figure 10. Structural section of Tregardock Beach showing a series of northward dipping extensional faults.

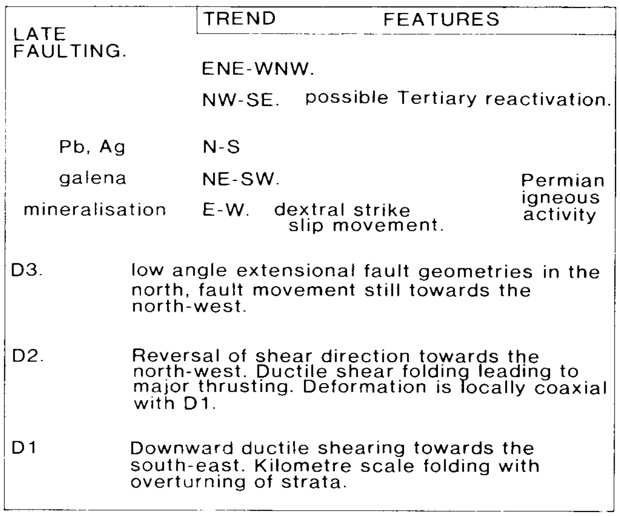

Figure 11. Summary of the deformation history.

boundary between the Tintagel Succession in the north and Pentire Succession in the south.

The north of the area is dominated by an extensional phase of faulting which has juxtaposed Upper Devonian and Lower Carboniferous rocks. This is well developed at Tregardock Beach (Fig. 10), where north dipping faults with extensional geometries are seen to cut D2 thrusts.

Late stage faulting was dominated by a series of E-W dextral strike-slip faults. These and associated fault trends can be tied in with phases of mineralisation and igneous activity which date movements at around late Carboniferous to early Permian times. This correlates well with a major E-W dextral strike slip event shown by Ziegler (1984) to have been active at this time across western and central Europe. A summary of the deformational history is represented by Fig. 11.

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