Journal of Structural Geology, Vol. 14, No. 3, pp. 373 to 375, 1992
Printed in Great Britain

0191–8141/92 $05.00+0.00

Vein morphology, host rock deformation and the origin of the fabrics of echelon mineral veins: Discussion

P. W. GEOFF TANNER

Department of Geology & Applied Geology, University of Glasgow, Glasgow G12 8QQ, U.K.

(*Received* 6 *September* 1991; *accepted* 12 *December* 1991)

FROM a study of the fabrics in a specimen containing en echelon veins from the Crackington Formation, southwest England, Nicholson (1991) has drawn the significant conclusion that the veins formed in two stages: fracture propagation followed by dilatation in the absence of ductile shear strain. This finding supports the suggestion by Beach (1975, p. 256) that some of the vein arrays found elsewhere in the Crackington Formation had developed in two stages. Nicholson & Ejiofor (1987) had also established that certain en echelon veins in these rocks form systems linked in three dimensions to a parent vein, but in neither this work nor in the paper under discussion was a description of the field setting of the veins given, the vein arrays having been sampled from loose blocks. However the main source of the material collected from the beach at Crackington Haven by Nicholson & Ejiofor (1987) is almost certainly in the well-exposed cliff section and headland on the north side of the cove (SX 140971). The en echelon veins in these rocks show features characteristic of the majority of such veins in the Crackington Formation, including the unlocated specimen from this formation described by Nicholson (1991). The field relations and geometry of these veins are described briefly here as the data both reinforce and amplify Nicholson's (1991) conclusions and give a new insight into the possible origin of the veins.

Sets of quartz-carbonate ± chlorite veins at Crackington Haven occur on both limbs of curvilinear, S-facing, tight to close D_1 folds which have gently inclined axial surfaces and have been warped by a later set of folds. The veins are up to 8 cm thick and have formed at a high angle to bedding in turbidite facies sandstone beds (up to 0.8 m thick) which are interbedded with siltstone and black slate. The veins, which generally have a tapered profile in cross-section, terminate abruptly at or near the bases of the sandstone beds but continue for a few cm as thin processes into the silty tops of the turbidite units. They are almost invariably filled with fibrous quartz and carbonate; the fibres lie within the plane of the bedding but when viewed orthogonal to bedding they are seen to make an angle of 65–90° with the vein margin (Fig. 1a). The orientation of fibres within individual veins is fairly constant but usually varies from vein to vein by as much as 25° within a set (Fig. 1a). Although most veins show wall-to-wall fibre growth, generally straight to slightly curved in plan view, others are vuggy and in the field some show internal features which appear to correspond with Nicholson's (1991) early crack–seal seams.

Careful examination of the numerous large blocks at the foot of the cliffs at Crackington Haven, as well as of sawn and sectioned specimens collected *in situ*, shows that as veins of the type described above approach either margin of a sandstone bed (but especially the finer-grained top) they split and pass into a series of en echelon segments or blades (Figs. 1b & c), as in the specimens illustrated by Nicholson & Ejiofor (1987). In this respect it is significant that the 'profile plane' of the en echelon vein described by Nicholson (1991) is parallel to bedding. Thus the en echelon veins appear to have formed by the mechanism described by Pollard *et al.* (1982) whereby a single dilating parent crack breaks down by mixed mode I–III loading into a series of en echelon segments as it encounters a mechanical discontinuity such as a bedding surface. Some veins have sets of thin en echelon veinlets oblique to their margins which give the parent vein a feathered appearance (Fig. 1d). These 'feather fractures' (Roering 1968) have been previously taken to indicate that the veins originated as shear fractures (Beach 1977) but it seems more likely that they have resulted from the propagation of the parent vein into the en echelon set which had formed at an earlier tip. Fibre orientations are commonly continuous from the central vein to the fringing growths (Fig. 1d) but, as predicted theoretically (Pollard *et al.* 1982, Nicholson & Pollard 1985), fibre growth in the en echelon blades which have been sectioned is slightly oblique to that in the parent vein.

Sets of *sigmoidal* en echelon veins are uncommon in these rocks and usually have a central fracture and show other features which indicate that the curved form of the veinlets is due to later shearing (cf. Roering 1968) acting parallel to the plane of weakness in the rock formed by the parent vein and its en echelon fringe. Two or more sets of veins occur in the exposures on the beach near the head of the cove and appear to form conjugate sets (Beach 1975). The original fractures may have formed simultaneously, possibly during layer-parallel shortening prior to fold development or during the early stages of fold amplification, but the fibre infills indicate that dilatation of these fractures to form veins occurred at different times as shown by the relationships seen in Fig. 1(e). This geometry suggests that fibre growth (in the

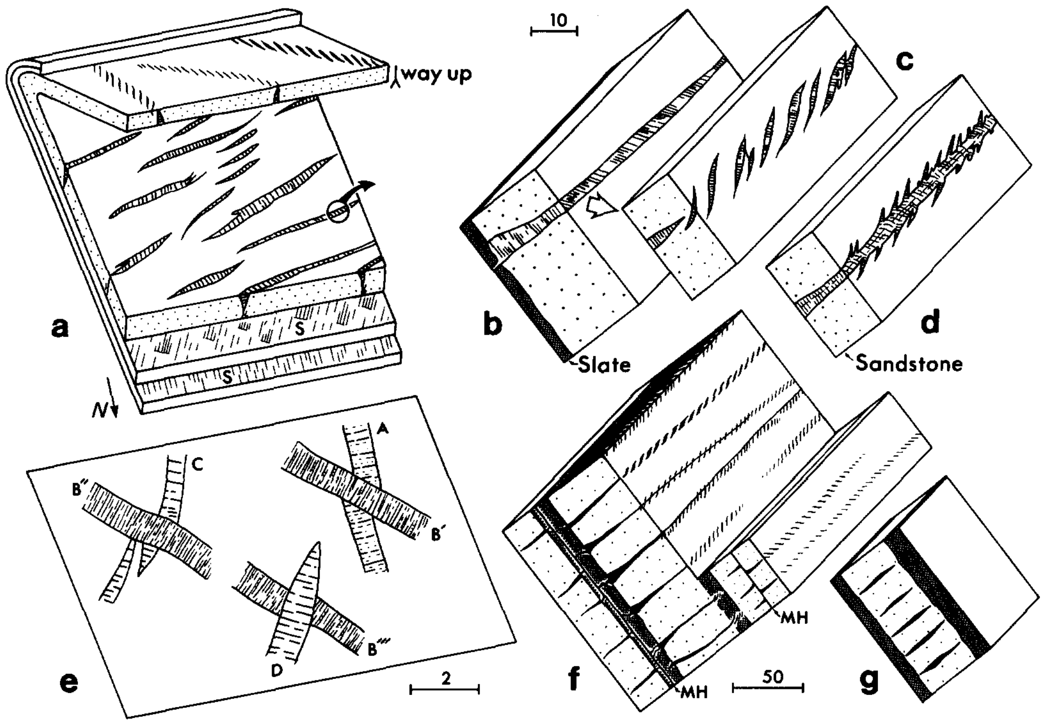

Fig. 1. Field relationships of some en echelon veins from Crackington Haven, southwest England. All scales are approximate and are given in cm. (a) Schematic isometric block diagram showing the relationship of one set of veins and their internal fibres (cross-hatched) to slickenfibre lineations (S) on movement horizons, and to the D_1 fold geometry. (b) A cross-fibre vein cutting a right-way-up sandstone bed, and (c) the en echelon vein set which develops on the upper surface of the bed. (d) shows a similar vein which has developed 'feather fractures' (see text). (e) Offsetting relationships shown on a bedding surface by cross-fibre veins; fibres within the veins are shown diagrammatically. (f) Sets of quartz veins (solid black) which link to movement horizons (MH). Sandstone, open stipple; slate, close stipple. Note the various types of symmetrical and asymmetrical en echelon patterns which develop on the tops of the beds and the plan view of a single vein shown on the upper left-hand side of the block. (g) 'Internal' quartz veins in a sandstone bed.

later veins, at least) represents the finite displacement direction and shows, for example, that the apparent offsetting of vein A by vein B′ (Fig. 1e) is due to dilatation in the plane of the bedding, not simple shear (cf. Beach 1977, p. 204). As noted by Beach at nearby Millook, there is no consistent relationship between the orientation of a vein and its relative age. In the absence of offset markers across most veins it is assumed in the following discussion that the fibres in the veins have tracked the opening trajectory, as in the above examples, although it is realized that this need not always be the case (Tanner 1989, p. 649).

The features displayed by these veins in the field, and in thin section (Nicholson 1991), indicate a dilatational origin unaccompanied by ductile shearing but this does not explain why the parent vein did not open normal to the original fractures rather than oblique to them, as shown by the fibre infills. Both Beach's and Nicholson's work on the internal fabrics in these veins suggests that some, at least, of the individual fractures had formed and had been cemented by fibred quartz growth before they were further dilatated and filled with fluid at a different stage(s) in the development of the fold structures, and under different stress conditions, to form fibred, vuggy or composite fibre-vuggy quartz–carbonate veins. Details of the timing of these processes is unknown and they may have occurred during a single progressive event. Of more relevance here is the observation that some of the sets of parent veins link up, often by means of narrow sinuous apophyses, with bedding-parallel fibrous quartz veins which have formed as a result of flexural-slip between packets of welded beds (Fig. 1f). This relationship is particularly well seen in clean, abraded exposures near the high tide mark at the head of the cove and is a common feature of upright flexural slip folds at Hartland Quay, North Devon (Tanner 1989), where fibres in the bedding-normal veins on the limbs of flexural-slip folds have the same trend as slickenfibre lineations on the linked movement horizon (flexural-slip surface). It indicates that, under conditions of high fluid pressure, fibre veins developed on the movement horizons at the same time as the cross-cutting veins described here formed within the packets of beds between them. This suggests that as these packets were rotated between movement horizons on the limbs of developing folds, the strains were partitioned into simple shear acting within and parallel to the movement horizons, and largely non-rotational strain within the packets. Some fluid was probably pumped into the bedding-normal veins via the movement horizons during this process. Complex strain patterns will develop within packets of beds on the limbs of plunging and curvilinear folds and this could explain the obliquity seen at Crackington Haven between the orientations of the slickenfibre lineations on the movement horizons, the fibres in the veins, and the normals to the fold axes; and between the fibres and the vein margins (Fig. 1a). Some extensional veins do not appear to be linked to movement horizons (the 'internal veins' of Fig. 1g) but where the tips of these veins, and of those which are linked with movement horizons, reach the top or the bottom of a sandstone bed, characteristic sets of en echelon veins develop (Fig. 1).

In conclusion, it is only by a detailed study of the internal fabrics of veins and country rock such as has been carried out by Nicholson (1991), together with a careful field examination and full geometric analysis of the veins and of any associated fold structures, that we can move towards an understanding of the mode of formation and kinematic significance of the various categories of en echelon veins. The main en echelon vein systems at Crackington Haven have developed where dilational veins, which have formed in packets of beds between movement horizons as a result of the partitioning of flexural-slip deformation, break down by mixed mode I–III loading where they meet the surface of a bed.

REFERENCES

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

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

Nicholson, R. 1991. Vein morphology, host rock deformation and the origin of the fabrics of echelon mineral veins. *J. Struct. Geol.* **13**, 635–641.

Nicholson, R. & Ejiofor, I. B. 1987. The three-dimensional morphology of arrays of echelon and sigmoidal mineral-filled fractures: data from North Cornwall. *J. geol. Soc. Lond.* **144**, 79–83.

Nicholson, R. & Pollard, D. D. 1985. Dilation and linkage of echelon cracks. *J. Struct. Geol.* **7**, 583–590.

Pollard, D. D., Segall, P. & Delaney, P. T. 1982. Formation and interpretation of dilatant echelon cracks. *Bull. geol. Soc. Am.* **93**, 1291–1303.

Roering, C. 1968. The geometrical significance of natural en echelon crack-arrays. *Tectonophysics* **5**, 107–123.

Tanner, P. W. G. 1989. The flexural-slip mechanism. *J. Struct. Geol.* **11**, 635–655.