Porphyroblast rotation versus nonrotation: Conflict resolution!: COMMENT and REPLY

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Fay et al. (2008) present a few numerical simulations (with unspecified code or boundary conditions) as evidence for nonrotation of porphyroblasts during non-coaxial flow. However, the large body of work on the behavior of porphyroblasts in deforming ductile rocks is significantly undervalued. Many authors have studied the rotation of porphyroblasts, often paying special attention to the cases where porphyroblasts do not rotate (much) because of their shape and orientation, shear localization, slip along the porphyroblast-matrix interface, etc. (Passchier, 1987; Masuda et al., 1995; Passchier and Trouw, 1996, and references therein; Bons et al., 1997; ten Grotenhuis et al., 2002; Ceriani et al., 2003, and references therein). Thus, it is well accepted that porphyroblasts do not rotate (much) under certain circumstances. In contrast, none of these authors argue that porphyroblasts are therefore, in general, inhibited in their rotation.

No current theory would predict that the porphyroblasts modeled by Fay et al. would rotate significantly, because of the low strain and the square shape. A two-dimensional simulation of a growing porphyroblast in a deforming viscous matrix shows the fallacy of the argument by Fay et al. If the porphyroblast and the foliation rotate at a similar rate, and the foliation is being shortened, a millipede inclusion pattern develops, even in simple shear (Fig. 1A). There is, therefore, no need for coaxial deformation to create a millipede structure, and especially no need to model the development as a two-stage, pure shear then simple shear, history. If, under otherwise identical circumstances, the foliation is parallel to the shear plane, a different, spiral inclusion pattern develops (Fig. 1B; also see Figure 7.22 of Passchier and Trouw, 1996). Our simulations were carried out with the software packages Elle (Jessell et al., 2001) and Basil (Barr and Houseman, 1996), using the script and boundary conditions described in experiment 9b of Bons et al. (2008). Both matrix and porphyroblast are noncompressible power-law viscous materials with a stress exponent of three and an effective viscosity contrast of ten.

Fay et al. (2008, p. 309) suggest that there is a "long-lived conflict between data from natural rocks on FIAs and experimental, theoretical, and analog modeling." This is a misleading statement, because it suggests a conflict with all data from natural rocks, not only with those relying on the FIA model (Bell et al., 1995). Starting with the pioneering work of Schoneveld (1977), a large body of research, based on field evidence, theoretical considerations, and physical and numerical experiments, has shown that porphyroblasts in deforming ductile rocks can rotate significantly, but has also recognized circumstances where the rotation of porphyroblasts is inhibited, sometimes to the extent of complete nonrotation. The "conflict" that is invoked by Fay et al. does not exist, and the "resolution" is therefore trivial.

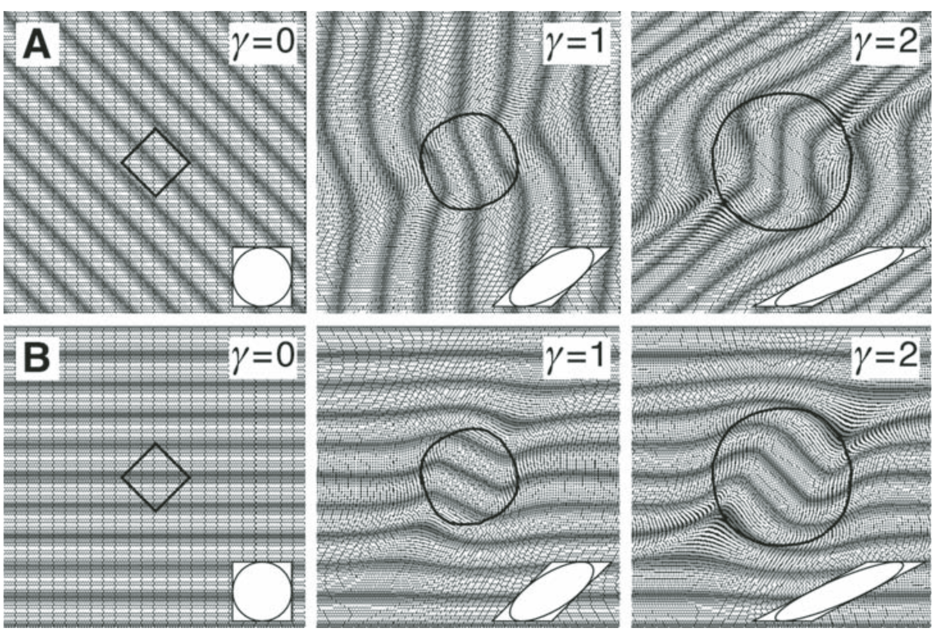

Figure 1. Numerical simulation of the development of inclusion patterns in a growing porphyroblast. A: An initially square object and a foliation at 45° to the horizontal shear plane. Because the porphyroblast initially rotates at about the same rate as the shortening foliation, a millipede inclusion pattern develops. B: Identical experiment, but with the foliation starting parallel to the shear plane. Now the porphyroblast rotates faster than the foliation, and a spiral inclusion pattern develops. Insets show dextral finite simple shear strain (γ) of 0, 1, and 2.

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The fundamental point missed by Bons et al. (2008) and illustrated in Fay et al. (2008) and Figure 1 is that porphyroblasts do not rotate because the strain and strain rate are partitioned into domains in the materials (Mohr-Coulomb [Figs. 1A–1F] and strain-rate-softening viscous materials [Fig. 1G]; they occupy regions of low strain rate. Figures 1A–1F show variously shaped “porphyroblasts” deformed at high strain under conditions most likely to cause rotation. Their lack of rotation is independent of shape and orientation. Figure 1G emphasizes that boundary conditions play little role in controlling the kinematics of the porphyroblasts, and that the key is whether localization occurs or not. The porphyroblasts sit in regions where the strain-rate is around 10^{-12} s^{-1}, whereas the bulk of the deformation is taken up in surrounding shear zones where the strain-rate reaches 10^{-9} s^{-1}. This behavior cannot occur in the models presented by Bons et al. (2008) or most other authors in the past. It is fundamental to controlling porphyroblast kinematics.

Only interpretations of the origin of variably oriented and spiral-shaped inclusion trails have been used to suggest porphyroblasts rotate significantly during ductile deformation of rocks. Data that are independent of the interpretation of the origin of such microstructures, such as foliation intersection/inflection axes (FIA) preserved in porphyroblasts (e.g., Bell and Mares, 1999; Cihan and Parsons, 2005; Sayab, 2005; Rich, 2006; Yeh, 2007), indicate that they do not. None of these FIA successions, matched by progressively younger ages when dated using monazite (Bell and Welch, 2002; I. Sanislav and A. Shah, 2008, personal commun.), can be explained if porphyroblasts rotate during ductile deformation.

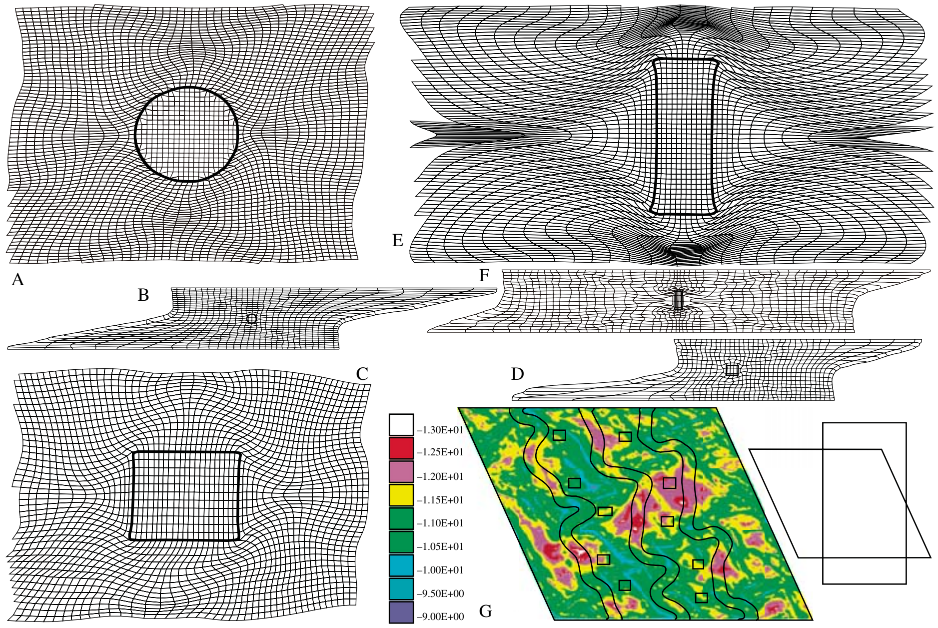

Figure 1. A-F: Simplified strain field for the full model, plus detail around “porphyroblasts.” Effects of shearing only (fixed velocity applied to the top and bottom with these constrained to remain straight and parallel; sides are free) after millipede geometries were developed by bulk shortening of a sphere (A, B), rectangle (C, D) and square (E, F) by 20, 50, and 20% shortening, respectively. G: “Porphyroblasts” and contoured logarithm of strain rate resulting from constant velocity parallel to initially vertical layers coupled with simple shearing normal to this direction. The horizontal velocity was adjusted to maintain an isochoric deformation. This elastic-viscous material can undergo both strain and strain-rate softening with the viscosity at strain-rate $\dot{\varepsilon}$ given by $\eta = \eta_o \varepsilon^p \left(\frac{\dot{\varepsilon}_o}{\dot{\varepsilon}}\right)^q$ where η is the current viscosity, η_o is the viscosity at a reference strain rate $\dot{\varepsilon}_0$, and *p* and *q* are strain and strain-rate softening parameters ($p = -0.8$ and $q = 2.0$; initial viscosity ratio between layers and embedding medium is 10).

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