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Vein arrays and their relationship to transpression during fold development in the Culm Basin, central south-west England

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Extension veins and associated en echelon vein arrays are common structures in sandstone units of the Crackington and Bude Formations in the Culm Basin. These structures were initiated prior to the folds, although they continued to dilate with their geometries being modified during progressive fold development. The geometry and opening history of the vein arrays and their relationship to folds, indicate that the principal tectonic stresses were directed NW-SE, which is oblique to the E-W fold-axis orientations. This asymmetry is consistent with an overall pre-fold and syn-fold E-W dextral transpression. The implications of this transpression for regional structure are examined.

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Introduction

En echelon vein arrays and pressure-solution structures which are common features of brittle and semi-brittle rock fracture in low-grade metamorphic terranes, are well developed in the Upper Carboniferous Crackington and Bude Formations of the Culm Basin. The quartz-carbonate veins described in this study are from sequences between Wanson Mouth (SS195012) and Millook Haven (S5184003) in north Cornwall (Fig. 1). They were previously described by Mackintosh (1967) and Beach (1975, 1977), who suggested that they might pre-date the chevron folds.

The objective of this paper is to describe the geometry of the veins, their opening history and to show how some of them are related to fold development. The modification of early vein sets and the formation of syn-fold vein sets are compared with the rotational train histories predicted by models of fold development during progressive simple shear (Sanderson 1979; Ridley and Casey 1989) and in transpression. On this basis and on the observed structural relations, a transpressional model is applied, which is consistent with available data and the stress systems required for the formation of the veins and the folds. The implications of this model for the regional structure are then discussed.

Structural Setting

The Culm Basin records a period of progressive, high-level Variscan deformation which produced a complex fold geometry with a broad fanning of fold facing directions. Deformation within the basin is generally described in terms of the generation of chevron folds (Ramsay 1974) with horizontal shortening of 35 to 60% (Sanderson 1979) during N-S directed compression (Whalley and Lloyd 1986) and with the deformation intensity increasing southwards.

The fold axes have an approximate east-west trend and are upward or south facing, with shallow north dipping to horizontal axial-planes between Wanson Mouth (SS195012) and Millook Haven (SS184002), and as far south as Rusey (SX124939). Axial planes are sub-vertical at Bude and farther north near Hartland Quay (SS223248) they are steeply inclined to the south. This transition from upright to recumbent folds has been described by Dearman (1969) with the corresponding decrease of interlimb angle and overturning of fold axial-planes noted by Sanderson (1979, 1982), who modelled the rotation using southerly directed simple shear. In this model, folds initiate as inclined or low amplitude structures which amplify, rotate and tighten with increasing shear strain. Similar fold attitudes and styles are documented for other fold-belts, such as the western Helvetic Alps where equivalent deformation models are applicable (Casey and Huggenberger 1985).

The effects of the regional simple shear deformation, in terms of modifications to individual pre-existing, upright chevron folds were noted by Zwart (1964), and re-examined by Lloyd and Whalley (1986) who ascribed the southwards shear to backthrusting during D1. In this context the process would represent coeval cover deformation in response to a blind thrust system; so within the basin both northerly and southerly directed thrusting and simple shear deformation is expected.

Significantly, the southerly directed shear produced a major anticlinal structure at the southern margin of the basin which Rattey and Sanderson (1982) termed the 'Millook Nappe'; corresponding to the Southern Culm Overfold of other workers (eg. Freshney *et al.* 1972). Upright, open folds on the upper normal limb and tighter, recumbent folds on the lower inverted limb of this structure correspond with the fold-transition sequence (Dearman 1969; Sanderson 1979). Although the inverted limb of the Millook nappe has since been stretched out by D2 extensional faults, its former extent can be visualised by matching the displaced stratigraphy across the faults (Freshney *et al.* 1972).

Vein array and fold relations

Numerous quartz-carbonate veins and pressure-solution structures occur in the interbedded sandstone and shale sequences of the Crackington and Bude Formations in the Culm Basin. Previous

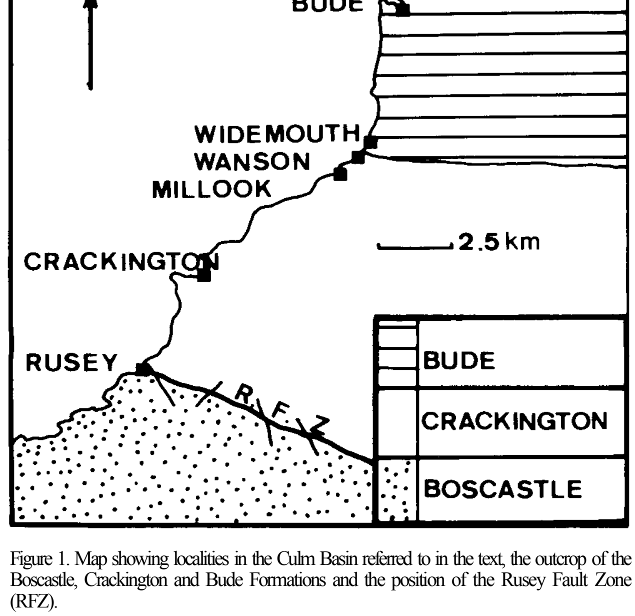

Figure 1. Map showing localities in the Culm Basin referred to in the text, the outcrop of the Boscastle, Crackington and Bude Formations and the position of the Rusey Fault Zone (RFZ).

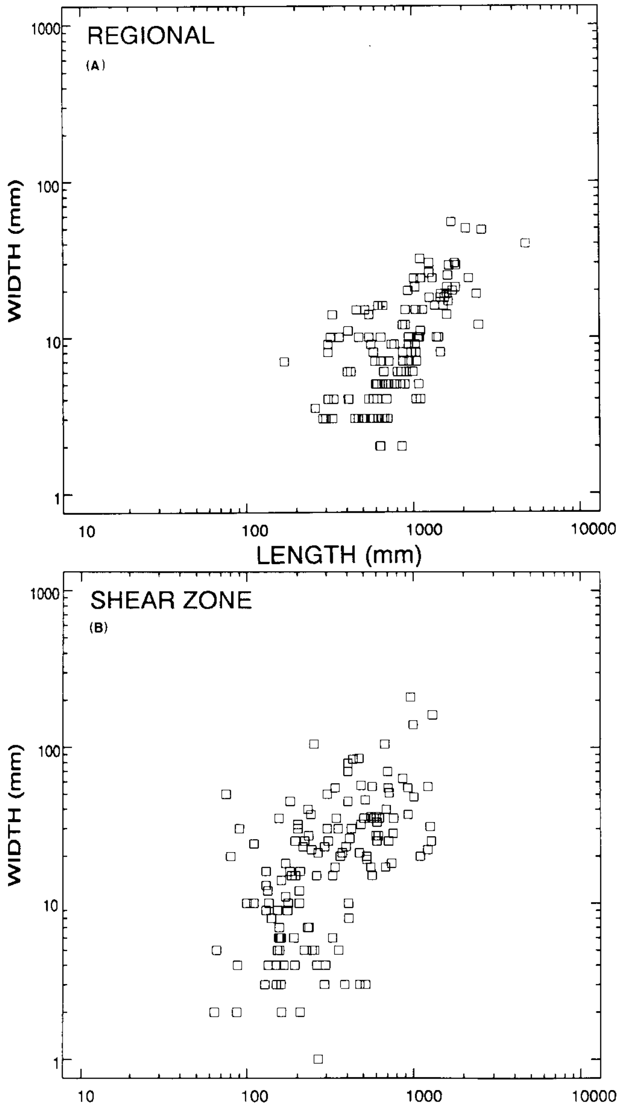

Figure 2. Log-log length-width plots for veins in the Wanson Mouth - Millook Haven sequence: (A) the distributed, regional vein set and (B) veins within en echelon arrays and shear zones which are sub-parallel to the regional, distributed vein set present in the same area.

work by Mackintosh (1967) and Beach (1977) indicated that some of these veins can be related to an early deformation phase predating main fold amplification. The objective of this study is to give a detailed analysis of the kinematics of the early regional vein set, the relations to folding and their consequent modification during fold development. There is no further discussion here of the syn-fold vein sets produced during hinge stretching, of limb accommodation features or of the fibre-sheets on bedding surfaces due to flexural-slip. For an overview of these types of small-scale structure, the reader is referred to Ramsay (1974) and Ramsay and Huber (1987).

Vein form and distribution

The veins are mainly confined to sandstone units and are oriented at high angles to bedding, generally terminating at bed margins with bed-thickness the primary control on size and spacing. Fig. 2 shows plots of length-width for the vein sets common to the normal and inverted fold-limbs in the study area. There is a wide range in their dimensions. The veins in en echelon arrays which are subparallel to the regional, distributed set, are characterised by smaller length-width (aspect) ratios (median = 17.0) than the similarly oriented regional veins outside the arrays (median = 96.1). Broadly, the veins are planar or slightly curved, often with forked or branching terminations (Beach 1977), or rarely, they may comprise of linked pull-aparts. Some of the veins form conjugate sets (Fig. 3).

Fold geometry in the Wanson Mouth-Millook Haven sequence

At Wanson Mouth, the chevron folds are upright or slightly overturned to the south. To the south of Wanson Mouth, between Foxhole Point (SS186007) and Millook Haven, the folds are asymmetric and recumbent, or with axial-planes inclined to the north at up to 20°. In this fold sequence there is a general increase in pressure-solution deformation southwards, which corresponds with the change in the fold attitude and the development of a spaced solution-cleavage (Sanderson 1979). Fold interlimb angle decreases southwards, with longer north dipping inverted fold limbs about 20% thinner relative to normal south-dipping limbs. Some of the folds near Foxhole Point have also developed distinctive curvilinear axes. Strain within the plane of bedding is negligible as goniatite casts from shale units at Foxhole Point have strain ratios of around 1.2 (Sanderson pers. comm.).

Vein geometry and kinematics

Mackintosh (1967) and Beach (1977) suggested that these veins pre-date the chevron folds. These early vein sets have been identified at localities throughout the Crackington Formation. The following sections summarise the geometry and kinematics of vein sets present on both normal and inverted fold limbs, mainly using examples from Millook Haven. Fig. 3 presents plan view summaries of the geometry of the veins and vein arrays exposed on bedding-planes, for the normal and inverted fold-limbs.

Data for the vein array, vein-fibre and vein orientations is shown in Fig. 4a and 4b in the form of azimuth-scatter plots and frequency histograms. The X-Y plots are produced by plotting the azimuth of each pair of geometric parameters (eg. vein array azimuth vs. vein azimuth). The graphs indicate the degree of normal, dextral or sinistral vein array or vein opening displacements. These enable visualisation of the geometry of individual vein arrays or set, and allow immediate comparisons between different fold limbs to be made. For some of the en echelon vein arrays the zone boundary displacement (Fig. 7) or vein opening vectors have been determined from measurements of array geometry and fibre orientation, by using a graphic construction developed by McCoss (1986).

Normal fold limbs. In these limbs the veins of the dominant vein set (V1 of Mackintosh 1967) are planar and constantly oriented, with a mean azimuth of 130° (Fig. 4a). Details of the fibre geometry shown in Fig. 4a indicate the veins have a range of opening displacements from normal to sinistral. The oblique opening component implies that this set was not initiated in a principal stress plane, and was sub-parallel to the regional direction (NW-SE) determined by correcting the early veins for tectonic rotation. Associated with these veins are conjugate en echelon vein arrays (Beach 1975) with mean trends of 095° and 165° which are marked as A and B respectively in Fig. 3a and 4a.

Inverted fold limbs. In the inverted fold limbs the vein geometry is more complex. There are two dominant vein sets (Fig. 3b) which intersect (V1 and V2 of Fig. 4b) to form a criss-cross network on bedding-plane surfaces. The mean azimuths for these sets are: V1 050° and V2 160°. Measurements of vein fibres (Fig. 3b) indicate vein opening directions for V1 are orthogonal-dextral and V2 are orthogonal-sinistral oblique. Vein intersections and offset relations, illustrated in Fig. 3b show both dextral and sinistral offsets are produced, although for any one vein the displacement sense is constant. Pinnate veins and pressure-solution zones (Fig. 4b) indicate shear displacement parallel to the vein margins by a later loading of both V1 and V2 by a near N-S principal compressive stress. Beach (1977) interpreted these vein set as contemporaneous conjugate sets of shear fractures. Although V1 and V2 were later synchronously loaded, they did not initiate as a conjugate set. The relationship is only an apparent one, because as will be demonstrated, the V1 vein sets are folded around the sub-horizontal fold-axes, so they pre-date the folds.

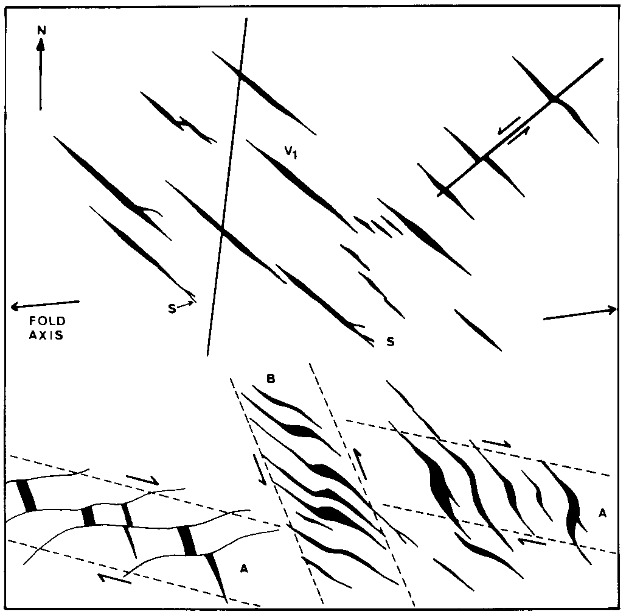

Figure 3a. Plan view summary of the vein arrays exposed on bedding-plane surfaces for normal fold-limbs at Millook Haven; not to scale. Conjugate sets of en echelon veins - A and B; regional, distributed veins with forked and branching terminations - S. V1 is the regional, distributed vein set.

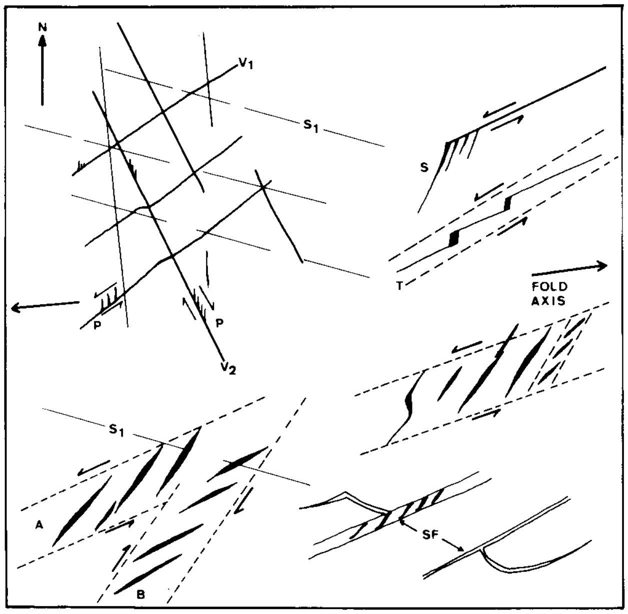

Figure 3b. Plan view summary of the vein arrays exposed on bedding-plane surfaces for inverted fold-limbs at Millook Haven; not to scale. Conjugate vein sets - A and B; branching terminations - S; pinnate veins - P; linked *pull*aparts-T; irregular shale-filled cracks, some containing sinistral vein arrays. *S1 is* the local trend of the spaced solution cleavage. V1 is the regional vein set and V2 the overprinting set which *is* syn-fold; both sets were subsequently loaded at a high angle.

The second vein set, V2, is not seen in normal limbs so it is likely to be syn-fold, indicating that the maximum principal compressive stress orientation determined for the pre-fold set V1 was maintained during folding. For the V2 set to be initiated in the same stress system as V1, the fold-limb would nave had to rotate through the vertical and into the extensional field of the shear couple (Sanderson 1979; Casey and Huggenberger 1985). The fold geometry at Millook Haven is compatible with such a model.

The V1 vein set is common to both fold limbs and is folded about the sub-horizontal east-west trending fold-axes. On the normal fold limbs this set trends NW-SE, while on the inverted limbs it is in a general NE-SW direction. Direct evidence of this is present at Foxhole Point where single veins can be traced on a bedding surface across and around the fold-hinge, where they were subsequently obliquely opened.

This geometry is illustrated in Fig. 5 where the measured intersection-lineation for a vein (Fig. 5b) which was traced around a single fold at Foxhole Point is plotted then rotated with bedding about the fold-axis to the horizontal. At this particular locality the fold-axis attitude is WNW-ESE rather than the regional E-W (eg. at Millook Haven in Fig. 6a); this does not significantly affect the original pre-fold vein orientation of NW-SE after the correction procedure has been applied.

Measurements of poles to veins from each fold-limb at the same locality (Fig. 5c) and for veins from normal and inverted limbs at Millook Haven (Fig. 6b) have been treated in the same way and rotated with the bedding about the mean fold-axes (8/286 and 4/086 respectively) to the horizontal. For these examples the orientation of the veins within bedding, prior to folding is determined to be NW-SE. This attitude is markedly oblique to the general EW trend of the fold-axes at these localities and throughout the Culm Basin.

En echelon vein arrays and pressure-solution structures

In the study area en echelon vein-arrays often occur near the terminations of the V1 vein sets. Two different configurations are observed (Fig. 3). Conjugate arrays are present on both fold-limbs and after rotation about the axis to the horizontal they broadly coincide; indicating that the fracture pattern was established prior to main fold-amplification. Both sets were modified during folding, with the displacement sense and morphology changing, eg. the A 095° (dextral) and B 165° (sinistral) conjugate arrays sets (Figs 3a and 4a) of the normal limbs, when inverted can become B 035° (dextral) and A 060° (sinistral arrays of the inverted limbs (Figs 3b and 4b).

The McCoss (1986) construction may be used to analyse vein opening displacements produced during zone dilation (Fig. 7). Measurements of zone boundary displacement vectors from vein and fibre geometry indicate that en echelon veins are not necessarily the product of zones of simple shear deformation and in many cases transtensional and transpressional models are more applicable (Jackson and Sanderson 1991).

En echelon vein arrays at Millook Haven show a spectrum of geometries. Members of this series, together with their zone displacement vectors are illustrated in Fig. 7. The constructed zone boundary displacement vectors for these examples illustrate the difference between these arrays and those which are conventionally attributed to simple shear deformation. At Millook Haven, there are some en echelon vein arrays which cannot be attributed to zones of simple shear deformation (cf. Beach 1975; Pollard *et al.* 1982):

(1) Transtensional vein arrays. Where veins propagate at low angles to the zone (<45°) with an accompanying zone dilation and formation of bridge structures as fracture-tips overlap and interact (Fig. 7a).

(2) Transpressional vein arrays. These have an associated volume loss and are dominated by pressure-solution structures which effect vein development by the formation of pull-aparts at solution-seam overlaps (Fig. 7c).

The relationship of the vein arrays to fold development

During deformation of the Crackington and Bude Formations it has been demonstrated that extension fractures initiated and propagated prior to fold development. Observations of the vein geome-

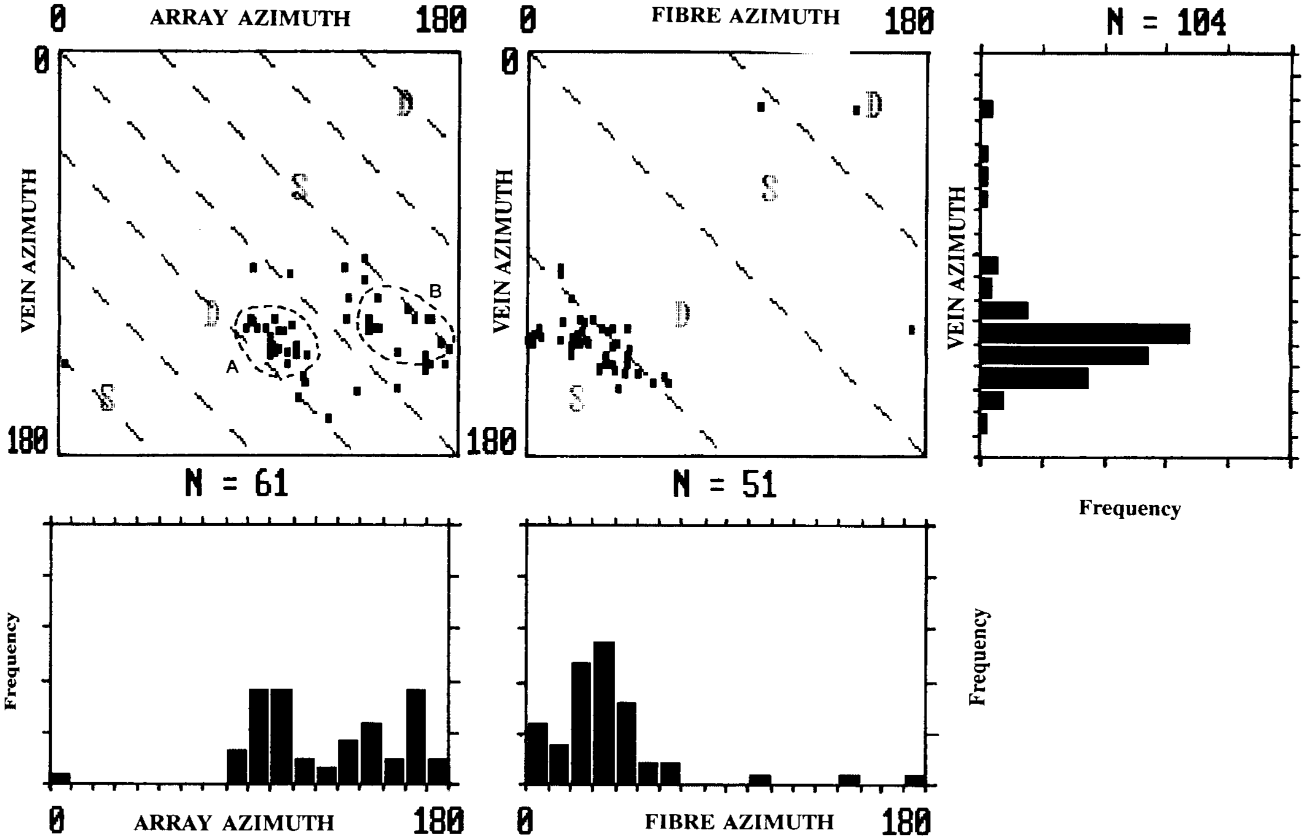

Figure 4a. Vein array, vein fibre and vein azimuth plots for vein sets from normal fold limbs at Millook Haven. The hatched lines define regions of pure dextral (D), sinistral (S) or orthogonal (0) displacement or opening displacement. A and B indicate the orientations of the conjugate vein sets shown in Fig. 3a.

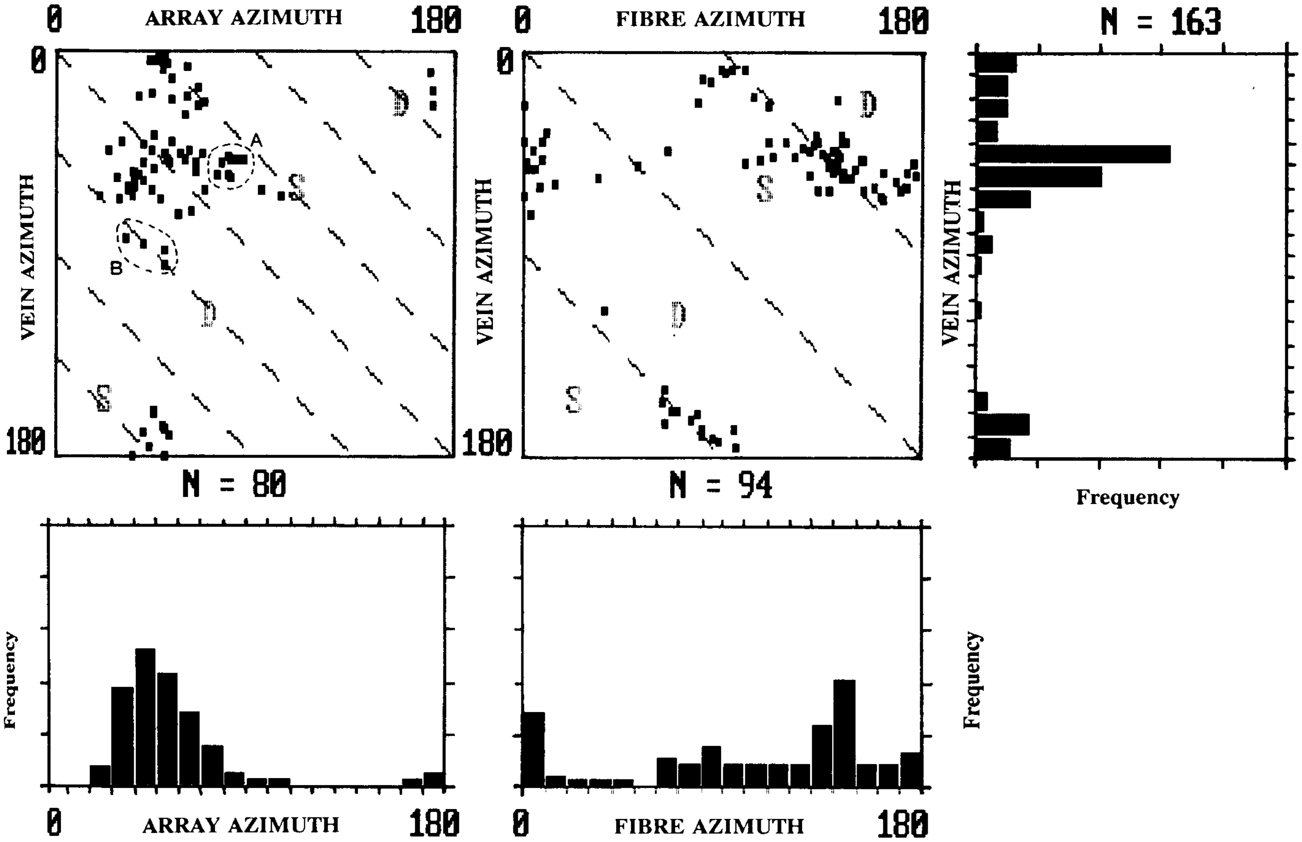

Figure 4b. Vein array, vein fibre and vein azimuth plots for vein sets from inverted fold limbs at Millook Haven. The hatched lines define regions of pure dextral (D), sinistral (S) or orthogonal (0) displacement or opening displacement. A and B are the conjugate vein sets shown in Fig. 3b.

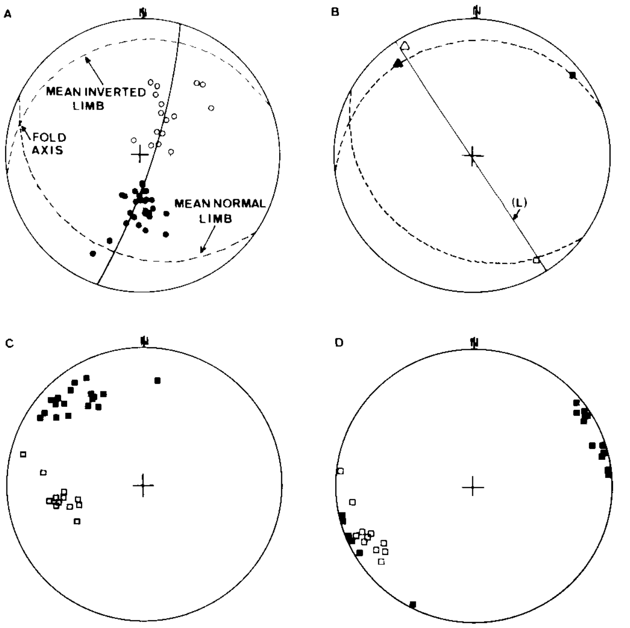

Figure 5. Lower-hemisphere stereographic projections showing: (A) Poles to bedding for normal (○) and inverted (●) fold limbs at Foxhole Point. (B) The bedding-vein intersection lineation for vein sets on normal limbs (■) and inverted fold limbs (▲) in their present position. The veins have been corrected for tectonic rotation by rotating them within bedding about the fold-axis to the horizontal. The pre-fold orientation of the vein on normal (□) and inverted (Δ) fold-limbs: note they are oblique to the fold-axis orientation. The line (L) through the stereogram shows the mean azimuth of the vein sets, after unfolding about the fold-axis. (C) Poles to veins from Foxhole Point for the normal (□) and inverted (■) fold-limbs. (D) Poles to veins for both limbs, after rotation within bedding, about the fold-axis.

try and their opening directions suggest they originated as fractures oblique to the regional principal stres σ_1.

Prior to folding the maximum principal stress, σ_1 was sub-horizontal within bedding and in a NW-SE direction, ie. the veins indicate the minimum principal stress, σ_3 was sub-horizontal and in a NE-SW direction. The NW-SE σ_1 stress orientation persisted during folding. This is inferred from the syn-fold V2 set present in the inverted fold-limbs which cuts through, offsets and displaces V1; and also from the oblique vein opening and loading effects.

The V1 and V2 vein-arrays are cross-cut by or displaced across a spaced pressure-solution cleavage which occurs only in the sandstone beds. In many places the cleavage intersection-lineation is noticeably oblique to the mean fold-axis direction with the angle and sense of transection variable. The geometric and kinematic relationship of the solution cleavage to fold development is not discussed further. The pressure-solution cleavage is cut by veins with trends of about 180° and 025°. These sets are common to both fold limbs and are likely to be post-fold, implying a late more NS directed maximum principal stress.

Vein and fold rotation model

In the Wanson Mouth-Millook Haven section the application of a rotational deformation model of fold development, such as those described by Sanderson (1979, 1982) and Ridley and Casey (1989) allows observations of vein geometry and opening history to be compared with fold kinematics.

The vein sets described were initiated prior to folding, or in the layer-parallel shortening stage of folding. They continued to dilate after the onset of buckling as further strain amplified and tightened initial low-amplitude structures. Continuing imposed strain and hinge migration before the folds were significantly tight led to the asymmetry observed at Millook Haven, with further shear leading to rotation and overturning of fold limbs. During this phase, the inverted fold limbs would have rotated through the vertical and into the extensional field of the overthrust shear couple so pre-existing vein sets are modified if they continue to dilate. They are obliquely loaded and opened as they no longer lie in a principal stress plane. New syn-fold vein sets were initiated so complex vein intersection and cross-cutting relations will result. Normal fold limbs will be expected to have a simpler deformation history as they have undergone less rotation and stress reorientation relative to the inverted limbs by maintaining a relatively constant orientation during folding. Observations of vein geometry and kinematics from the Wanson Mouth - Millook Haven section agree qualitatively with this model.

Transpression Model

The upright to recumbent fold transition which has been modelled in terms of progressive, southerly directed simple shear deviates from ideal simple shear. The maximum principal stress σ_1, prior to fold development has been shown to be NW-SE and this was maintained during the folding. This stress orientation is oblique to the E-W fold-axes and suggests that the observed structural relations are not simply the result of N-S directed compression. The obliquity is consistent with dextral E-W transpressional shear prior to and during fold development.

Transpression involves a range of strains between compression and wrench. So in a zone of transpressional deformation a combination of wrench shear and horizontal compression across the zone with vertical lengthening along the shear plane will result (Sanderson and Marchini 1984). Modelling the Culm Basin in these terms would lead to horizontal shortening accommodated by folding and thrusting with a transcurrent shear parallel to the basin margins. Partitioning of this deformation may occur and there would be complex strain patterns at the basin margins. In some cases this could lead to the reactivation of basin bounding faults as high-angle thrusts. These features are consistent with the observed deformation in the Culm Basin.

Transpression might be generated in the Culm Basin by oblique convergence at the southern margin of the basin (ie. an approximate 320° convergance of an E-W striking basin). Southwards of the Rusey Fault Zone and towards the Tintagel High Strain Zone the regional transport direction is consistently towards the NNW, so transpression may be generated by the interaction between regional thrusting and the basin margin: if one assumes the Rusey Fault represents an original basin boundary. The transpression would then be a relatively local phenomenon, restricted to the basin margins. The presence of these en echelon vein sets and their consistent fold relations throughout the Crackington Formation suggest the early and syn-fold transpression was a basin wide process. This may indicate that there is a greater E-W syn-sedimentary influence throughout the basin than has been previously thought. In addition, the stress system required for the formation of the suite of pre-fold contractional and extensional structures described by Mapeo and Andrews (1991), is consistent with deformation in a dextral transpressive regime.

Recent models of the structural style of central SW England, which have been in terms of foreland basin development (Shackleton et al. 1982; Seago and Chapman 1988; Hartley and Warr 1990) followed by structural inversion (eg. Selwood 1990) are compatible with transpressional deformation envisaged for the Culm Basin.

Conclusions

The analysis of en echelon vein array and fold relations in this study shows the following general features:

(1) Veins initiated prior to fold development; some of them were opened oblique to the primary stress.

(2) The principal stresses are oblique to the fold-axes because prior to folding the maximum principal stress, σ_1 was directed NW-SE and this was maintained during main fold amplification.

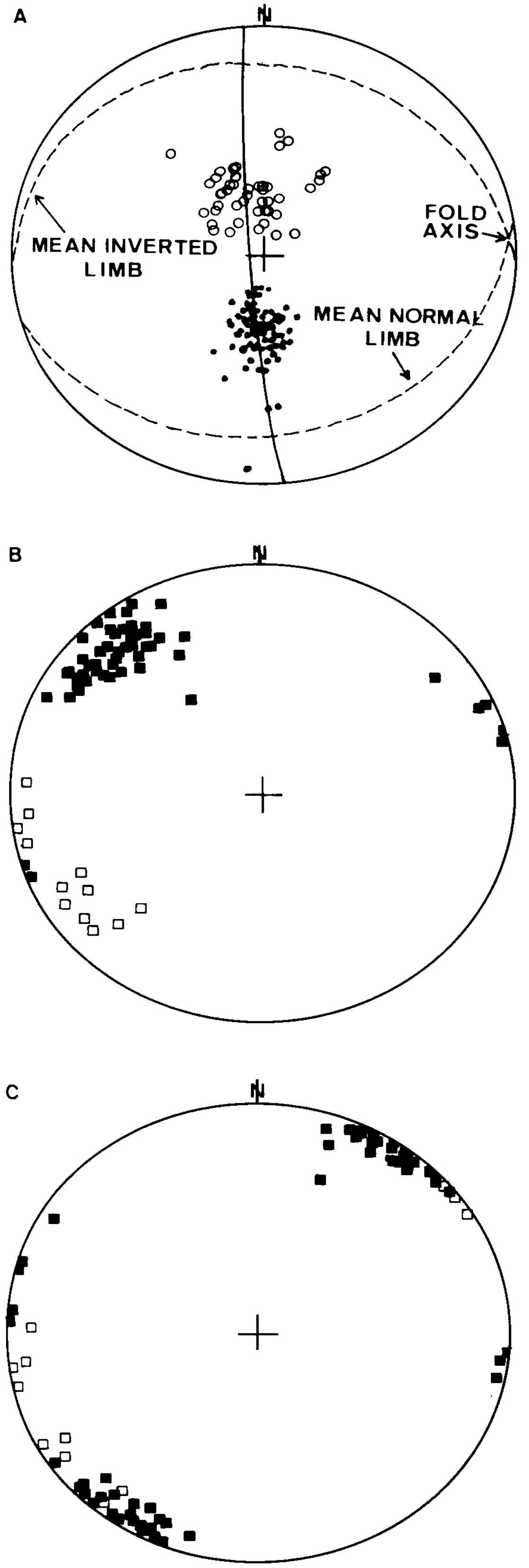

Figure 6. Lower-hemisphere stereographic projections showing: (A) Poles to bedding for normal (○) and inverted (●) fold-limbs at Millook Haven. (B) Poles to veins from Millook Haven for veins on normal (□) and inverted (■) fold-limbs. (C) The attitude of the veins from inverted and normal limbs after rotation about the fold-axis. Note that their orientations are asymmetric to the fold-axis orientation.

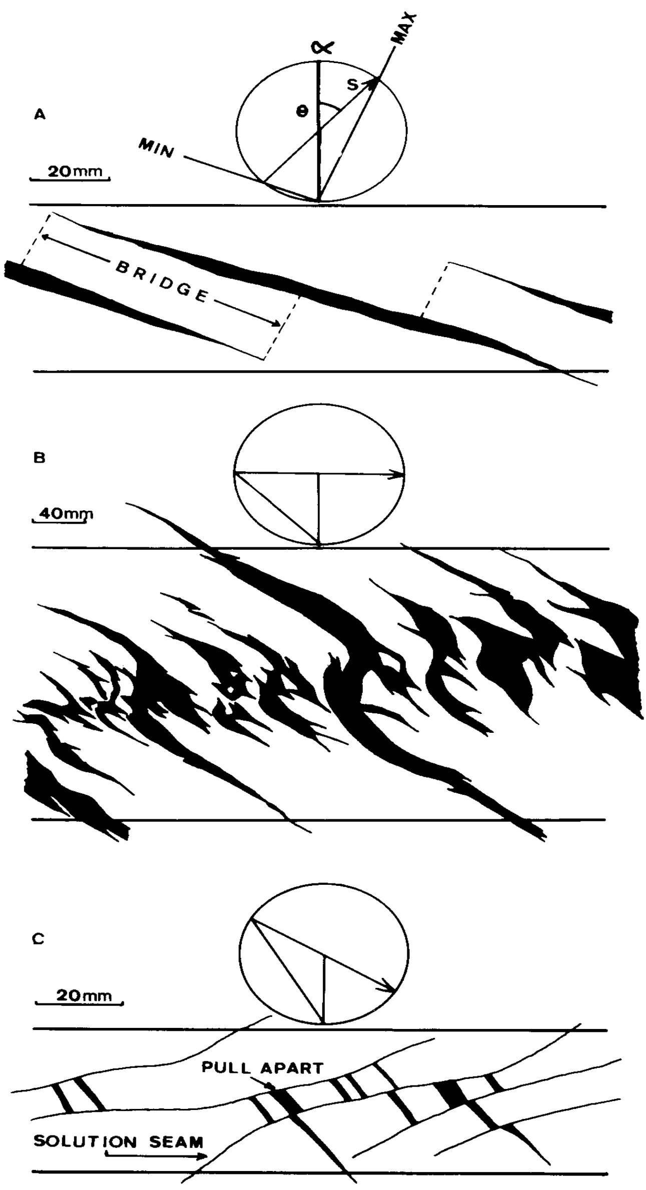

Figure 7. Examples of en echelon vein arrays present in the Wanson Mouth - Millook Haven sequence. Note they show a range of geometric forms and there is a wide variation in the vein-array angle.

(A) Vein array with the McCoss construction, indicating that zone displacement S is divergent and oblique to the array trend. The zone displacement is determined as follows: (i) Project a line normal (α) to the vein array trend and draw a circle of arbitrary radius centred on this line, tangential to the vein array trend; (ii) draw lines parallel and perpendicular to the vein (these are the maximum and minimum axes of infinitesimal strain ellipse) so they intersect the point where the circle meets the vein array boundary; (iii) Project these lines so they intersect the circle; now draw a line through the circle centre to connect the intersections. Vector sense is from the minimum to the maximum axis.

(B) The `classic', simple shear type array, the displacement vector indicates the zone displacement is parallel to the array trend; as θ=90°.

(C) An example of a vein array where the zone displacement vector S, indicates a state of transpressional deformation, this particular example is also shown in Ramsay and Huber (1987, page 630 figure 26.44).

(3) During folding, early vein sets were modified due to the oblique loading and opening effects as fold limbs were rotated relative to the remote principal stresses.

(4) Complex cross-cutting and vein intersection relations were generated in the inverted fold limbs. Normal limbs have a simpler deformation history as they were subject to less stress re-orientation, by maintaining a relatively constant attitude in fold development. These phases of vein development can then in turn, be related to a rotational deformation model.

(5) Structural relations between vein array development and folding in the are are consistent with an overall pre-fold and syn-fold E-W dextral transpression. This transpression may be generated by oblique convergence and the interaction between regional thrust transport (NNW) and an E-W trending basin margin. Consequently, causing a phase of backfolding and backthrusting which was also transpressive.

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References

Beach, A. 1975. The geometry of en-echelon vein arrays. *Tectonophysics,* 28, 245-263.

Beach, A. 1977. Vein arrays, hydraulic fractures and pressure solution structures in a deformed flysch sequence, S.W. England, *Tectonophysics,* 40, 201-225.

Casey, M. and Huggenberger, P. 1985. Numerical modelling of finiteamplitude similar folds developing under general deformation histories. *Journal of Structural Geology, 7,* 103-114.

Dearman, W. R. 1969. On the association of upright and recumbent folds on the southern margin of the Carboniferous synclinorium of Devonshire and North Cornwall. *Proceedings of the Ussher Society, 2,* 115-121.

Freshney, E. C., McKeown, M. C. and Williams, M. 1972. Geology of the coast between Tintagel and Bude. *Memoir of* the *Geological Survey of Great Britain.*

Hartley, A. J. and Warr, L.N. 1990. Upper Carboniferous foreland basin evolution in SW Britain. *Proceedings of the Ussher Society,* 7, 212-216. Jackson, R. R. and Sanderson, D. J. 1991. Transtensional modelling of en echelon vein arrays. GAC/MAC Meeting, Toronto. *Geological Association of Canada, Program with Abstracts,* 16, A60.

Lloyd, G. E. and Whalley, J. S. 1986. The modification of chevron folds by simple-shear: examples from North Cornwall. *Journal of the Geological Society, London, 143,* 89-94.

Mackintosh, D. M. 1967. Quartz-carbonate veining and deformation in Namurian turbidite sandstones of the Crackington Measures, North Cornwall. *Geological Magazine, 104,* 75-85.

Mapeo, R.B. and Andrews, J.R. 1991. Pre-folding tectonic contraction and extension of the Bude Formation, North Cornwall. *Proceedings of the Ussher Society,* 7, 350-355.

McCoss, A.M. 1986. Simple constructions for deformation in transpression/transtension zones. *Journal of Structural Geology,* 8, 715-718.

Pollard, D.D., Segall, P. and Delaney, P. T. 1982. Formation and interpretation of dilatant echelon cracks. *Geological Society of America Bulletin, 93,* 1291-1303.

Ramsay, J. G. 1974. Development of chevron folds. *Bulletin of the Geological Society of America, 85,* 1741-1754.

Ramsay, J.G. and Huber, M.I. 1987. *Techniques of Modern Structural Geology, Volume Two: Folds and Fractures,* Academic Press, London.

Rattey, P.R. and Sanderson, D. J. 1982. Patterns of folding within nappes and thrust sheets: Examples from the Variscan of southwest England. *Tectonophysics, 88,* 247-267.

Ridley, J. and Casey, M. 1989. Numerical modelling of folding in rotational strain histories: Strain regimes expected in thrust belts and shear zones. *Geology,* 17, 875-878.

Sanderson, D. J. 1979. The transition from upright to recumbent folding in the fold belt of south west England: a model based on the kinematics of simple shear. *Journal of Structural Geology, 1,* 171-180.

Sanderson, D. J. 1982. Models of strain variation in nappes and thrust sheets: A review. *Tectonophysics, 88,* 201-233.

Sanderson, D J. and Marchini, W.R.D. 1984. Transpression. *Journal of Structural Geology,* 6, 449-458.

Seago, R. S. and Chapman, T. J. 1988. The confrontation of structural style and the evolution of a foreland basin in central southwest England. *Journal of the Geological Society, London, 145,* 789-800.

Selwood, E. B. 1990. A review of basin development in central south-west England. *Proceedings of the Ussher Society,* 7, 199-205.

Shackleton, R. M., Ries, A, C, and Coward, M. P. 1982. An interpretation of the Variscan structures in southwest England. *Journal of the Geological Society, London,* 139, 533-541.

Whalley, J. S. and Lloyd, G. E. 1986. Tectonics of the Bude formation, North Cornwall - the recognition of northerly directed decollement. *Journal of the Geological Society, London,* 143, 83-89.

Zwart, H. J. 1964. The development of successive structures in the Devonian and Carboniferous of Devon and Cornwall. *Geologie en Mijnbouw, 43,* 516-526.