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

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Abstract—Observed differences in *c*-axis fabrics between quartz porphyroclasts and recrystallized quartz from the same quartzite samples suggest some changes in the fabric-forming parameters during deformation. The fabric patterns are consistent with a change in the incremental strain history from flattening to constriction during duplex development, which is supported by the observed overprinting of structures in the field.

INTRODUCTION

THE study of quartz crystallographic fabrics provides useful information on: (1) finite strain states (Marjoribanks 1976, Price 1985); (2) strain path, and in particular coaxial vs non-coaxial deformation (Lister & Williams 1979); and (3) sense-of-shear (Lister & Williams 1979, Bouchez *et al.* 1983). Crystallographic fabric patterns are the product of intrinsic (e.g. temperature, strain rate, impurity content) and extrinsic (e.g. finite strain, stress history, kinematic history) parameters (see Hobbs 1985 for discussion). Crystallographic fabric analysis can be complicated by any of these parameters changing with time or being heterogeneously distributed during deformation. Lister & Hobbs (1980) and Lister & Williams (1980) addressed in some detail the effects of changing kinematic framework during the closing stages of deformation, and discussed how earlier stages can be obscured or lost. However, apart from kinematic considerations, very little work has been done to document the effects of the other parameters on crystallographic fabrics.

By comparing fabrics from different populations of quartz within the same sample, it might be possible to decipher part of the deformation history. For example, quartzites, initially composed of detrital grains, usually evolve with progressive deformation into a bimodal rock containing porphyroclasts and recrystallized quartz grains (Marjoribanks 1976, White 1976). In such rocks it could be argued that the fabrics shown by the porphyroclasts would be the products of, and thus representative of, the kinematic framework(s) present during most of the crystal-plastic deformation history. On the other hand, given the cyclic nature of strain and recrystallization (Means 1981), the fabrics of recrystallized aggregates might record only the last stages of plastic deformation.

Similar fabrics for both porphyroclasts and recrystallized aggregates in the same sample might suggest that the kinematic framework did not markedly change during the closing stages of plastic deformation (e.g. Marjoribanks 1976, Law 1986). In contrast, different fabrics might suggest a significant change of the kinematic framework and thus provide a partial picture of the deformation history. Other possible causes for different fabrics between porphyroclasts and recrystallized grains in the same sample will be discussed later.

In this paper, we document quartz *c*-axis fabrics from the White Range duplex, central Australia, which suggest a change in kinematic framework during the last increments of deformation; this interpretation is consistent with structural relationships observed in the field.

GEOLOGY

The 25 km^2 White Range duplex is one of several duplexes in the intraplate Arltunga Nappe Complex in central Australia (Fig. 1). Multiply deformed lower Proterozoic basement overlain by Proterozoic quartzite (Heavitree Quartzite) and dolostones (Bitter Springs Formation) were involved in major, crustal-scale, N–S overthrusts during the Paleozoic Alice Springs Orogeny (Forman 1971, Stewart 1971, Collins & Teyssier 1989). The greenschist-grade White Range duplex is composed of seven thrust sheets of Heavitree Quartzite with floor and roof thrusts at the contact with the retrogressed basement (Fig. 1). Recumbent isoclinal folds are ubiquitous in the duplex, with axial planes coplanar with a gently N-dipping foliation, and hinge lines colinear with a N-trending stretching/mineral lineation. The N-dipping foliation and N-trending lineation, defined by the ellipsoidal shapes of quartz grains and mica folia, approximate the *XY* plane and *X* axis of the finite strain ellipsoid, respectively. South-directed thrusts, *S–C* foliation, shear bands and sheared quartz veins all indicate north-over-south sense of shear. The duplex-related structures are overprinted by NE-trending folds and crenulations. All of these structures are interpreted as having developed progressively during the formation of the Arltunga Nappe Complex.

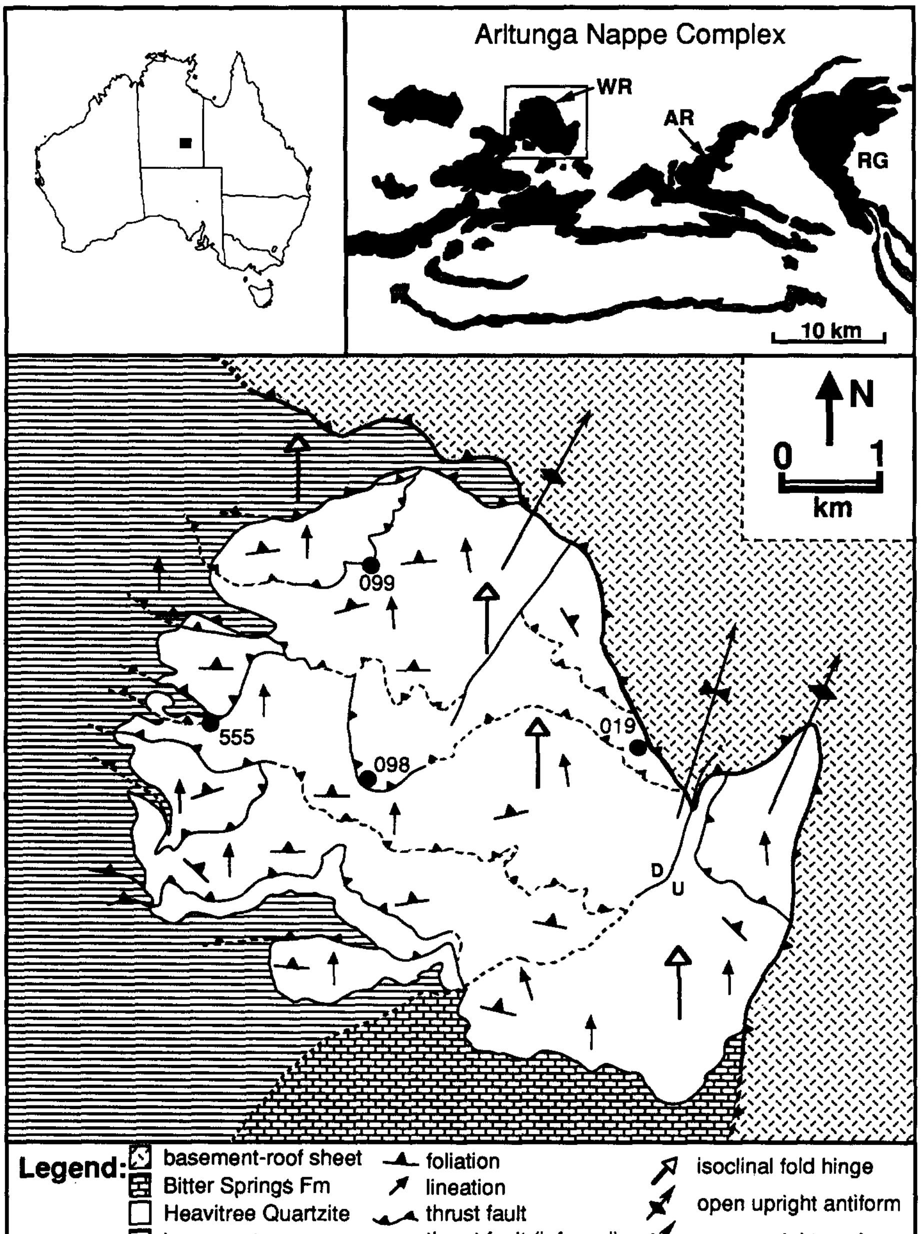

Fig. 1. The upper right diagram is the outcrop map of Heavitree Quartzite which delineates the Arltunga Nappe Complex (WR, White Range; AR Atnarpa Range; RG, Ruby Gap). The lower diagram is a simplified geologic map of the White Range duplex. The foliation dip and lineation plunge rarely exceed 15°N. Localities of samples discussed in the text are shown on map.

MICROSTRUCTURE

Undeformed Heavitree Quartzite, present only south of the White Range in the foreland of the orogen, is composed of detrital quartz grains (average diameter 0.5–0.7 mm) in a quartz cement—muscovite 'matrix'. Within the White Range, the Heavitree Quartzite exhibits a repetitive sequence of microstructures that are spatially related to individual thrusts.

In the internal zones of the sheets, farthest from the bounding thrusts, there is a bimodal distribution of ellipsoidal quartz porphyroclasts and recrystallized quartz. Quartz overgrowths are no longer present, and the quartz porphyroclasts are surrounded by muscovite and recrystallized quartz. Undulatory extinction, deformation bands, and optical subgrains are moderately well developed in the porphyroclasts. The porphyroclast grain boundaries are similar to typical core–mantle structures described by White (1976), where recrystallized grains entirely surround (mantle) the clasts, and probably formed by progressive subgrain rotation relative to the host grains.

The long axes of the porphyroclasts define a lineation and lie in the plane of muscovite foliation. Porphyroclasts in 14 quartzite samples located throughout the White Range record apparent flattening to plane strain (Fig. 2). The short-axes of the porphyroclasts are approximately 0.20 mm in length, and the recrystallized grains are approximately 0.07 mm in length.

With increasing proximity to the thrusts, the por-

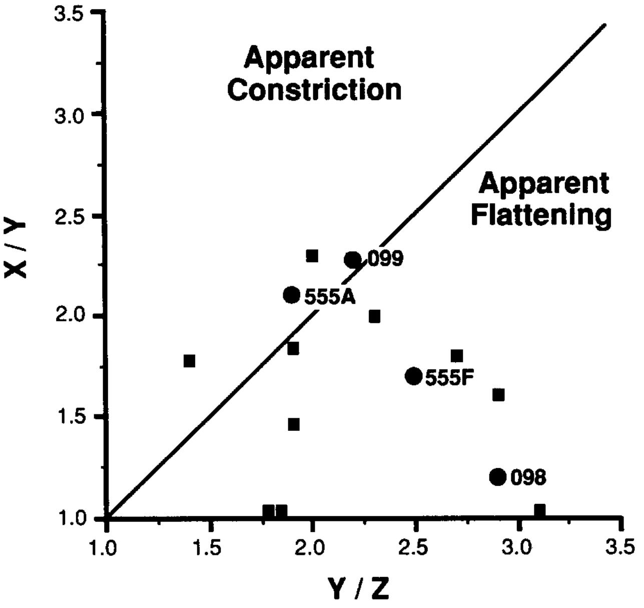

Fig. 2. The strain ellipsoids of fourteen quartzite samples plot mainly in the apparent flattening field of the Flinn diagram. The data were obtained by Fry analysis and are very similar to strain values determined by R_f/ϕ method for the same thin sections. The circles with sample numbers are those samples whose fabrics are shown in Fig. 3.

phyroclasts are progressively more deformed and recrystallized. Only fragments of the porphyroclasts remain and exhibit undulatory extinction, deformation bands and optical subgrains. Long axes of the fragments lie approximately in the plane of foliation. Recrystallized quartz grains are elongate, either with their long axes oriented obliquely to the muscovite foliation, or parallel to foliation in areas of high muscovite content. Muscovite alignment defines a pervasive *C*-foliation through the rock, though, locally it is reoriented along narrow shear bands (*C*′-foliation). Within each ductile thrust zone, which are individually a few meters in width, 90–100% of the quartz is recrystallized.

c-AXIS FABRICS

In the White Range, five samples illustrate the systematic differences in *c*-axis fabrics between quartz porphyroclasts and recrystallized quartz grains (Fig. 3). Porphyroclast *c*-axes are absent in the foliation plane, and define either single or double maxima. In the same thin-sections, the *c*-axes of recrystallized grains clearly define girdles disposed at high angles to the foliation plane. The entirely recrystallized sample (019) near the roof of the duplex clearly displays a cross-girdle fabric.

The amount of mica, varying from 26 to 8% in these five samples, does not appear to play a significant role in the type of fabric developed. The amount of quartz recrystallized relative to total quartz varies from 73% in sample 098 to 89% in sample 099 and 100% in sample 019. Although fabric skeletons do not markedly change, fabric intensity slightly increases with degree of recrystallization.

DISCUSSION

Preferred orientations of crystallographic fabrics are the product of many parameters affecting the rock during deformation (Hobbs 1985). For example, the fabrics of recrystallized grains that develop by sub-grain rotation can be influenced by the host grain orientations (Hobbs 1968). Heterogeneous flow of the recrystallized 'matrix' around more rigid porphyroclasts might also result in different fabrics developing (Lister & Price 1978, Law *et al.* 1984, Takeshita 1989). Although both of these parameters were probably important during the quartzite deformation, our data at present can neither preclude nor constrain their effects. Based upon field relationships and preliminary isotopic analysis, the possible roles of strain, temperature and fluid involvement in fabric development will each be discussed.

Strain

Many studies document a good correlation between crystallographic fabrics and finite strain states for quartz aggregates (see Price 1985 for compilation and discussion of data). The fabrics of porphyroclasts reported here (Fig. 3) are similar to fabrics of samples that have recorded apparent flattening strain (cf. Price 1985, fig. 6g), and are also in agreement with computer simulations of flattening strain (Lister & Hobbs 1980).

The fabrics of recrystallized grains are similar to fabrics of samples that have recorded apparent plane to constrictional strain (cf. Price 1985, figs. 13e and 14g) and are also in agreement with computer simulations involving plane to constrictional strain (Lister & Hobbs 1980). Thus, according to the hypothesis that fabrics of porphyroclasts are the product of much of the crystal-plastic deformation history, and that fabrics of recrystallized grains document the last stages, a simple deformation history of flattening strain progressing to plane or constrictional strain is suggested for these samples.

Is there independent evidence to suggest such a history? Upright folds and crenulations trending NNE overprint the mylonitic fabric in the duplex, thus suggesting a change in the strain field during the final stages of deformation. The deformation history can be divided into three increments which reflect progressive reorientation of strain and kinematic axes. During the formation of the duplex, a S-directed shear (probably resulting in flattening strains, cf. Fig. 2) produced the foliation, lineation and porphyroclast crystallographic fabrics. During the last stages of plastic deformation, the incremental strain may have gone through a plane to constrictional state with the elongation orientation remaining unchanged, thus producing the crystallographic fabrics of the recrystallized grains. Eventually, the duplex underwent further shortening in a WNW–ESE direction, to produce upright folds, minor faults and crenulations.

Yar Khan (1972) proposed a similar flattening to constrictional strain history for the Atnarpa Range, to the foreland of the White Range (Fig. 1), where the

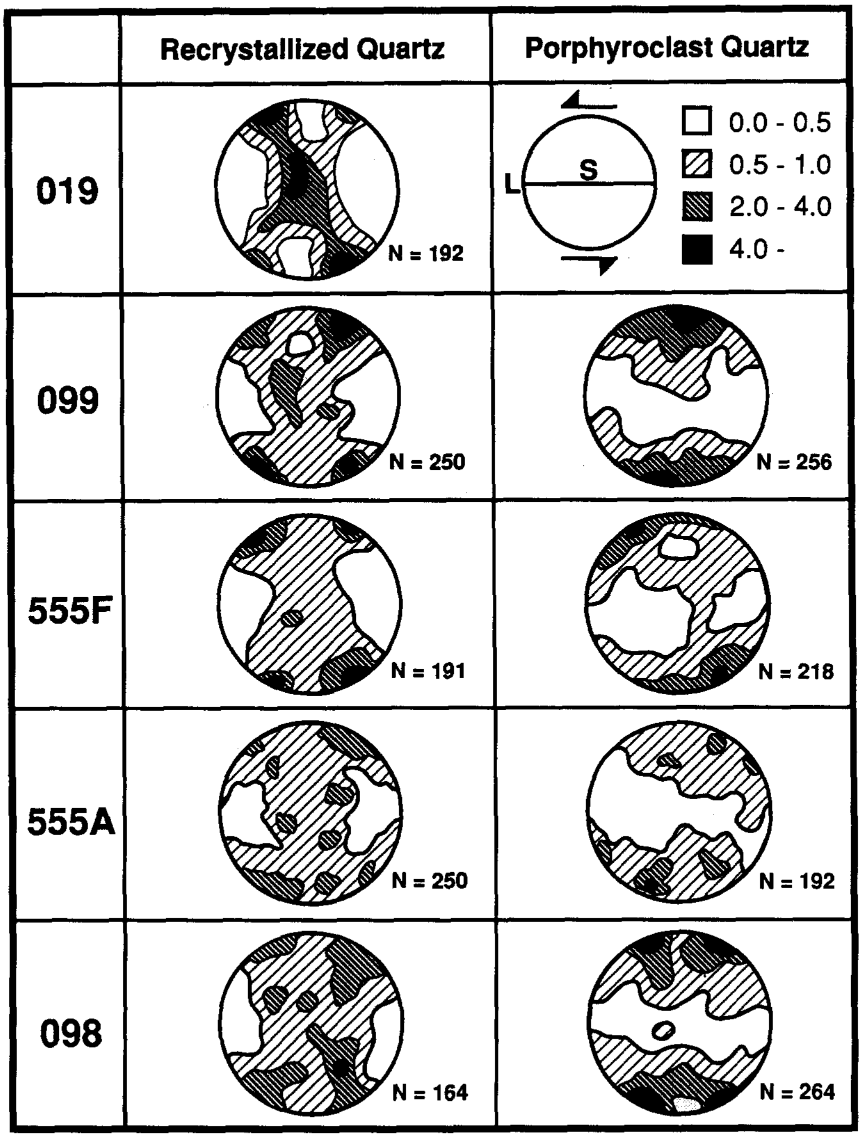

Fig. 3. Crystallographic fabrics of quartz *c*-axes for five Heavitree Quartzite samples from the White Range duplex. The porphyroclast fabrics and recrystallized quartz fabrics from the same thin sections differ significantly in their patterns. Number of grains measured is shown at lower right-hand corner of each fabric. Contours are 0.5, 2.0 and 4.0% per 1% area on a Schmidt, lower-hemisphere stereonet.

rocks are less deformed but exhibit similar meso- and microstructures. Thus, the quartzite from the more deformed, hinterland White Range might have experienced a similar history.

Temperature

A change in temperature during the deformation history could also account for the observed differences in fabrics. Experimental results on single crystals indicate that at low temperature basal ⟨*a*⟩ is the easiest slip system to activate; however, with increasing temperature prism ⟨*a*⟩ slip becomes relatively easier (Tullis *et al.* 1973, Blacic 1975). Geometrically, the observed fabrics of the porphyroclasts might suggest basal ⟨*a*⟩ was the dominant slip system, especially when considering the single maximum fabric of sample 099 (Fig. 3). In contrast, the fabrics of the recrystallized grains might suggest basal, prism and rhomb ⟨*a*⟩ slip systems were operative. Provided the fabrics of the porphyroclasts are less sensitive to change, the different fabric patterns between recrystallized grains and porphyroclasts might suggest an increase in temperature. Such a scenario is not unrealistic, given that metamorphic grade increases from south to north in the Arltunga Nappe Complex (Yar Khan 1972) and is related to overthrusting of deep crustal rocks onto supracrustal sedimentary rocks.

Fluid involvement

In grains with low concentrations of aqueous related species, basal slip is the most active slip system; while at higher concentrations prismatic slip is also an important slip system (see Paterson 1989 for discussion). Thus, an increase in fluid involvement during deformation could explain the observed differences between fabrics of porphyroclasts and recrystallized quartz.

Based on recent work (Teyssier & Gregory 1989) in the nearby Ruby Gap duplex (Fig. 1), homogenization of oxygen isotope values in the Heavitree Quartzite corresponds with increased recrystallization and crystallographic fabric development. Correspondingly, the homogenization of the isotopes might indicate a greater fluid involvement during the development of the recrystallized grains. Preliminary isotopic analyses of nine samples in the White Range suggest a similar correlation between isotopic homogenization and degree of recrystallization and fabric development.

CONCLUSIONS

A number of factors might explain the differences in fabrics of porphyroclasts and recrystallized grains from the same samples: an increase in temperature or fluid involvement during deformation, the influence of host grain orientations, and/or the heterogeneous flow of matrix around clasts. However, the observed differences in the crystallographic fabrics of the White Range can most readily be explained by a change in the incremental strain history. This is most favorably supported by meso- and macroscopic overprinting of structures, and is consistent with the observations of Yar Khan (1972) to the foreland of the White Range.

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