ELSEVIER

Journal of Structural Geology 26 (2004) 601–602

JOURNAL OF STRUCTURAL GEOLOGY

www.elsevier.com/locate/jsg

Discussion

# Comment on “Folding in high-grade rocks due to back-rotation between shear zones” by Lyal B. Harris

Tom Blenkinsop

*School of Earth Sciences, James Cook University, Townsville, QLD 4811, Australia*

Received 10 January 2003

*Keywords:* Back-rotation; Shear zones; Folds; Reference frame; Shear sense

This interesting paper suggests that folding can occur in high-grade rocks when “back-rotation“ of foliation occurs between shear zones, so that the foliation enters the shortening field of the finite strain ellipse and buckles. The photographs and well-drawn diagrams clearly illustrate the association between some folds and shear zones.

The term “back-rotation” is becoming more widely used in structural geology literature (e.g. Koyi, 1995; Marques and Cobbold, 1995; Rahn and Grasemann, 1999; Johnson, 1999, 2000a,b; Grasemann and Stüwe, 2001; Harris et al., 2002; Chang et al., 2003). However, it is potentially very confusing (cf. Kraus, 2000). A complete description of rotation should specify the entity that is rotated, the reference frame, orientation of the rotation axis, the rotation angle, and a convention about the sense of rotation. The importance of the reference frame has been stressed frequently—Kraus and Williams (2001) give a good summary, and describe possible choices of reference frames. In several of the publications referred to above, “back-rotation” of structural elements is described relative to the kinematics of a local shear zone, and the rotation axis is implicitly taken as perpendicular to the field of view. The phrase “back-rotation” alone does not contain any useful information that indicates what is rotated, what reference frame is used, or the orientation of the fold axis.

It is particularly important to distinguish rotation relative to a kinematic reference frame, such as the instantaneous stretching axes (vorticity) from rotation in an external reference frame (spin, cf. Passchier and Trouw, 1996). Which of these does “back-rotation” refer to, and what is rotated? Harris (2003) can be read to imply that gneissic/regional foliation was rotated, relative to “bounding shear zones”. The nature of the foliation is then important: can it be assumed to have been passive, was it related to finite strain, the instantaneous strain, or was it a strain insensitive foliation? What was the orientation of the fold axis of the “back-rotation”, and what was its relation to the vorticity axis of the shear zones? These may not be easy questions to answer, yet they are fundamental to understanding the process of “back-rotation”, and to the interpretation that structures observed in the field formed by this process.

One requirement of the hypothesis that folding is linked to back-rotation between shear zones is that “back-rotation”, folding and shearing occur synchronously as part of a single unique deformation event. The existence of some folds illustrated in Harris (2003) that are clearly not associated with shears (e.g. Fig. 7c top, Fig. 11a lower left and top right, and Fig. 12h top left), and folds that have shear zones only on one side (Fig. 7d right and Fig 8a left) strongly suggests that buckling between shear zones was not the only folding process in these examples. Such folds cannot form by the proposed process. These folds could, in principle, be associated with shear zones that are out of the section, but this is not demonstrably the case.

Deducing deformation histories from finite deformation geometries is well known to be problematic, since the same deformation state can be reached via many different deformation paths. One hypothetical alternative, permitted by the data presented, for some folds in Harris’ Figs. 7, 8 and 11 is as follows: an early deformation produced dextrally verging, asymmetric folds by a component of dextral simple shear. The sinistral shear zones may have evolved later in this deformation event, or as a separate later event, possibly localised along the fold limbs. In either case,

*E-mail address:* thomas.blenkinsop@jcu.edu.au (T. Blenkinsop).

0191-8141/$ - see front matter 
doi:10.1016/j.jsg.2003.08.007

the shear zones were not associated with the formation of folds, although they could have been modifying agents. There may be more complex alternatives.

Are such alternative interpretations important? The possibility proposed above would have quite different kinematic implications from the deformation history implied by the "back-rotation" process. Moreover, the sense of rotation on the foliation is actually forward with respect to the sense of shear during the formation of the folds in this alternative.

The main purpose of this comment is to point out that at least one folding process other than "back-rotation" may have been operating in the examples given by Harris (2003). The extent to which any of the folds are related to back-rotation is therefore questionable. As pointed out by Harris (2003), it is notable that layering in all other published examples of "back-rotation" between faults and shear zones, remains essentially planar, including experiments. Diagnostic, not merely indicative, criteria need to be established that allow attribution of folding to "back-rotation". A precise definition of the term "back-rotation", including specification of the reference frame and the orientation of the rotation axis, would be useful. A dynamic understanding of the hypothesis of folding due to "back-rotation" should be sought through theoretical and/or numerical modelling. This would give much greater confidence to the interpretation of structures observed in the field.

## References

Chang, C.-P., Angelier, J., Lee, T.-Q., Hung, C.-Y., 2003. From continental margin extension to collision orogen: structural development and tectonic rotation of the Hengchun peninsula, southern Taiwan. Tectonophysics 361, 61–82.

Grasemann, B., Stüwe, K., 2001. The development of flanking folds during simple shear and their use as kinematic indicators. Journal of Structural Geology 23, 715–724.

Harris, L., 2003. Folding in high-grade rocks due to back-rotation between shear zones. Journal of Structural Geology 25, 223–240.

Harris, L.B., Koyi, H.A., Fossen, H., 2002. Mechanisms for folding of high-grade rocks in extensional tectonic settings. Earth-Science Reviews 59, 163–210.

Johnson, S.E., 1999. Near-orthogonal foliation development in orogens: meaningless complexity, or reflection of fundamental dynamic processes? Journal of Structural Geology 21, 1183–1187.

Johnson, S.E., 2000a. Back-rotation during crenulation cleavage development: implications for structural facing and cleavage-forming processes. Journal of Structural Geology 21, 139–145.

Johnson, S.E., 2000b. Back-rotation during crenulation cleavage development: implications for structural facing and cleavage-forming processes: reply. Journal of Structural Geology 22, 153–156.

Koyi, H., 1995. Mode of internal deformation in sand wedges. Journal of Structural Geology 17, 293–300.

Kraus, J., 2000. Back-rotation during crenulation cleavage development: implications for structural facing and cleavage-forming processes: discussion. Journal of Structural Geology 22, 149–151.

Kraus, J., Williams, P.F., 2001. A new spin on "non-rotating" porphyroblasts: implications of cleavage and reference frame. Journal of Structural Geology 23, 963–972.

Marques, F.G., Cobbold, P.R., 1995. Development of highly non-cylindrical folds around rigid ellipsoidal inclusions in bulk simple shear regimes: natural examples and experimental modelling. Journal of Structural Geology 17, 589–602.

Passchier, C.W., Trouw, R.A.J., 1996. Microtectonics, Springer-Verlag, Berlin.

Rahn, M.K., Grasemann, B., 1999. Fission track and numerical thermal modeling of differential exhumation of the Glarus thrust plane (Switzerland). Earth and Planetary Science Letters 169, 245–259.