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Quartz *c*-axis fabric differences between porphyroclasts and recrystallized grains: Discussion

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RECENTLY, Kirschner & Teyssier (1991) identified differences between quartz *c*-axis fabrics of porphyroclasts and recrystallized grains in mylonitic quartzites (Heavitree Quartzites), and interpreted these differences as indicating a change in the kinematic framework during the deformation history. In this discussion, we suggest an alternative interpretation of such fabrics derived from our current research on sheared granitoids (see the Appendix for a description) from the Archean Bonfim Metamorphic Complex in the Quadrilatero Ferrifero, southeast Brazil. In these rocks, differences between *c*-axis fabrics shown by old and new grains resulted from the heterogeneous disappearance of porphyroclasts with increasing recrystallization. The porphyroclasts that disappeared faster were ones more favourably oriented to undergo dynamic recrystallization by subgrain rotation. Heterogeneous disappearance of porphyroclasts gradually altered the deformation fabric initially shown by porphyroclasts by reinforcing the orientations most resistant to recrystallization in the most recrystallized samples. It is suggested that the porphyroclast fabrics displayed by Kirschner & Teyssier (1991) have a similar origin.

Before we deal with Kirschner and Teyssier's paper itself, a brief comment on both selective recrystallization and residual fabric is necessary, as these are the keys to our reinterpretation of the Heavitree Quartzite fabrics.

THE CONCEPT OF RESIDUAL FABRIC

Quartz porphyroclast fabrics are usually considered to represent intracrystalline deformation fabrics (Marjoribanks 1976, Lister & Price 1978, Law *et al.* 1984, Law 1986, Dell'Angelo & Tullis 1989, and many others). However, this is true only if relicts of nearly all original grains are still present. When porphyroclasts begin disappearing, obliteration of the deformation fabric generally begins, because the disappearance rate (which relies on the ease of recrystallization) is not uniform along the whole fabric skeleton. With increasing degree of recrystallization, a change in the porphyroclast fabric might be expected, firstly in the strength and distribution of the maxima, and then in the fabric skeleton itself. Thus, a fabric that portrays the orientation of the porphyroclast relicts most resistant to recrystallization (the 'residue' of the recrystallization) might be gradually displayed. In this Discussion, it is called the residual fabric.

Unfortunately, residual fabrics have not received attention in studies on quartz microfabric, probably because they are more noticeable when the amount of porphyroclasts is relatively low. Commonly, there are insufficient porphyroclasts in a single thin section to permit the construction of fabric diagrams. In these cases, two or more thin sections of the same sample are required to obtain a representative plot.

Some studies of quartzites with low degrees of recrystallization (more than 50% of porphyroclasts relative to total quartz), show only a subtle dissimilarity between *c*-axis fabrics of old and new grains in the most deformed samples (e.g. Law 1986), which may indicate the beginning of a residual fabric appearance. In contrast, Saha (1989) found significant *c*-axis fabric differences between porphyroclasts and the matrix (analogous to those described by Kirschner and Teyssier) dealing with highly recrystallized quartzites, which probably reflects a mature residual fabric development.

Figure 1 displays a complete *c*-axis fabric transition in a 2 m-wide shear zone, in which the appearance and strengthening of a residual fabric with increasing recrystallization is clearly seen.

SELECTIVE RECRYSTALLIZATION

In transitional conditions between coaxial strain and ideal simple shear (as occurs in the Heavitree Quartzites), quartz grains develop an asymmetric cross-girdle deformation fabric (Schmid & Casey 1986) in which the stronger maximum lies in the girdle synthetic to the shear sense (e.g. Behrmann & Platt 1982, Garcia Celma 1982). The grains in the antithetic girdle are in metastable orientations (Urai *et al.* 1986) and tend to disappear faster than other grains either by subgrain rotation (e.g. Garcia Celma 1982) or by grain boundary migration recrystallization (e.g. Urai & Humphreys 1981; see Urai *et al.* 1986 for discussion) preventing

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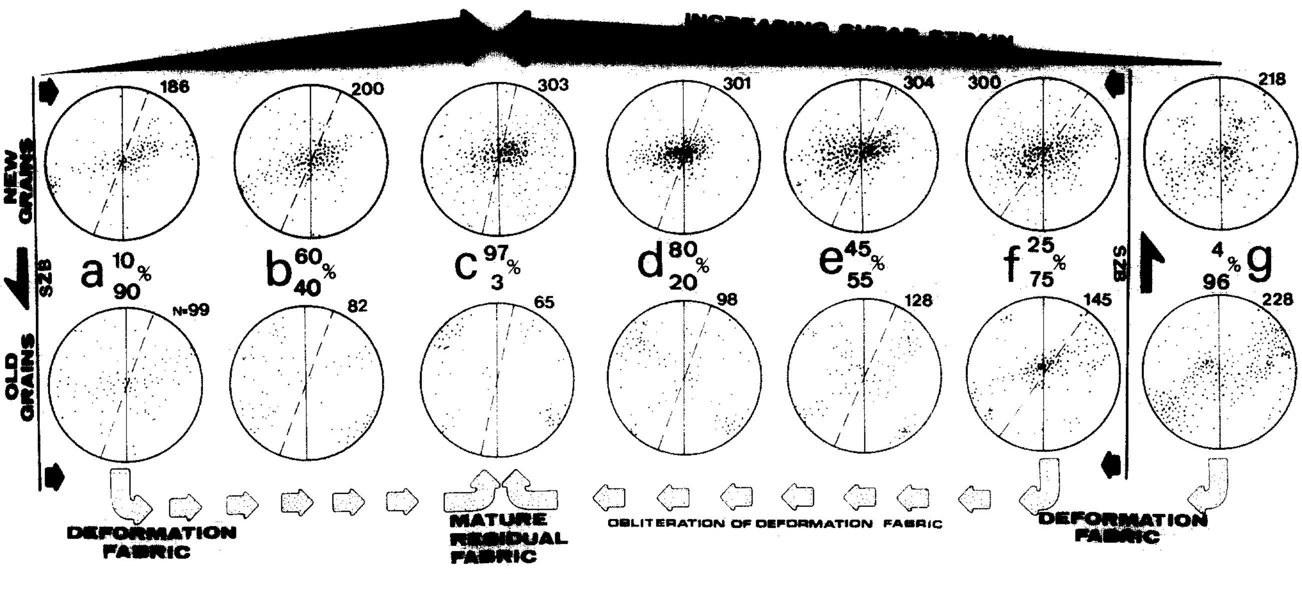

Fig. 1. Evolution of *c*-axis fabric of porphyroclasts and recrystallized grains with increasing recrystallization and shear strain in a 2 m-wide low-grade shear zone. Percentages indicate partitioning of quartz between porphyroclasts and new grains in each sample. A *C*-foliation parallel to the shear zone boundary (SZB) and an *S*-foliation (dashed line) are indicated in each plot. Similar fabric skeletons to porphyroclasts and new grains are found in the samples with low degrees of recrystallization (a, f and g). Samples highly recrystallized (b, c, d and e) show increasing fabric differences that result in the gradual appearance of a residual fabric in the porphyroclast plots (dotted arrows).

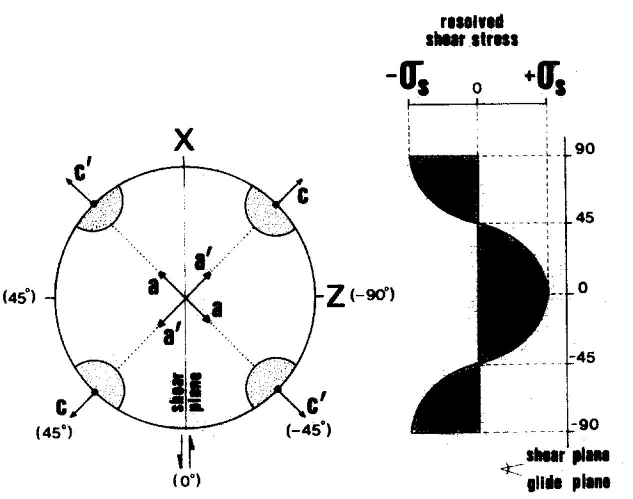

Fig. 2. Orientation of *a*-axes to porphyroclasts oriented with *c*-axes in the maxima of the mature residual fabric (sample c). Note that *a*-axes lie in two planes with zero resolved shear stress (cf. Krohe 1990).

fabric hardening (Lister & Hobbs 1980). According to Urai *et al.* (1986), grains oriented favourably to accommodate slip on a single glide system tend to be homogeneously deformed and may be recrystallized more slowly than ones deforming by multiple slip.

We have found, however, that some porphyroclasts in theoretically metastable hard orientations can, in fact, be very resistant to recrystallization and are the last to disappear in granitoids and sericitic quartzites subjected to shear strain, without provoking significant bulk strain hardening. We suggest that, in non-coaxial strain regimes, relatively hard porphyroclasts can survive dynamic recrystallization when other deformation mechanisms (e.g. microfracturing of feldspars in granitoids, grain boundary sliding in micaceous quartzites) reduce the flow stress (as probably has occurred in the micaceous Heavitree Quartzites). In these cases, the strain component due to intracrystalline plasticity can be accommodated exclusively by grains in orientations favourable to single slip, in which there is a maximum resolved shear stress acting upon a single glide system (see Krohe 1990). In contrast, in many of the grains oriented favourably for multislip, there may be insufficient resolved shear stress on any one system to permit significant deformation. Thus, such grains may have a low rate of increase in stored distortional energy and, therefore, be very resistant to recrystallization during the deformation history. On the other hand, in monomineralic quartzites, where the flow stress is entirely consumed by intra-crystalline plasticity, multislip may be favoured and stimulate fast recrystallization of metastable grains (cf. Urai *et al.* 1986).

PROBLEMS WITH KIRSCHNER AND TEYSSIER'S INTERPRETATION

The most noticeable difference between the fabric skeletons of old and new grains shown by Kirschner & Teyssier (1991) is the lack of porphyroclast *c*-axes near the *Y*-axis of the finite strain ellipsoid (Fig. 3a). Porphyroclasts show either single or double maxima near the foliation pole, while recrystallized grains have a type I cross-girdle fabric (Lister 1977, Lister & Williams 1979). Kirschner and Teyssier suggest that these fabrics reflect a change from flattening (as indicated by the porphyroclast fabrics) to plane strain (as indicated by the recrystallized grain fabrics) during the deformation history. However, Kirschner and Teyssier obtained their porphyroclast fabrics in samples that have been

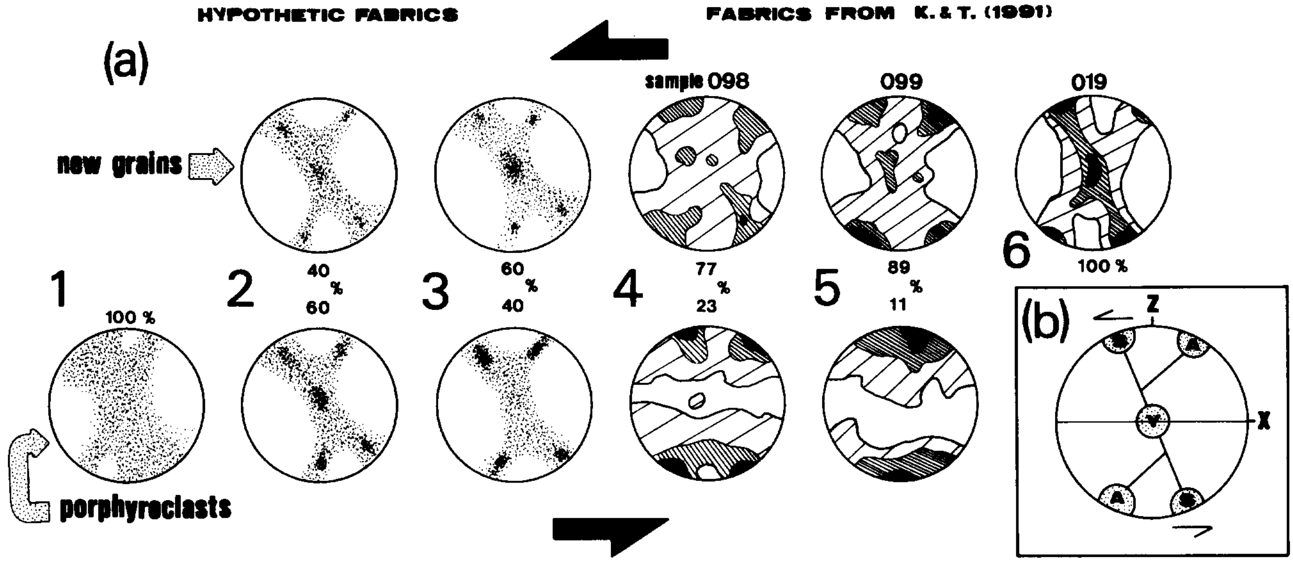

Fig. 3. (a) Fabric evolution with increasing recrystallization (1–6) suggested for Heavitree Quartzites. Percentages indicate partitioning of quartz between porphyroclasts and recrystallized grains. Note the decreasing Y-maximum in the porphyroclast fabric in parallel with an increasing Y-maximum in the recrystallized grain fabric. (b) Synthetic (S), antithetic (A) and Y maxima in asymmetric cross-girdle fabrics (sinistral shear sense). Note the increasing S-maximum in the recrystallized grain fabric and an A-maximum in the porphyroclast residual fabric (099).

intensely recrystallized, leaving small amounts of remaining porphyroclasts (11–27%) relative to the total quartz content. Therefore, how can Kirschner and Teyssier be sure that the porphyroclasts of the Heavitree Quartzites still depict an intact deformation fabric, and that porphyroclasts of some specific orientations have not already disappeared due to selective recrystallization?

Another problem in studying c-axis fabrics in highly recrystallized samples involves distinguishing old grains from recrystallized grains if there is not a significant grain size contrast (>3 times) between them. When recrystallization occurs by subgrain rotation (Hobbs 1968, Poirier & Nicolas 1975), distinguishing old grains is particularly difficult because the most intensely recrystallized porphyroclasts can survive as aggregates of only two or three subgrains and be very similar in shape and grain size to the adjoining recrystallized grains.

In the quartzites studied by Kirschner and Teyssier, there is no marked grain size contrast (<3 times) between recognized porphyroclasts (0.2 mm) and recrystallized grains generated by subgrain rotation (0.07 mm). Thus, it is possible that the porphyroclasts that had been most favourably oriented to undergo recrystallization now occur in the grain-size interval 0.2–0.1 mm, and were inevitably deleted from plots of porphyroclast fabric.

A REINTERPRETATION IN A RESIDUAL FABRIC MODEL

We argue that porphyroclasts in the Heavitree Quartzites show an annihilated cross-girdle deformation fabric which, during the initial stages of recrystallization, may have been similar in skeleton to fabric developed by the recrystallized grains, as usually occurs in mylonitic rocks (e.g. Bell & Etheridge 1976, Marjoribanks 1976, Law 1986). The lack of porphyroclasts oriented with c-axis near to the intermediate axis of the finite strain elipsoid indicates that such porphyroclasts disappeared faster during recrystallization. In non-coaxial strain regimes where prism ⟨a⟩ is a highly operative glide system (as occurs in the Heavitree Quartzites and in the shear zone of Fig. 1), a maximum near the Y-axis of finite strain may develop in the fabric of the recrystallized grains at the expense of the porphyroclasts in this same orientation.

Such fabric evolution can explain the fabric differences reported by Kirschner & Teyssier (1991). A weakening maximum near Y in the porphyroclast fabric may represent the first stage of the annihilation of the original deformation fabric (see stages 2 and 3 in Fig. 3a). Another example of similar intensification of a Y-maximum in the fabric of the recrystallized grains in parallel with a decreasing Y-maximum in the porphyroclast fabric is indicated by fig. 15 of Law *et al.* (1984).

With increasing recrystallization of the Heavitree Quartzite, the residual fabric changes from a double to a single maximum near the foliation pole. In most of the porphyroclast fabrics shown by Kirschner and Teyssier, this single maximum has an obliquity opposite the indicated shear sense (cf. Simpson 1980). This remaining single maximum shows orientations which probably were inherited from the antithetic maximum of the original asymmetric cross-girdle deformation fabric (see Fig. 3b), and reflects porphyroclasts in orientations that were relatively hard and very resistant to recrystallization (a mature residual fabric). Similarly, in the fabric evolution displayed in the Fig. 1, the mature residual fabric also reinforces the harder orientations (two maxima 45° oblique to the shear plane). However, in this case, the residual fabric reflects conditions near to ideal simple shear during the deformation history (see Fig. 2).

CONCLUSIONS

Fabric differences between porphyroclasts and matrix, such as those reported by Kirschner and Teyssier in the Heavitree Quartzites, can be developed without any change in the kinematic framework during deformation history. The later plane strain history documented in the Heavitree Quartzites, can account for both the porphyroclast fabric and the new grain fabric, and probably erased quartz crystallographic fabrics developed in the early flattening history (see Lister & Hobbs 1980). Fabric differences between porphyroclasts and matrix probably resulted from the heterogeneous disappearance of porphyroclasts (a consequence of selective recrystallization) in the samples with higher degrees of recrystallization.

Evaluating residual fabrics is a useful tool for studying recrystallization history because they point out the orientations most resistant for dynamic recrystallization.

Residual fabrics seem to be controlled mainly by the kinematic framework and can also reflect strain partitioning.

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APPENDIX

DESCRIPTION OF THE SHEARED GRANITOID OF THE BONFIM COMPLEX

Figure 1 shows *c*-axis fabrics in a coarse-grained granite subjected to simple shear in a 2 m-wide low-grade retrograde shear zone. Away from the shear zone, the granite is isotropic and has large (5–10 mm) globules of quartz which show a random crystallographic orientation. In the vicinity of the shear zone quartz already shows undulose extinction bands, subgrains and an incipient edge recrystallization (core–mantle microstructure). Subgrains and recrystallized grains are similar in shape and grain size, indicating that recrystallization occurs by subgrain rotation. *S*- and *C*-foliations develop within the shear zone, and the angle between them decreases with increasing shear strain. The grain size and the amount of old grains of quartz also decrease towards the most deformed inner domain. The amount of sericite increases with the deformation in parallel with the gradual disappearance of feldspars. Deformation mechanisms other than intracrystalline plasticity (e.g. microfraturing and retrograde softening reactions in feldspars, boundary sliding along (001) planes of mica, dissolution-accommodated deformation in quartz) have been recognized to play a important role in the microstructural evolution.