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A new model for the development of the Variscan facing confrontation at Padstow, north Cornwall

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Models to explain the confrontation of fold facing at Padstow, north Cornwall, involve either *in situ* refolding or backthrusting. It is commonly accepted that south-transporting deformation (D1n) has deformed the earlier north-transporting deformation (D1s). A new model is proposed here, in which south-facing folds developing in the north (F1n) are refolded at their southern limit by structures formed during north-transporting deformation (D1s). A north-transporting thrust separates north-facing folds (F1s), developed further to the south, with this overprint zone and marks the position of the facing confrontation.

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Introduction

In the coastal sections near Padstow, north Cornwall, two stratigraphic successions thought to be laterally equivalent (Gauss and House 1972), are exposed (Figs 1 and 2). North of Trebetherick Point (SW 9250 7798), the Pentire Succession has suffered polyphase deformation; facing on the primary slaty cleavage (S1n) is to the south. The Trevone Succession to the south shows only one significant deformation with northward facing on the slaty cleavage (S1s). Folds with opposed facing in this area were first identified by Roberts and Sanderson (1971) who proposed a model involving refolding. Gauss (1973) suggested that the structural zones were juxtaposed by a north-dipping thrust, and in a more regional context Coward and Smallwood (1984) suggested that large-scale backthrusting was involved.

Andrews et al. (1988) present a modified version of the Roberts and Sanderson model, in which structures resulting from an early northward-transporting deformation (D1s) were subsequently refolded by a south-facing fold (F1n). The area of main structural overprinting is referred to as the confrontation zone.

During 1:10,000 mapping of the confrontation zone, as part of a NERC/University contract for the revision of BGS Geological sheet 336 (Camelford), the line of confrontation has been identified as a south-dipping, northward-transporting thrust (Figs 2 and 3) extending inland from Trebetherick Point. The geology of the confrontation area is more effectively described in terms of two structural zones lying to the north and south of this thrust.

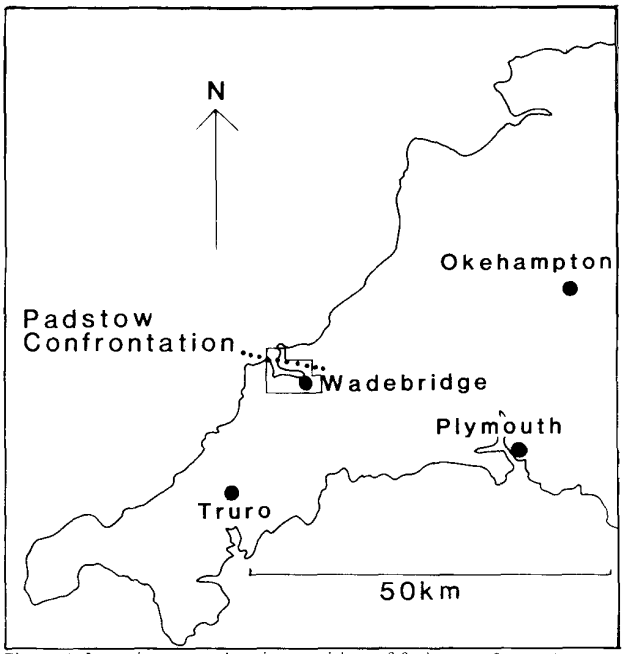

Figure 1: Location map showing position of facing confrontation.

Southern zone

In the coastal section on the west side of the Camel estuary between Padstow (SW 920 754) and Hawker's Cove (SW 913 776), the Trevose Slate Formation (older) is thrust over the Harbour Cove Slate Formation (younger) just south of St George's Cove (Fig. 4a). The hanging-wall sequence of Trevose Slate Formation is inverted with folds on various scales indicating southward vergence. The sequence therefore comprises the overturned north-facing limb of a hanging-wall anticline. The right-way-up limb is seen in the coastal section at Bedruthen Steps (SW 8485 6965) where the sequence is the right way up and all-scale folds verge to the north. The footwall sequence of the Harbour Cove Slate Formation is essentially the right way up and the small-scale folds indicate a neutral vergence and probably occupy the core of a frontal syncline. The presence of overprinting crenulation cleavages (see below), which locally deform the S1 fabric, does not indicate that there is any major refolding of pre-existing structures.

Northern zone

The southern and northern zones are separated by a thrust juxtaposing the Harbour Cove Slate Formation (older) and the Polzeath Slate Formation (younger) (Figs 2 and 3). Multiple cleavages occur immediately to the north of this fault resulting in more complex deformation compared to that to the south of the fault.

Four distinct cleavages have been identified in the coastal section from Trebetherick Point to Pentire Point:

S4: A steeply inclined NNW-SSE trending crenulation cleavage, which is locally intense. This cleavage has also been observed in the southern zone and is developed throughout Devon and Cornwall (Hobson and Sanderson 1983).

S3: A moderate south-dipping crenulation cleavage is locally developed in both the northern and southern zones. This cleavage is axial planar to north-verging shear folds (F3) which deform pre-existing folds and fabrics.

S2: A flat-lying or gently south-dipping crenulation cleavage, which deforms earlier structures. It is associated with asymmetric north-verging folds (F2) with wavelengths of 1 to 10m. Tension gashes associated with this cleavage at Trebetherick Point indicate northward shear. F2 folds on a centimetre to metre scale, locally refold D1 structures into asymmetric, north-verging folds. Fold axes trend NE-SW and plunge gently in either direction but there is no major refolding of the F1 structures.

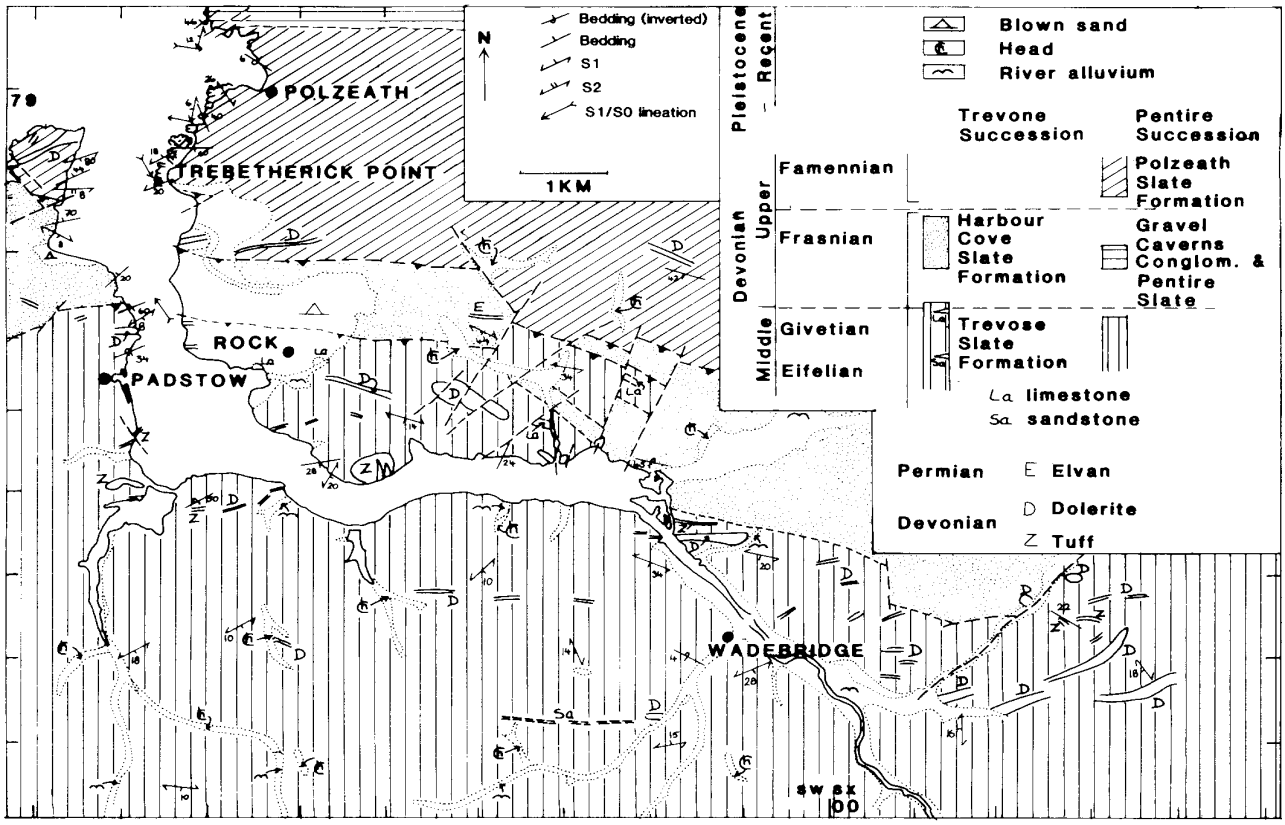

Figure 2: Geological map and successions of the Padstow area. Thrusts illustrated with barbs on hanging wall.

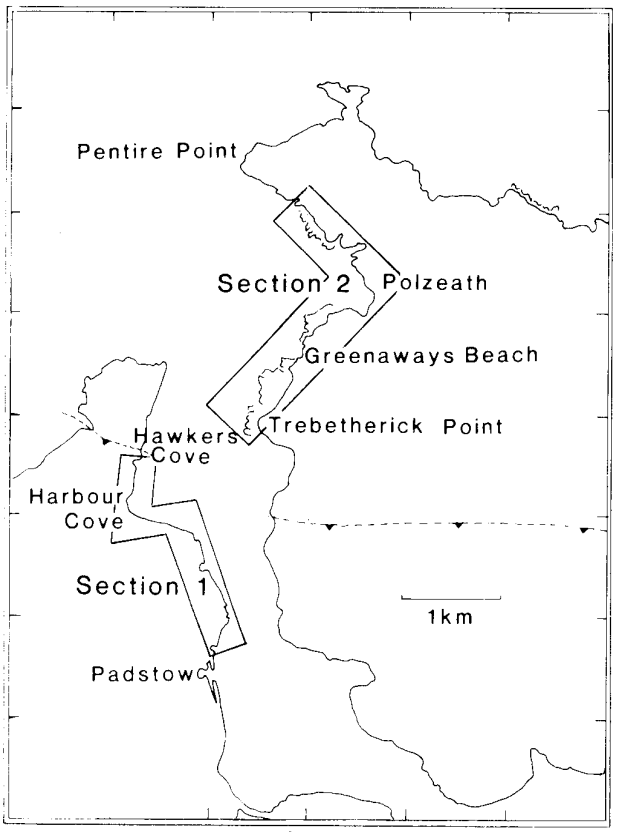

Figure 3: Location map showing position of coastal sections.

Sl: This is a slaty cleavage and is the earliest cleavage to form (S1n). North of Greenaways Beach it dips to the NW. In the northern zone (Fig. 4b), the S1n cleavage is orientated clockwise of inverted north-dipping beds when viewed with north to the left. These relationships indicate that the facing along the cleavage is to the south. Local changes in bedding/cleavage relationship are a function of F1 folds. However, southward facing is a consistent feature of this section. At Greenaways Beach (SW 9280 7830) bedding and cleavage are parallel, or cleavage is orientated anticlockwise of bedding and indicate the presence of a south-verging asymmetric synform. Sedimentary structures in the form of local channelling indicate that the structure is synclinal and facing on the cleavage is to the south.

Correlation of the deformation chronology

The attitude of the second phase structures (D2n) of the northern zone is similar to the first phase (D1s) structures of the southern zone, and it is therefore suggested that they resulted from the same deformational event. It follows that within the northern zone there is a pre-existing fold phase (F1n) not present in the southern zone.

Folds produced during this phase of deformation locally face downwards, and have been identified further north (Warr 1988; see also Reid *et al.* 1910). Northward-transporting deformation (D1s), may have begun further south prior to or at the same time as the southward-transporting deformation (Seago and Chapman 1988). The structures resulting from D1s overprint those formed during D1n resulting in D2n structures. Continuing northward-transporting deformation was first expressed as shear folds (F3). The deformation then became brittle and northward-transporting thrusts shortened and juxtaposed the two zones giving rise to a facing confrontation (Fig. 5). Late faults occur in both zones and cross-cut the late

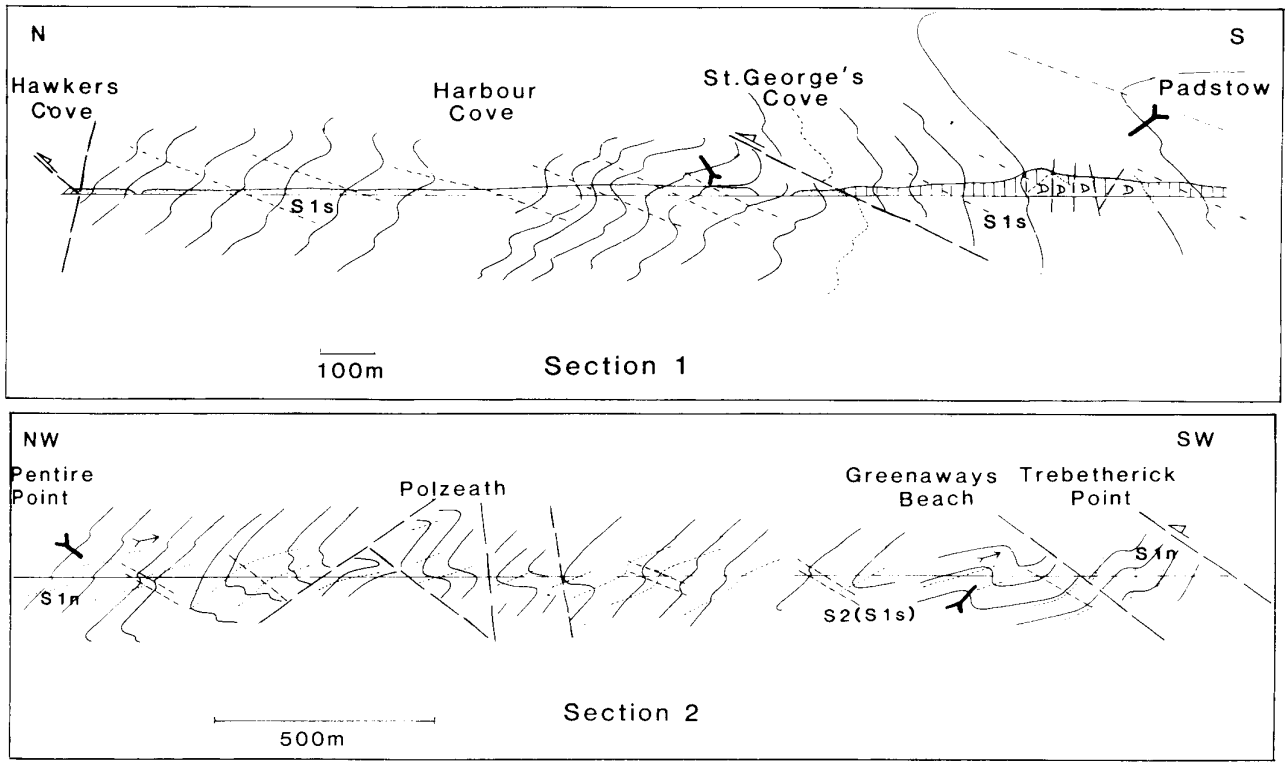

Figure 4: (a) Schematic coastal section 1. Southern Zone - Padstow to Hawker's Cove. (b) Schematic coastal section 2. Northern Zone - Trebetherick Point to Pentire Point. Ornamentation as in Fig. 2. Solid lines indicate orientation of bedding; dotted line indicates orientation of S1n; dashed lines indicate orientation of S2(S1s); thick arrows indicate younging direction; steep dashed lines indicate positions of faults.

upright crenulation cleavage (S4) developed during a final phase of deformation (Hobson and Sanderson 1983).

Discussion

It is the view of Andrews et al. (1988) that D1s predates D1n in the confrontation zone. However, data presented here indicates the presence of pre-existing southward-directed structures (D1n) overprinted by northward-directed structures (D1s) (Seago and Chapman 1988). This requires the slaty cleavage of the confrontation zone to be S1s, distributed about a large D1n fold hinge. This rotation of cleavage is not observed. It is therefore not necessary to assume the S1 cleavage to be S1s. The slaty cleavage is primarily south-facing and the first overprinting crenulation cleavage is the expression of S1s.

The evidence derived from shear indicators which Pamplin and Andrews (1988) use to support early northward transport in the confrontation zone is not conclusive. In the example from an unnamed cove 200m south of Trestram Cove (Pamplin and Andrews 1988, p.75, fig. 5c) the vein could have buckled during bedding-parallel flattening. In its present form the overprinting S2 (S1s) cleavage displaces the small veins giving a northwards sense of offset. Similarly, the asymmetric augens at Trestram Cove (Pamplin and Andrews 1988, p.74, fig. 5) may be interpreted differently. A sea stack at this locality contains a metre-scale north-closing F1 fold with a lower subhorizontal limb and an upper limb dipping moderately north. The axial plane cleavage dips gently north. Elsewhere in the cove the cleavage has a gentle southwesterly dip. Where cleavage cuts across thin sandstone beds asymmetric augens indicating northward shear are developed. Pamplin and Andrews (1988) interpret this as evidence of early northward shear. However, these augens have the appearance of shear bands and cut both limbs of the fold. This structure therefore indicates an early period of southward-directed shear to form the fold which was overprinted by a period of coaxial northward shear. Small

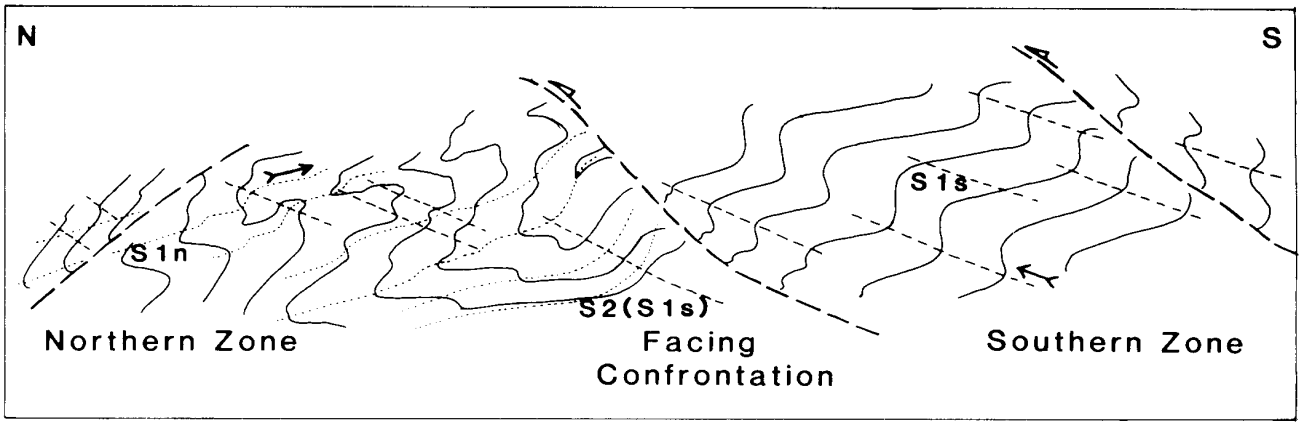

Figure 5: Schematic structure of the Padstow Confrontation.

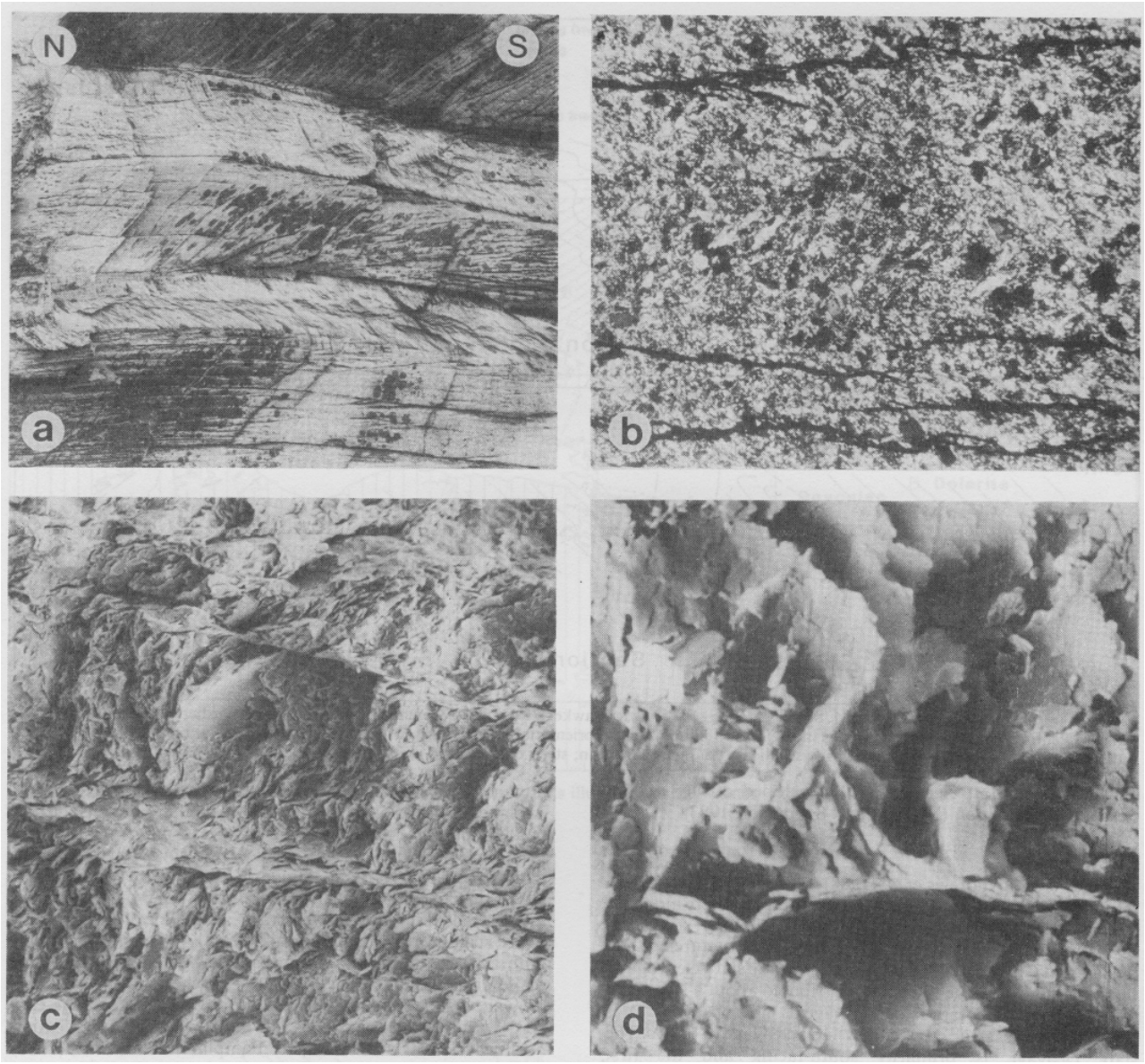

Figure 6: (a) Field photograph of purple (dark grey) and green (light grey) bedded slate at Trebetherick Point. The S1n slaty cleavage dips to the north in the purple units and to the south in the green units; fold hinges coincide with bedding planes. The S1s cleavage which cuts across S1n is flat lying and well developed within the purple units. Field of view is 2m. (b) Photomicrograph of thin section of specimen taken from the purple horizon. Steep S1n, a mica alignment fabric, is openly folded with S1s pressure solution stylolites developing within some hinge regions. Magnification x100. (c) SEM photograph of specimen from purple unit. Steep S1n cleavage is clearly seen as an alignment of mica flakes with S1s defined by spaced plans of recrystallised mica cutting across from left to right. Magnification x384. (d) An enlarged view where folded sheets of mica defining the steep S1n cleavage bend into and are cross-cut by recrystallised micas defining a flat-lying S1s. Magnification x3000.

locally developed south-transporting thrusts cross-cut the augens indicating renewed southward shear. The S2 cleavage associated with northward shear then overprints all earlier structures.

The evidence (Pamplin and Andrews 1988, p.74, fig. 6) for early northward shear in the Polzeath Slate Formation at Trebetherick Point (SW 925 779) is based on an incorrect interpretation of the cleavages. Two cleavages are present within the purple and green banded rocks, a steep cleavage which is folded into chevron folds and dips to the north in the purple units and to the south in the green units, and a flat-lying almost bedding-parallel cleavage which is only developed in the purple units. Field evidence shows that the bedding-parallel cleavage cross-cuts and so postdates the steep cleavage. This is confirmed in thin section and under the SEM where the steep cleavage is crenulated by the flat-lying cleavage (Fig. 6). Hence the interpretation for this section is that a steep, early cleavage with facing on the cleavage upwards and to the south is chevron-folded during northward shear (indicated by adjacent tension gashes within the green units). Therefore shear indicators imply an early phase of deformation (southward facing) which is overprinted by northward shear. Selwood and Thomas (1988) argue that the steep early cleavage is an unrotated early feature, and that the flat-lying cleavage is the product of flattening associated with northward overthrusting. However, the upright attitude of the early cleavage appears to be due to refolding in D2n, as, when followed northwards, the steep cleavage rotates into a gentle northerly dip. The steepness is a localised feature and is also seen at Pentireglaze (SW 9320 7975) where its attitude is determined by additional F2 folding.

Conclusions

The order of events in the region of the facing confrontation is as follows:

1. Southward-directed deformation to produce large south-facing folds (D1n) in the north. Further south, north-facing folds begin to develop (D1s).

2. First expression of northward-transporting deformation in northern zone develops local shear bands which cut early south-facing folds.

3. Continued southward deformation produces localised south-transporting thrusts.

4. Northward-transporting deformation (D1s) continues and refolds the main south-facing fold (F1n) at its southern limit, this overprinting is the complex confrontation zone between Trebetherick Point and Pentire Point.

5. Continued northward-transporting deformation develops local crenulation cleavage (S3) in both zones which are now adjacent. Brittle thrusts shorten the structure and bring northfacing structures (D1s) over south-facing structures (D1n).

6. Late faults and crenulation cleavage (S4).

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