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Back-rotation during crenulation cleavage development: implications for structural facing and cleavage-forming processes: Discussion

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1. Introduction

In his recent article, Johnson (1999a) discusses the relationships between bedding (S_0) and two generations of cleavage (S_3 and S_4) in a metamorphosed turbidite–mudstone sequence from the overturned limb of a large F_3 antiform in the Cooma Complex of N.S.W., Australia. Johnson claims that an S_4 crenulation cleavage developed from an S_3 differentiated layering in the incompetent pelitic beds, but not in the psammitic beds. The S_0/S_4 asymmetry and the gradual decrease of the S_0/S_4 dihedral angles towards the pelitic tops (resulting in a smooth curvature of S_4; Johnson's fig. 6) are indicative of F_4-related sinistral S_0-parallel shear. In the competent psammitic beds, S_3 is undeformed, and is either parallel or at a low angle to S_0 with a sinistral S_0/S_3 asymmetry (Johnson's figs. 4 and 6). For the pelitic beds, Johnson assumes that the orientation of S_3 preserved in the S_4 microlithons, which appear to be consistent in orientation in a hand-specimen-sized domain, does not reflect the orientation of S_3 prior to its crenulation by S_4 (Johnson's fig. 6). Connecting S_3 folia across several microlithons results in an S_3 'form surface' that yields a dextral asymmetry with respect to layer boundaries. Thus, S_3 in the psammitic and pelitic beds has contrasting asymmetries ('herringbone pattern'), and structural facing determined on S_3 in adjacent beds yields contradictory results (the same is valid for the determination of F_3 fold vergence based on bedding–cleavage relationships). Johnson therefore advises that facing is only reliable, when determined on S_3, which was not crenulated by S_4 (i.e. in the psammitic beds). He believes that the opposite S_0/S_3 asymmetry in the pelitic beds (relative to the psammitic beds) is a function of 'back-rotation' of S_3 (with respect to S_0) in the S_4 microlithons during crenulation. The original orientation of S_3, he speculates, was identical in all rock types, and is preserved in the psammitic beds (Johnson's fig. 8). Based on the observed porphyroblast–S_4 relationships and the S_3–S_4 angular relationships in the pelitic beds, Johnson concludes that synkinematic porphyroblasts grow generally during crenulation-cleavage development, and that back-rotation of the crenulation hinges (with respect to the S_4 septa) minimises shortening across the microlithons, thus preserving space for the redeposition of quartz dissolved from the developing septa.

In my opinion, Johnson's argument for cleavage back-rotation, as well as his suggested implications for structural facing, are implausible. An alternative explanation is offered here.

2. Discussion

1. Johnson gives little background information helpful for the reader to test his argument. The open questions are: What are the S_3–S_4 relationships on the other, normal-lying limb of the F_3 antiform? What is the evidence that S_3 is genetically associated with the large F_3 structure? Is there an F_4 associated with S_4?

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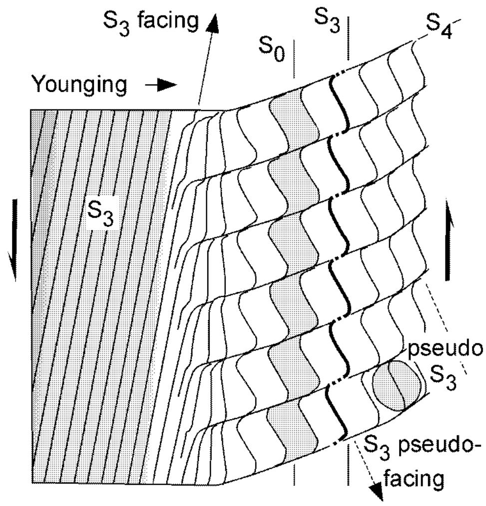

Fig. 1. Reinterpretation of the relationships in metamorphosed psammites (gradational shading) and pelites on the overturned limb of the F_3 anticline presented by Johnson (1999a; figs. 6 and 8). The dip of S_3 in the pelites, which results in a dextral S_0/S_3 asymmetry, is an optical illusion. The real S_3 orientation is given by the (inferred) enveloping surface to the crenulations (thick marker line), and approximates the orientation of bedding (shaded marker horizon). Structural facing determined on S_3 in the pelite is therefore neutral. S_4 and the porphyroblasts and S_3 folia in the S_4 microlithons rotate anticlockwise and thus synthetically with respect to sinistral layer-parallel shear (card deck model). The rotation has the same sense as the bulk flow: it is thus forward rather than backward.

2. The consistent and small S_0/S_3 dihedral angle in all rocks, taken as a starting orientation for the S_4-development model (Johnson's fig. 8a), appears somewhat unrealistic. First, taking into account the heterogeneous nature of deformation, S_3, where not transposed, must have become refracted across layer boundaries during F_3. Second, S_3 in the pelites must have been approximately parallel to S_0 after F_3, because, otherwise, S_3 would not have been in the F_4 shortening field and subject to crenulation (cf. Kraus and Williams, 1998, fig. 6d). Third, although the F_4-related S_0-parallel shear strains appear to be smaller than the F_3-related shear strains (both have sinistral sense), it is highly unlikely that the S_0/S_3 dihedral angles in the psammites remained constant throughout F_4 (Johnson's fig. 8). If this were the case, then S_3, where parallel to S_0 (as reported for most of the psammites), should have been crenulated during F_4. Therefore, a more realistic scenario is that, prior to F_4 (the increment corresponding to Johnson's fig. 8a), the S_0/S_3 dihedral angles were moderate to small in the psammites and small to infinitely small in the pelites.
3. Although S_4 is reported to occur only in the pelitic beds, it appears to be well developed in the psammitic beds shown (Johnson's figs. 5 and 7). In his fig. 5, S_4 constitutes a high-angle fracture cleavage with sinistral asymmetry (best developed between coin and line indicating orientation of S_3). In the upper and lower portions of his fig. 7, an S_4 crenulation cleavage is locally continuous from the psammitic into the pelitic bed, and its curvature beautifully reflects the gradient of the F_4-related sinistral S_0-parallel shear strain consistent with the gradual decrease in competency towards the pelitic tops.
4. My main criticism is that there is no dextral S_0/S_3 asymmetry in the pelitic beds and thus no need to discuss contrasting structural-facing directions on S_3 in the psammitic and pelitic beds (Fig. 1 and Johnson's fig. 6). In fact, the suggested orientation of S_3 relative to S_0 in the pelites is an *optical illusion* (Fig. 1) similar to the one described by Williams (1985, fig. 3). The illusion is the effect of different observation scales: the orientation of bulk bedding is equated with the orientation of S_3 in the microlithons, because S_3 is not continuous between microlithons and septa. That means, the orientations of the enveloping surfaces to crenulated S_0 and one of the two sets of crenulation limbs (defined by S_3) are compared (Fig. 1). However, the orientation of S_3 in the pelites, regarded as 'unreliable' by Johnson, cannot be real, because this S_3, on a scale larger than one microlithon, does not constitute a set of single surfaces (Fig. 1).

   The true orientation of S_3 is given by the inferred enveloping surface to several crenulations of a single folium (thick marker line in Fig. 1). Although such a marker surface is absent in the pelites, it is a valid interpretation, for reasons given in (2), that S_0 and S_3 were approximately parallel after F_3 and remained so during F_4. This interpretation is further supported by Johnson's fig. 7, in which the enveloping surfaces to several microfolds at the psammite–pelite transition immediately adjacent to the line indicating the orientation of (bulk) S_0 are approximately parallel to this line. Alternatively, if the S_0/S_3 dihedral angles in the pelites were initially small (as in Johnson's fig. 8a), the enveloping surface of crenulated S_3 should yield even smaller angles with S_0 such that the sinistral S_0/S_3 asymmetry is preserved after F_4. In the first scenario, structural facing on S_3 is neutral, and in the second, the facing has the same sense as in the psammites.
5. In the pelitic beds, after initial microfolding, all structural elements (S_4 and the porphyroblasts and S_3 folia in the microlithons) rotate anticlockwise (= synthetically) in response to sinistral layer-parallel shear (Johnson's figs. 6 and 8, summarized in Fig. 1). Hence, the local vorticity has the same sense as the bulk vorticity (on the scale of the diagram), and the rotation is forward (cf. Jiang, 1994, p. 1161). The catchy term 'back-rotation', used to explain the apparent reversal of S_0/S_3 asymmetry in the pelites, is therefore a misnomer (this also applies to

Johnson, 1999b, fig. 2). In his concluding discussion, Johnson changes his theme and refers to back-rotation of the S_3 folia in the microlithons towards orthogonality with respect to the S_4 septa. The question is, whether Johnson's implications, that is porphyroblast growth during crenulation-cleavage development, space creation for quartz deposition (dissolved from the developing septa), and minimization of shortening across the microlithons, are the result or the cause of this 'back-rotation'. The reader is referred here to studies, in which the geometrical aspects of crenulation-cleavage development were discussed in detail (e.g. Schoneveld, 1979; Williams and Schoneveld, 1981).

3. Concluding remarks

In his paper, Johnson (1999a) introduces a 'back-rotation' model to explain apparently opposing S_0/S_3 asymmetries and facing directions on S_3 in contrasting beds on the overturned limb of a large F_3 fold after S_4 crenulation (see also Johnson, 1999b). Closer inspection, however, shows that the 'reversed' S_0/S_3 asymmetry in the pelites (relative to the psammites) is an optical illusion resulting from different observation scales applied to S_0 and S_3. Thus, Johnson solves a non-existing problem. While the 'back-rotation' proposed by Johnson has no bearing on structural facing as long as the orientations of crenulated foliations are determined correctly, this discussion has implications for other areas, particularly for low-grade greenstone and slate belts. Here, phyllosilicate-rich rocks commonly contain several generations of 'intersecting' crenulation-type cleavages. Care is advised in such rocks when using the orientations of foliations for unravelling the structural histories in a spatial context and for reconstructing kinematic frames.

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