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Reply to comment by A. Stallard on "Crystallographic orientation, chemical composition and three-dimensional geometry of sigmoidal garnet: evidence for rotation"☆

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We are grateful to Stallard (2003) for his comment, which provides a platform for further discussing our new data regarding the formation of sigmoidal garnets and other such porphyroblasts.

Both rotationalists and non-rotationalists agree that porphyroblasts with coeval curved inclusion trails formed due to relative rotation between the porphyroblast and coexisting matrix foliation. The choice of reference frame for describing this effect is one of convenience and it is this choice alone that will determine whether an individual porphyroblast has rotated or has remained fixed. We, therefore, agree wholeheartedly with the comment of Stallard that the geometry of curved inclusion trails in such porphyrobasts will not be diagnostic of whether the porphyroblast or the matrix rotated. Both descriptions are equally valid.

A more fundamental aspect of the rotationalist vs. non-rotationalist view of porphyrobasts is whether or not curved inclusion trails formed during a single tectonometamorphic event or if they represent the accumulated effects of several independent events. This second distinction is of more than semantic interest and has significant implications for the interpretation of microstructures in metamorphic rocks (e.g. Bell and Johnson, 1992).

In our paper we investigate two well-developed sigmoidal garnet grains with tightly curved inclusion trails. We propose that these inclusion trails formed during a single tectonometamorphic event based on gradual changes in the orientation of the internal fabric, the chemical composition of the garnet, and the external morphology of the garnet as shown by chemical contours. The rationale for this approach is that polyphase tectonic histories will, in general, form a series of independent deformational fabrics and these should or at least are likely to be associated with recognizable concomitant changes in metamorphic conditions. Such changes in deformation fabric and P–T conditions will be reflected in changes in the orientation of the internal fabric and chemical composition. However, our studies reveal no major breaks or sudden changes in the inclusion trails or garnet composition and where our data do allow for some minor discontinuities the two features do not coincide. In addition to these data, our studies of the external morphology of the garnet also suggest continuous shape changes (Fig. 6 in Ikeda et al., 2002). In order to avoid subjectivity in our analysis of how the orientation of the long axis of the chemical contours changes, we used parameters in the contour map for constructing the plot. This result is clearly distinct from the roughly orthogonal shape changes predicted by the godfather of the non-rotationalist school, Tim Bell (Bell et al., 1992). In our paper we indicate how these shape changes can be incorporated in a single-phase rotational model.

In response Stallard proposes that shape changes in garnet need not be near orthogonal even in a polyphase evolution and that polyphase deformation with associated foliations at high angles to each other may develop during a single phase of garnet growth. He concludes that our observations and data do not exclude the possibility of a non-rotationalist polyphase development of snowball garnet. We make no claim that our contribution is a complete

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rebuttal of the non-rotationalist school. There may, for instance be significant breaks in the features of garnet that are smaller than the resolution of our investigation. We contend, however, that our results are very difficult to incorporate in the main type of non-rotationalist model so far proposed in the literature (e.g. Bell et al., 1992). Alternative polyphase non-rotationalist models exist that may be more difficult to distinguish from the rotationalist single-phase model (e.g. Stallard et al., 2003). However, we emphasize that to account for garnet such as that discussed in our paper by a polyphase model would require the fortuitous sequential development of a series of deformation phases with particular geometric characteristics during a single phase of garnet growth or a sequence of growth phases where the P–T conditions closely coincided. Such coincidences are inherently unlikely, but, we admit, not impossible.

One further consideration in favour of a single phase rotationalist model comes from an understanding of the metamorphic changes associated with particular deformation phases. One of the samples (#80904) underwent two distinct major phases of penetrative ductile deformation, only one of which has been considered to be synchronous with garnet growth (Treagus, 1974; Pattison and Voll, 1991; Ikeda, 1996). We cannot completely exclude the possibility such that polyphase deformation associating with sequential development of foliations took place during prograde metamorphism and that this is genetically related to the formation of the continuous inclusion patterns. However, despite careful studies of both major and minor structures in the area, no evidence has been reported to support such a deformation history and any such suggestions are pure speculation.

We do agree with Stallard, however, that a universal and infallible test to differentiate the rotationalist single-phase model from non-rotationalist polyphase models for porphyroblast development has yet to be devised.

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