

The structural evolution of the Davidstow Anticline, and its relationship to the Southern Culm Overfold, north Cornwall

L.N. WARR

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The formation of the Davidstow Anticline is regarded as synchronous with the development of the Tintagel High Strain Zone, which evolved during early heterogeneous D2 shear strain directed towards the NNW. This movement wedged (underthrust) beneath the Culm trough sediments, initiating backthrusting and the formation of the Southern Culm Overfold during early Stephanian times. F1 folds south of the Rusey Fault Zone are attributed to an earlier phase of backthrusting occurring between post-lowest Namurian and pre-late Westphalian times (315-300±SMa). These F1 fold axes were subsequently rotated during D2 high shear strain towards the principal stretching direction, initiating 'folds oblique to the regional trend'. Continued wedging of the Culm flysch basin initiated late F2 folding in the wedge. The low angle north-dipping faults of the Tintagel and Boscastle area are considered to be the same generation of low angle extensional faults as affect the southern Culm Synclinorium; reactivation of D1 backthrusts is probable. Ruck folds in the fault zones of the Tintagel area are attributed to the sticking of basal fault surfaces during extensional movements.

L.N. Warr, Department of Geology, University of Exeter, North Park Road, Exeter EX4 4QE.

Introduction

The Davidstow Anticline is a regional scale, gentle fold structure in Lower Carboniferous and Devonian rocks lying south of the Culm Synclinorium and north-west of the Bodmin Moor granite (Fig. 1). Interpretations of its origin have ranged from up-doming by the granite (Wilson 1951), late regional fold episodes (Sanderson and Dearman 1973) to an antiformal stack of D2 thrusts above a blind lateral/oblique ramp (Andrews et al. 1988).

Lying north of the Davidstow Anticline, the Southern Culm Overfold represents the transition from upright to flat-lying south-facing folds that occurs from Wanson Mouth to Rusey Cliff. It has long been recognised that facing on the S1 cleavage between Wanson Mouth and Padstow is towards the south (Freshney et al. 1972; Sanderson and Dearman 1973). Early tectonic modelling involved a single deformation event which evolved as a regional scale south-facing overfold (Sanderson 1979; Rattey and Sanderson 1982). Subsequently the Southern Culm Overfold was interpreted as representing the suprastructure of a nappe pile overriding a highly strained infrastructure (Tintagel High Strain Zone; Sanderson 1979). The high strain zone and the occurrence of 'folds oblique to the regional trend' (Sanderson 1973) in the Lower Carboniferous and Upper Devonian rocks south of the Rusey Fault Zone were considered the result of southward D1 shear. The importance of northward transport has been shown in more recent studies (Selwood et al. 1985; Andrews et al. 1988). The revision of the stratigraphy and adjacent inland mapping by the University of Exeter (Selwood et al. 1985) led to the suggestion of southerly

derived nappe sequences which underthrust the southern margin of the Culm Synclinorium. More specific analysis of shear indicators and rock fabrics (Andrews et al 1988) in the Tintagel High Strain Zone indicates the majority of strain to be the result of NNW shear, synchronous with greenschist facies metamorphism.

This paper presents a new deformation chronology for the Boscastle area, and suggests a mechanism involving early wedging (underthrusting) of the Culm flysch basin, to explain the deformational histories of the Davidstow Anticline and Southern Culm Overfold. It provides a new model for the occurrence of D1 south-facing deformation, within a northward propagating system (Dodson and Rex 1971; Selwood and Thomas 1986b), involving the early backthrusting of the contents of sedimentary basins, initiated by a wedging process.

Stratigraphy

Three stratigraphic successions can be recognised in the area (Figs 2 and 3). The Southern Culm Succession: thick Namurian flysch (Crackington Formation), represented in a conformable Upper Devonian to Lower Westphalian sequence; the Boscastle Succession: a sequence of shallow water marine elastics and limestones of Upper Devonian to earliest Namurian age (Selwood et al. 1985), lying south of the Rusey Fault Zone, and the Tintagel Succession: a sequence of Upper Devonian to Lower Carboniferous slate and volcanics, interpreted as marine shelf and basinal facies (Selwood and Thomas 1986a).

Each succession is separated by gently northward-dipping faults. The Rusey Fault separating the Southern Culm and Boscastle Successions marks the boundary between two structural regimes; a feature emphasised by the magnetic anomaly across it (McKeown et al. 1973).

Structure

The Southern margin of the Culm Synclinorium (Figs. 4 and 5a) is dominated by F1 south-facing chevron style folds forming the Southern Culm Overfold which developed during D1 southward simple shear (Sanderson 1979; Lloyd and Whalley 1986). Facing directions are generally perpendicular to the southern margin of the Synclinorium (Fig. 4, stereo. 1) which is marked by the Rusey Fault Zone. South of this, the regional structure is dominated by the Davidstow Anticline which is an

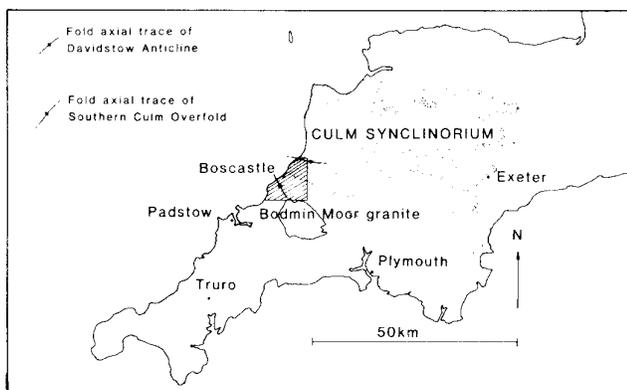


Figure 1. Location of the area of study: the Boscastle region.

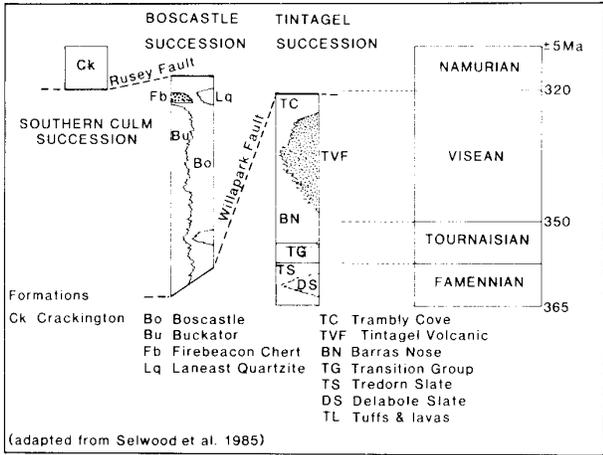


Figure 2. Stratigraphic successions of the Boscastle area.

open fold structure deforming S1 (Fig. 4, stereo. 3). Its fold axis plunges 10/330 (NNW) in the trend of the regional stretching lineation (Fig. 4, stereo. 2). Since this lineation is consistent on both limbs of the structure, it is regarded as synchronous with the formation of the regional fold. Mineral lineations of the same trend are also present in the aureole of the granite, as weak alignments of andalusite and cordierite porphyroblasts in schists. These may represent the overgrowth of a pre-existing lineation, although not observed in the equivalent rock type outside the aureole. An alternative interpretation is that the contact metamorphism was partly synchronous with the formation of the stretching lineation.

Studies of minor structures exposed in the Tintagel High Strain Zone indicate that high ductile strains occurred during an early D2 stretching event (Andrews et al. 1988), which was synchronous with greenschist facies metamorphism. Shear indicators show a NNW sense of shear, with varying amounts of strain recorded during the evolution of these structures. Estimates from boudins in the Barras Nose Formation indicate 40% stretching of the bedding (Ferguson and Lloyd 1982), whereas shear fibre growth (Andrews et al. 1988) suggests that stretching may have locally reached 300%.

F1 fold axes show a rotation towards the stretching lineation trend around the nose of the Davidstow Anticline. They have been rotated from an original E-W strike in the south, towards NNW-SSE through the Tintagel area, and return to an E-W strike just south of the Rusey Fault. It is this pattern of high strain modifying the F1 fold axes around the nose of the anticline, that has given rise to the large degree of sheathing of F1 fold axes (Sanderson 1973) in the Tintagel and Boscastle area. The D1 strain was largely rotational and initiated much folding, whereas the early D2 strain was irrotational and largely coaxial to D1. F1 structures were thus tightened and extended rather than refolded during D2. Although from a regional viewpoint the majority of the strain occurred in these rocks during early D2, the observed sheathing of folds is the result of both D1 and D2 strain components. The amount of curvature of F1 fold axes before their modification by early D2 strain is uncertain. Complications in determining the original orientation of early D2 and D1 structures in the highly anisotropic Boscastle Formation is caused by intense late F2 refolding (the zig-zag folds of Dearman and Freshney 1966). Late F2 fold axes are commonly curvilinear (< 30°), verge to the north, and represent a continuation of D2 shear towards the

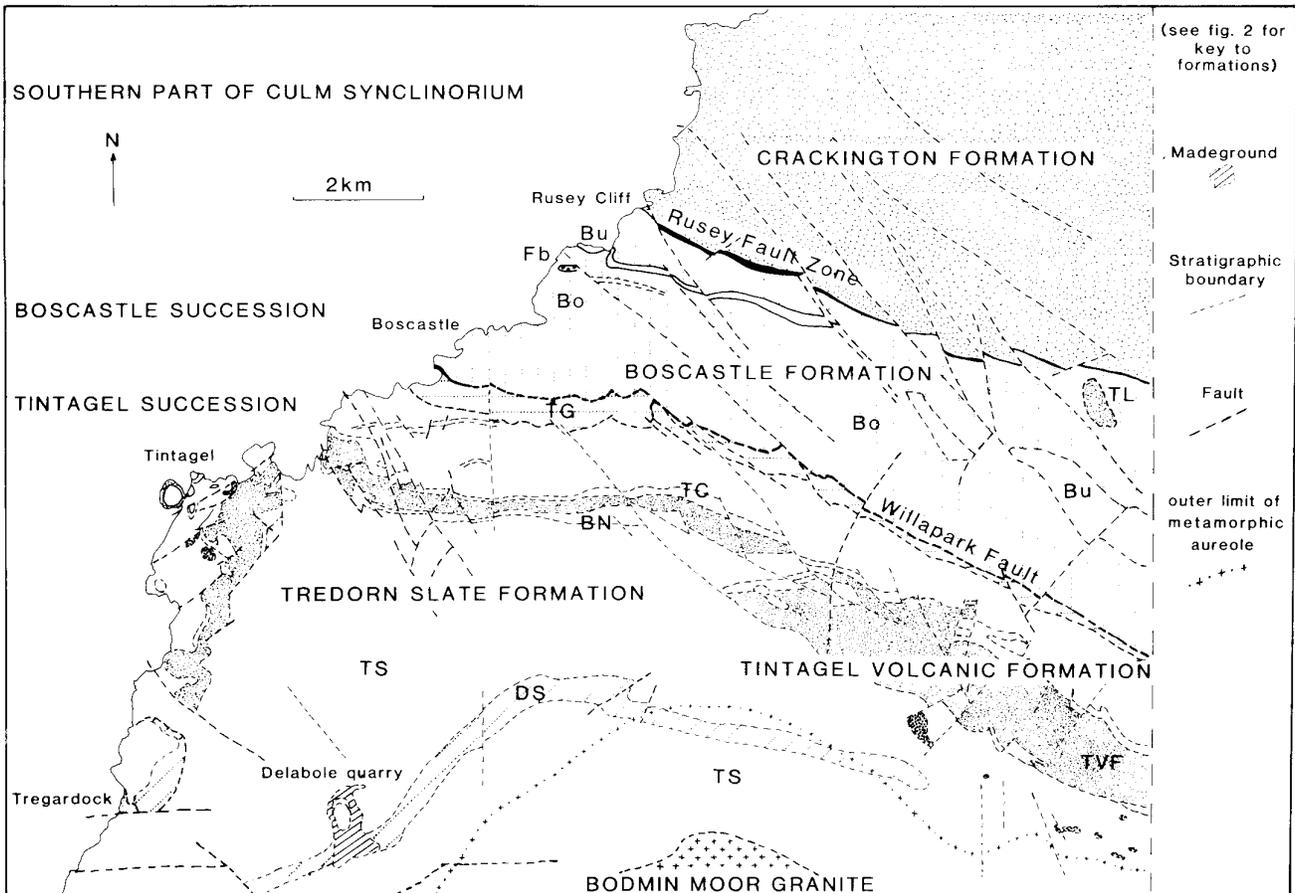


Figure 3. Geological map of the Boscastle area (use Fig. 2 for key).

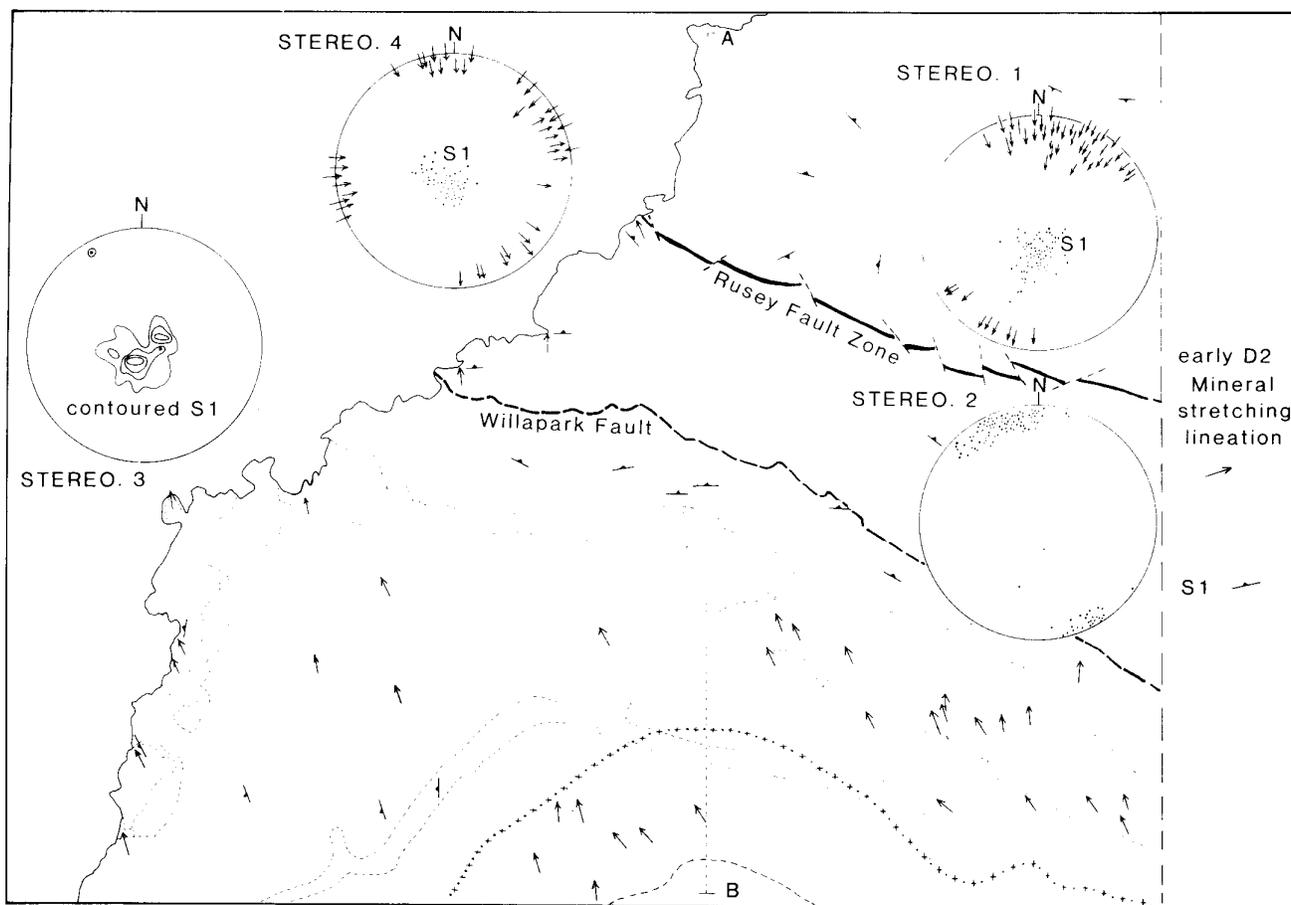


Figure 4. Structural map of the Boscastle area, with stereographs of selected structural data. Stereo. 1: Southern Culm Overfold, arrows represent direction and dip of facing on S1, dots are poles to S1. Stereo. 2: dots represent D2 mineral stretching directions across the Davidstow Anticline. Stereo. 3: Contoured plot of poles to S1 across the Davidstow Anticline. Stereo. 4: S1 facing and poles to S1 in the Boscastle Formation.

NNW. Allowing for late F2 folding, facing on S1 is commonly towards a southerly or north-easterly direction (Fig. 4, stereo. 4). This complex variation of facing is interpreted as sheath folds with noses sheared out in a general NW-SE direction.

Studies on minor structures show that a transition from D2 ductile strain to brittle thrusting occurred within the Tintagel High Strain Zone (Andrews et al. 1988; Warr 1988). Most authors have ascribed to the original view of Wilson (1951), that the gently northward dipping faults reported throughout the area represent northward directed thrusts (Selwood and Thomas 1986a; Andrews et al. 1988), subsequently tilted towards north and north-west about the Davidstow Anticline. However, many of these faults show extensional geometries (Freshney et al. 1972; Andrews et al. 1988; Warr 1988), and some cut D2 thrusts (Warr 1988). Locally developed rock folds in the fault zones are transected by fault surfaces, indicative of the sticking of the basal fault surfaces during extensional movements. These faults are more likely to be D3 structures of the same generation as the normal faults affecting the southern part of the Culm Synclinorium (Freshney 1972; Lloyd and Whalley 1986). It is probable that reactivation of D1 (e.g. Willapark and Rusey Faults), and D2 thrusts occurred during D3 movements.

Wedging of the Culm flysch basin

Density data (Freshney et al. 1972) show a density contrast of around 4.4% between the rocks of the Culm Synclinorium and those of the Boscastle and Tintagel successions. Such a density contrast and the attitude of the boundary between were favourable (Zang et al. 1984) for underthrusting (Fig. 5b and c) rather than overthrusting of the southern successions during Variscan shortening. It appears that wedging movements of the

Tintagel High Strain Zone 'locked up' during late D2 times producing localised strains (late F2), and the displacement transferred to a lower decollement surface passing beneath the Culm Synclinorium.

Deformational chronology and regional implications

A new deformational chronology is proposed for the area (Fig. 6). Although F1 folds face southwards throughout the area, the F1 folds north and south of the Rusey Fault Zone are attributed to different backthrusting events. The first occurred between post-earliest Namurian and pre-late Westphalian ($315300 \pm 5\text{Ma}$) and involved the Boscastle and Tintagel successions. This is seen as synchronous with Culm flysch sedimentation to the north, with deposition occurring in a foreland basin setting. The second, north of Rusey, occurred during post-late Westphalian times ($300-295 \pm 5\text{Ma}$), and gave rise to the Southern Culm Overfold. The latter event is regarded as synchronous with D2 movements of the Tintagel High Strain Zone.

The Davidstow Anticline evolved around lower Stephanian times ($300-295 \pm 5\text{Ma}$), during early D2 heterogenous shear strain towards the NNW. This fold structure is also regarded as synchronous with the Tintagel High Strain Zone, the majority of strain occurred during early D2, synchronous with greenschist facies metamorphism. Strain modification of F1 fold axes occurred around the nose of the antiformal structure and rotation of originally E-W axes of south facing folds towards the D2 principal stretching direction gave rise to 'folds oblique to the regional trend'. It is this early D2 shear towards the NNW which wedged beneath the southern margin of the

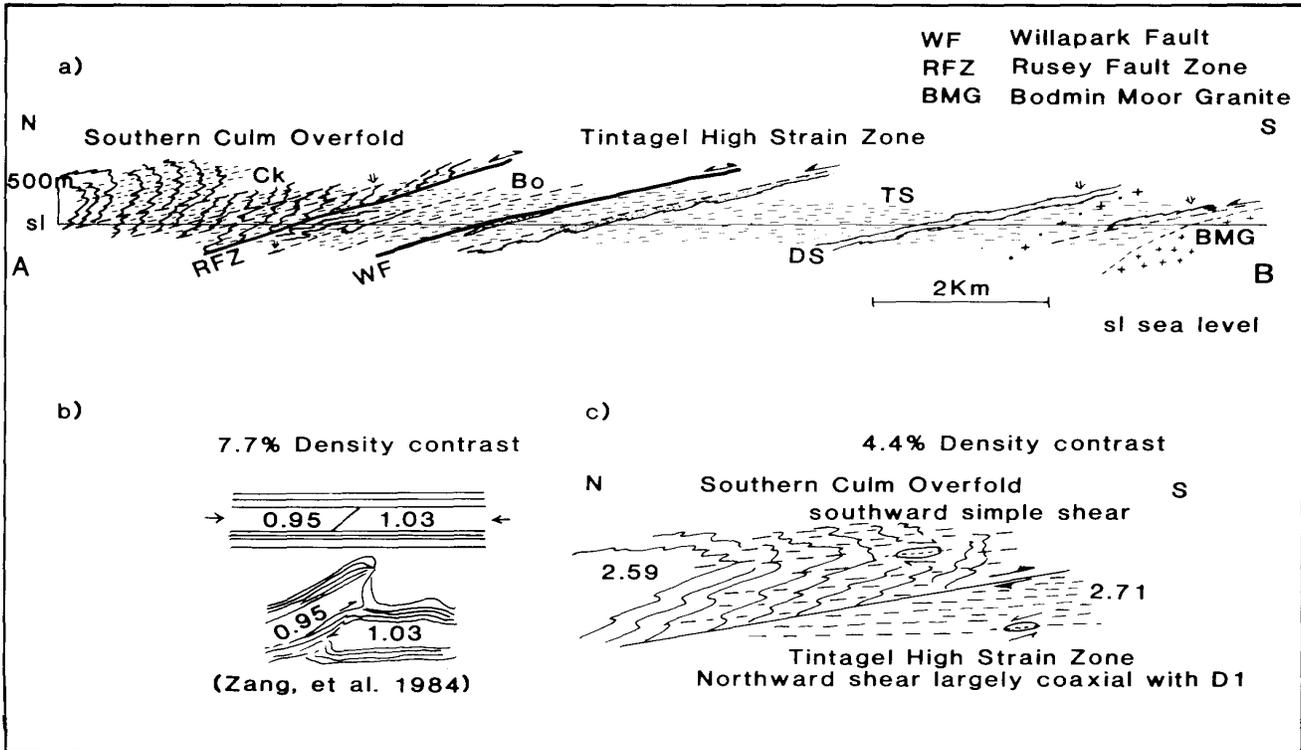


Figure 5. a) Structural section A-B across the Boscastle area (see Fig. 4). b) Experimental modelling (Zang *et al.* 1984), showing underthrusting of denser clays beneath less dense (density in gm cm⁻³) Schematic cross section showing underthrusting of the Tintagel High Strain Zone beneath the Southern Culm Overfold.

Culm flysch basin, initiating backthrusting and formation of the Southern Culm Overfold. The obliqueness of opposed transport directions across the Rusey Fault Zone is seen as characteristic of NNW wedging of an E-W trending sedimentary basin. Transport within the southern Culm basin was perpendicular to the basin margin (SSW) and not related to the direction of the wedging (NNW). Continued wedging initiated late F2 folding within the Davidstow Anticline area, with strains becoming more localised during a 'locking up' of the wedging movement. The low angle north dipping faults across the area are considered as a separate (D3) phase of faulting. Their extensional geometries are original and ruck folds within the fault zones developed by sticking of the basal fault surfaces during extensional movements.

The NNW regional transport of the Variscan foreland belt of south-west England migrated northwards, deforming a series

of E-W trending sedimentary basins. The Culm flysch basin was a symmetrical basin with a density contrast > 4% across its southern margin. These boundary conditions were favourable for the wedging of denser Boscastle and Tintagel successions beneath the less dense Culm sediments. Wedging of sedimentary basins provides a mechanism for the occurrence of early south-facing folding in north Cornwall within a northward propagating system, with the backthrusting of the contents of sedimentary basins controlled by basin geometry and in this case aided by a density contrast across its southern margin. The D1 south-facing deformation is therefore considered to be strongly diachronous across north Cornwall.

There remains a problem in providing the necessary uplift to source Famennian to earliest-Namurian paralic and deltaic sediments of central south-west England and north Cornwall (Boscastle Succession in this area). Facies modelling (Selwood and Thomas 1986b) led to the suggestion of a southerly source of sediment, with deposition occurring syntectonically in advance of the northerly progress of the Carrick Nappe. These rocks were subsequently transported tens of kilometres northwards as the furthest travelled nappes. The early structural history of these rocks involves southerly transport, it is therefore structurally more favourable to maintain these successions within the region of D1 south-facing structures between the Culm Synclinorium and the Padstow Confrontation Zone. The question as to the source of these sediments is left open.

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Stratigraphic chronology	Southern Culm Overfold	Tintagel High Strain Zone
Post-lowest Namurian - pre-late Westphalian 315-300-5Ma	Deposition occurring in Culm Flysch Basin	D1 South facing folding
Post-late Westphalian 300-295-5Ma	D1 South facing folding	early D2 late D2 Ductile shear towards NNW with transition to brittle thrusting
Post-late Westphalian	D3 North dipping extensional faults	D3 North dipping extensional faults

Figure 6. A new deformation chronology for the Boscastle area.

References

- Andrews, J.A., Barker, A.J. and Pamplin, C.F. 1988. A reappraisal of the facing confrontation in north Cornwall; fold- or thrust-dominated tectonics? *Journal of the Geological Society, London*, 145, 777-788.
- Dearman, W.R. and Freshney, E.C. 1966. Repeated folding at Boscastle, north Cornwall, England. *Proceedings of the Geologists' Association*, 77, 199-215.
- Dodson, M.H. and Rex, D.C. 1971. Potassium-argon ages of the slates and phyllites from south-west England. *Quarterly Journal of the Geological Society, London*, 126, 469-499.
- Ferguson, C.C. and Lloyd, G.E. 1982. Palaeostress and strain estimates from boudinage structure and their bearing on the evolution of a major Variscan fold-thrust complex. *Tectonophysics*, 88, 269-289.
- Freshney, E.C., Mckeown, M.C. and Williams, M. 1972. Geology of the coast between Tintagel and Bade. *Memoir of the Geological Survey of Great Britain*.
- Lloyd, G.E. and Whalley, J.S. 1986. The modification of chevron folds by simple shear: examples from north Cornwall and Devon. *Journal of the Geological Society, London*, 143, 89-94.
- Mckeown, M.C., Edmunds, E.A., Williams, M., Freshney, E.C. and Masson Smith, D.J. 1973. Geology of the country around Boscastle and Holsworthy. *Memoir of the Geological Survey of Great Britain*.
- Rattee, P.R. and Sanderson, D.J. 1982. Patterns of folding within nappes and thrust sheets; examples from the Variscan of south-west England. *Tectonophysics*, 88, 247-267.
- Sanderson, D.J. 1973. The development of fold axes oblique to the regional trend. *Tectonophysics*, 16, 55-70.
- Sanderson, D.J. 1979. The transition from upright to recumbent folding in the Variscan fold belt of south-west England: a model based on the kinematics of simple shear. *Journal of Structural Geology*, 1, 171-80.
- Sanderson, D.J. and Dearman, W.R. 1973. Structural zones of the Variscan fold belt in SW England, their location and development. *Journal of the Geological Society, London*, 129, 527-536.
- Selwood, E.B., Stewart, I.J. and Thomas, J.M. 1985. Upper Palaeozoic sediments and structure in north Cornwall - a reinterpretation. *Proceedings of the Geologists' Association*, 96, 129-141.
- Selwood, E.B. and Thomas, J.M. 1986a. Upper Palaeozoic successions and nappe structures in north Cornwall. *Journal of the Geological Society, London*, 143, 75-82.
- Selwood, E.B. and Thomas, J.M. 1986b. Variscan facies and structure in central SW England. *Journal of the Geological Society, London*, 143, 199-207.
- Warr, L.N. 1988. The deformational history of the area north-west of the Bodmin Moor granite, north Cornwall. *Proceedings of the Ussher Society*, 7, 67-72.
- Wilson, G. 1951. The tectonics of the Tintagel area, north Cornwall. *Quarterly Journal of the Geological Society, London*, 106, 393-432.
- Zang, W., Zhong, J., Shan, J. and Wang, Z. 1984. Underthrust or Overthrust. *Kexue Tongbao*, 27, 4, 619-621.