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

Jürgen Kraus

Geological Survey of Canada, 601 Booth St., Ottawa, ON K1A 0E8, Canada

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 $S_4$?
3. Although of the Fig. 1. Reinterpretation of the relationships in metamorphosed and approximates the orientation of bedding (shaded marker hor-
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 S0/S3 dihedral angle in all rocks, taken as a starting orientation for the S4-
development model (Johnson’s fig. 8a), appears somewhat unrealistic. First, taking into account the 
heterogeneous nature of deformation, S3, where not transposed, must have become refracted across layer 
boundaries during F3. Second, S3 in the pelites must have been approximately parallel to S0 after F3, 
because, otherwise, S3 would not have been in the F3 shortening field and subject to crenulation (cf. 
Kraus and Williams, 1998, fig. 6d). Third, although the F4-related S0-parallel shear strains appear to be 
smaller than the F3-related shear strains (both have sinistral sense), it is highly unlikely that the S0/S3 
dihedral angles in the psammites remained constant throughout F4 (Johnson’s fig. 8). If this were the 
case, then S3, where parallel to S0 (as reported for most of the psammites), should have been crenu-
lated during F4. Therefore, a more realistic scenario is that, prior to F4 (the increment corresponding to 
Johnson’s fig. 8a), the S0/S3 dihedral angles were moderate to small in the psammites and small to in-
finity small in the pelites.

3. Although S4 is reported to occur only in the pelitic beds, it appears to be well developed in the psammit-
ic beds shown (Johnson’s figs. 5 and 7). In his fig. 
S4 constitutes a high-angle fracture cleavage with sinistral asymmetry (best developed between coin 
and line indicating orientation of S3). In the upper 
and lower portions of his fig. 7, an S4 crenulation 
 cleavage is locally continuous from the psammitic 
into the pelitic bed, and its curvature beautifully 
reflects the gradient of the F4-related sinistral S0-
parallel shear strain consistent with the gradual 
decrease in competency towards the pelitic tops.

4. My main criticism is that there is no dextral S0/S3 
asymmetry in the pelitic beds and thus no need to 
discuss contrasting structural-facing directions on S3 
in the psammitic and pelitic beds (Fig. 1 and 
Johnson’s fig. 6). In fact, the suggested orientation 
of S3 relative to S0 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 S3 in the microlithons, because S3 is not continuous between micro-
lithons and septa. That means, the orientations of 
the enveloping surfaces to crenulated S0 and one of the two sets of crenulation limbs (defined by S3) are 
compared (Fig. 1). However, the orientation of S3 
in the pelites, regarded as ‘unreliable’ by Johnson, 
cannot be real, because this S3, on a scale larger 
than one microlithon, does not constitute a set of 
single surfaces (Fig. 1).

The true orientation of S3 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 S0 and 
S3 were approximately parallel after F3 and 
remained so during F4. This interpretation is further 
supported by Johnson’s fig. 7, in which the envelop-
ing surfaces to several microfolds at the psammitic– 
pelite transition immediately adjacent to the line 
indicating the orientation of (bulk) S0 are approxi-
mately parallel to this line. Alternatively, if the S0/ 
S3 dihedral angles in the pelites were initially small 
as in Johnson’s fig. 8a), the enveloping surface of 
crenulated S3 should yield even smaller angles with 
S0 such that the sinistral S0/S3 asymmetry is pre-
served after F4. In the first scenario, structural 
facing on S3 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 (S4 and the porphyroblasts and 
S1 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 S0/S3 asymmetry in the pelites, 
is therefore a misnomer (this also applies to
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 unraveling the structural histories in a spatial context and for reconstructing kinematic frames.

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References


