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Kinematic analysis — the sense of shear-sense. Discussion of: 'Essay Review: Kinematic analysis — pure nonsense or simple nonsense' by D. Flinn

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We are pleased to see that our recent publication (Hanmer and Passchier 1991) has come to the attention of Derek Flinn (Flinn 1994). However, we are surprised by his negative attitude, as well as by the form taken by his contribution. As clearly stated in our title *Shear-sense indicators: a review*, we reviewed a large body of work by countless researchers in the field of vorticity analysis. Yet Derek Flinn appears to take issue with the concepts, and thereby their originators, rather than our presentation of them. Indeed, much of his contribution expresses his disagreement with researchers whose work is not even the subject of our review. Furthermore, he contends that we reinforce the 'widespread view that monoclinic structures are due to simple shear and that all deformation [sic] is simple shear'. This is surprising, given our insistence on general non-coaxial flow, as opposed to idealized flow types such as simple shear, and our treatment of the kinematic vorticity number of flow (W_k; Means *et al.* 1980), a useful quantitative expression of deviation from both simple and pure shear flows. Far from ignoring the possibility that deformation structures may result from progressive pure shear, we were explicitly concerned with structures which form in more complex, general non-coaxial flows. Clearly the subject requires further elaboration.

Take the case of sheath folds (Cobbold and Quinquis 1980), just one of the examples mentioned by Derek Flinn. It was not our intention to examine the myriad of possible strain paths leading to their formation, but to caution against their injudicious use as shear-sense indicators even where they *had* formed in non-coaxial flow. Flinn states that we consider that 'shear zones are zones of simple shear, possibly accompanied by a minor component of two-dimensional pure shear . . .'. Again, this is surprising as a kinematic vorticity number (W_k) approaching zero (our Figure 23) is equivalent to pure shear with a minor component of simple shear. We present many natural examples of winged inclusions whose long axes have come to rest at an orientation which is not a stable position of rest in non-coaxial flow *unless* the kinematic vorticity number of the flow (W_k) approaches zero (see our Figure 23, and the gist of the entire first chapter of our paper). One of those examples was even used to illustrate the cover of the paper. We also discuss, at some length (pp. 44–52), the now common observation that some structures may *appear* to rotate backwards, whereas others *really* do rotate backwards with respect to the kinematic axes and the bulk vorticity of the flow. With the aid of 14 illustrations, we carefully explain that the former case is well known in pure shear flow (e.g. Ramsay 1967), whereas the latter case requires a *significant* deviation from simple shear.

Derek Flinn concludes that we 'divorce [our] determinations of shear sense from any interpretation of the rock mass . . .'. However, five pages of the first chapter are dedicated to examining the influence of

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rheological anisotropy and competency on the locally resolved deformation history, how the nature of the rock mass may enhance the pure shear component of the flow and how it may control the partitioning of the pure and simple shear components. Most importantly, two-thirds of the entire paper are concerned with the examination of real structures in real rocks, mostly from areas we have systematically mapped.

Flinn claims that we consider deformation to be two dimensional, that we 'prescribe ... ignoring the third dimension', and that we advise 'the structural geologist ... to assume the deformation is two dimensional' when it is so clearly three dimensional. We fully agree that three-dimensional flow and deformation can be very complex, and that analyses of structural problems should not be restricted to single two-dimensional sections. However, the study of shear-sense is one of the few structural geological topics which lends itself to a two-dimensional approach. The monoclinic symmetry of non-coaxial flow in shear zones is reflected in the developing structures. Once the symmetry axis of the structures is determined (normally assumed to develop parallel to the vorticity vector of the flow), shear-sense is either sinistral or dextral, and the problem reduces to two dimensions. Accordingly, kinematic analysis of shear zones is always a two-step process. The latter step is the subject of our review. Furthermore, we made the decision not to discourage potential readers by presenting a rigorous mathematical treatment of the subject. The development of shear-sense indicators in ductile shear zones is an extensive and rapidly developing topic. Many of the structures presently used as shear-sense indicators are empirically established and await further study. As stated in the first sentence of the first chapter (Flow and rheology in progressive deformation) of our paper: 'In the following paragraphs, we shall present a *simple*, non-mathematical summary of flow and progressive deformation. For a more rigorous approach, we recommend that the interested reader consult some of the more geologically oriented sources on the subject ...' (our emphasis). Nonetheless, methods to analyse the full three-dimensional aspects of vorticity and flow, besides shear-sense, are currently under development and we hope they will shortly become available to the geological community.

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