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Inter-array and intra-array kinematics of en échelon sigmoidal veins in cross-bedded sandstone, Merimbula, southeastern Australia: Reply

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Nicholson suggests that the paper under discussion (Smith, 1999) is not successful in showing the applicability of bridge-bending kinematics to the field examples presented. Nicholson and co-workers (papers cited in his point 2) developed the analysis of curved bridges of rock between fractures in studies of field examples that had angles between fractures and their host array (fracture-array angle) of about 10° and less. [In one of those papers (Nicholson, 1991) the main array has a fracture-array angle of about 22° but with minimal curvature of bridges; the curved bridges occurred in 'sub-arrays' with fracture-array angles of about 10°.] Their work has included schematic diagrams and graphs of geometric parameters at higher fracture-array angles but no field examples of such vein systems were described in those papers to support the extension of their model to arrays with higher fracture-array angles.

As shown in detail in my paper (fig. 9) the veins at Merimbula have a wide range of fracture-array angles. I proposed that geometric observations support the formation of the sigmoidal vein shape by bending of bridges of rock between fractures. The fact that Nicholson and co-workers disallowed bridge shortening or material transfer in their analysis of low-angle en échelon fracture arrays does not prohibit these processes from occurring in arrays of higher fracture-array angles formed by bridge-bending. By acknowledging their work I did not intend to imply that I would limit the bridge-bending process to the features observed and conditions implied from their range of field examples.

More specifically, Nicholson (point 1) states that in my presentation of bridge-rotation "bridges are defined by an already existing planar anisotropy (bedding for example), shortened as veins open". This is an inaccurate characterisation of my presentation of the bridge-rotation model. My field data showed that some veins occur on bedding and cross-bedding while others occur on newly formed fractures. In the bridge-rotation model, bridges bend after fractures have propagated and thus fractures 'pre-exist' the bending process even though they may "arise as part of the vein-forming process" (as Nicholson put it). One point of evidence of this, from a different field area (Smith, 1996), is the change of vein shape from planar to sigmoidal without an increase in length of veins in serial profile sections. This is in contrast to the vein-rotation model in which rotation and fracture propagation are truly simultaneous. Also, I did not contend that shortening of bridges must occur. Nicholson may be referring to the geometric shortening caused when the bridges are rotated and thus present a decreasing dimension along the length of the array. However, shortening along bridges may occur and contribute to the ultimate morphology of the veins and bridges.

In my schematic representation (fig. 7) of an asymmetric vein that could accommodate different degrees of bending in its adjacent bridges, Nicholson notes (point 3) that the lengths of the vein margins differ. Clearly, without some bridge deformation there would be incompatible strains. A real example of such a vein is shown in fig. 6(b) and the caption to that photograph specifically draws attention to the deformation

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of the bridges. No particular pattern of bridge deformation (other than bending) is shown in the schematic diagram and, as the paper concluded, such bridge deformation is highlighted as needing further investigation.

In response to point 4, I reply that I have been successful in showing that bridge bending can explain the observed sigmoidal shapes in these relatively high-angle en échelon vein arrays. Detailed aspects of the model of Nicholson and co-workers derived from studies of relatively low-angle en échelon vein (and other fracture) arrays cannot be considered to limit the extension of the general kinematic model to a different range of structures.

References

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