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A spherical electron channelling pattern map for use in quartz petrofabric analysis: correction and verification

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Abstract—The recent paper by Lloyd & Ferguson on the use of a spherical electron channelling pattern (ECP) map in quartz petrofabric analysis contained an unfortunate error due to the incorrect indexing of the quartz single crystal used to construct the map. This error can be corrected by a simple 60° rotation of the spherical ECP-map and a re-definition of the individual ECPs (specifically those of the positive and negative rhombs and trigonal prisms). The verification of this correction, and of the technique as a whole, is supported by a comparison between pole figure diagrams for a quartzite obtained from the same specimen by ECP analysis and X-ray texture goniometry.

INTRODUCTION

THE PURPOSE of this short note is two-fold: (1) to correct an error of crystal indexing in the recent paper by Lloyd & Ferguson (1986); and (2) to provide verification of the technique described in that paper. The paper by Lloyd & Ferguson (1986) concerned the application of the scanning electron microscope (SEM) electron channelling (EC) technique to quartz petrofabric analysis and presented a spherical electron channelling pattern (ECP) map of the quartz stereographic unit triangle necessary for the recognition (indexing) of individual ECPs. The map was constructed 'blind' by cutting 33 specimens from a single crystal of Brazilian hydrothermal vein quartz. Unfortunately, diagnostic crystal faces were not particularly well developed on this crystal and this has led to an error in indexing the whole crystal since the positive and negative rhombs (*r* and *z* forms) were confused. This means that the poles to positive and negative trigonal prisms (or *a* axes), which can be distinguished via their respective ECPs, were also confused. The first indication of this error only came when pole figures obtained by SEM/EC analysis (Lloyd *et al.* 1987) were compared with those obtained *from the same specimen* by X-ray texture goniometry (see below). It was immediately obvious that the SEM/EC *r* axis pole figure was practically identical to the X-ray *z* axis pole figure, and vice versa.

The theory of X-ray texture goniometry is well established and it is known that although *r* and *z* reflections cannot be distinguished by direct measurement, *r* contributes ~69% of the total *r* + *z* signal (see Schmid & Casey 1986, table 1). On this basis, and using crystal symmetry, individual *r* and *z* axes pole figures can be calculated through the Orientation Distribution Function (Casey 1981, Schmid *et al.* 1981). If the quartz ECP-map (Lloyd & Ferguson 1986, fig. 5) is examined in the region of the two rhomb orientations, the signal from the one to the right (indexed as *z* by Lloyd & Ferguson 1986, fig. 4d) is stronger (brighter) than the other (indexed as *r* by Lloyd & Ferguson 1986, fig. 4c). The theory of electron channelling (Hirsch *et al.* 1962), which was actually proposed before the effect was observed (Booker *et al.* 1967, Coates 1967), is based on the theory of X-ray diffraction and it is therefore probable that the efficiency of electron channelling from *r* and *z* planes shows a similar discrepancy. Thus, the equivalence of SEM/EC *r* axes and X-ray *z* axes pole figures (and vice versa) can be explained by an error in indexing of the quartz single crystal, involving the confusion of the positive and negative rhomb faces. This is further supported by the fact that SEM/EC and X-ray *c* axis and *m* axis pole figures (see Fig. 2 below) are practically identical.

CORRECTION

The corrections necessary to the indexing of the spherical ECP-map for quartz described by Lloyd & Ferguson (1986) (see also Fig. 1a) are listed in Table 1. Fortunately, these corrections do not require the construction

Table 1. Comparison between incorrect (Lloyd & Ferguson 1986) and correct (this paper) indexing of the spherical ECP-map for quartz

	Axis	Zone	Zone	Axis			
Incorrect	*c*	*m*(*r*)*c*	*m*(*z*)*c*	−*a*	+*a*	*r*	*z*
Correct	*c*	*m*(*z*)*c*	*m*(*r*)*c*	+*a*	−*a*	*z*	*r*

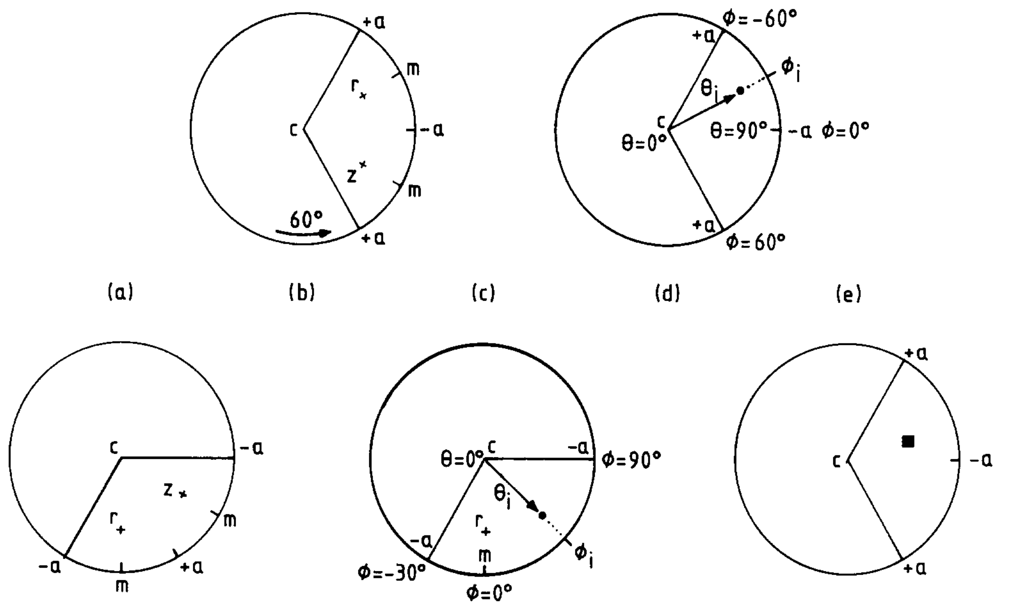

Fig. 1. Corrections necessary to the definitions proposed in Lloyd & Ferguson (1986) in the indexing of the spherical electron channelling pattern map used in quartz petrofabric analysis. (a) Indexing used by Lloyd & Ferguson (1986, figs. 3 and 5). (b) Corrected indexing; simplest correction involves a 60° anticlockwise rotation of the original case shown in (a). (c) Original definition of the inverse pole figure derived from the spherical ECP-map (Lloyd & Ferguson 1986, fig. 8a). (d) Corrected definition of the inverse pole figure. (e) Position occupied by the data of Lloyd & Ferguson (1986, fig. 8b) plotted in the correct inverse pole figure.

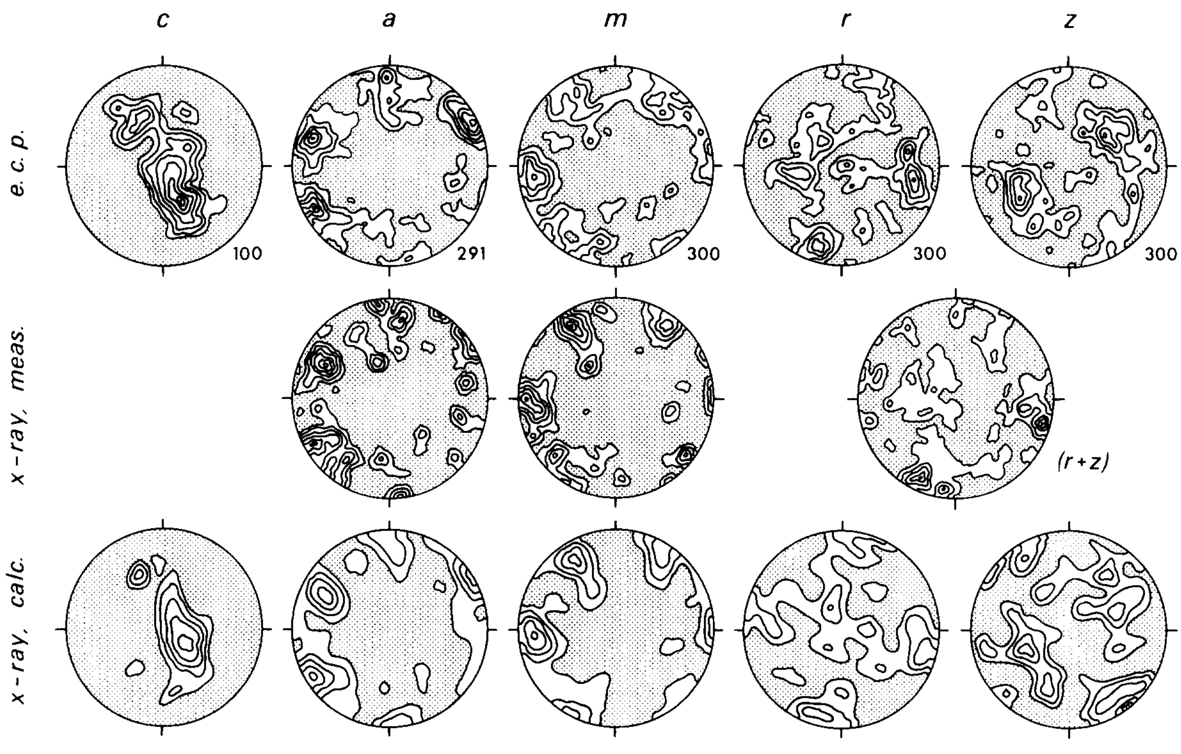

Fig. 2. Comparison between SEM/EC derived pole figures (top row, after Lloyd *et al.* 1987) and those derived from the same specimen by X-ray texture goniometry (middle row are figures actually measured and bottom row are calculated from the derived Orientation Distribution Function). All stereograms contoured using a modified version of the computer program described in Starkey (1970); contour intervals are 1–8 times uniform distribution, less than uniform stippled. The numbers beside the ECP stereograms are the actual number of crystal axes measured from 100 grains.

of a new ECP-map since the original map (Lloyd & Ferguson 1986, fig. 5) extends over the complete trigonal symmetry unit triangle. Consequently, this map merely has to be rotated, for example anticlockwise, through 60° (Fig. 1b). However, the corrections do require a new definition of the inverse pole figure calculated from the ECP-map. The original definition (Lloyd & Ferguson 1986, fig. 8a) is shown in Fig. 1(c), whilst the corrected definition is given in Fig. 1(d). The corrected definition is used in the paper by Lloyd *et al.* (in press, fig. 3a).

The example of SEM/EC analysis given in Lloyd & Ferguson (1986) obviously involves the incorrect definition of the inverse pole figure, but it is nevertheless internally consistent since the angular misorientations determined (Lloyd & Ferguson 1986, figs. 8c and 9) are independent of this definition. However, for completeness we present in Fig. 1(e) the subgrain data of Lloyd & Ferguson (1986, fig. 8b) plotted in the correct inverse pole figure construction.

The definition of pole figure diagrams determined via SEM/EC given in Lloyd *et al.* (1987, fig. 3b) is based on the correct indexing of the quartz crystal and ECP-map and therefore requires no modification.

VERIFICATION

Verification of the accuracy of the SEM/EC technique comes from comparison between SEM/EC derived pole figures (see Lloyd *et al.* 1987, for full details of their construction) and those obtained from X-ray texture goniometry. The difference between the two techniques is that SEM/EC is discriminate and permits the orientation of individual grains to be determined, whereas X-ray goniometry is indiscriminate and provides only average orientation data. But both techniques can be performed on the same specimen and hence a direct comparison between them can be made.

We have performed such a comparison using the same specimen of quartzite described in Lloyd & Ferguson (1986) and Lloyd *et al.* (1987). The comparison (Fig. 2) is extremely good and we are therefore confident of the applicability of the SEM/EC technique to petrofabric studies. The only question remaining is when to use this technique and to a large extent this depends on the specific problem to be solved. If rapid analysis of essentially pure specimens with fine–medium grain size is required, then X-ray goniometry is recommended. But if the specimen is impure and/or has variable grain size, then SEM is better, in spite of the extra labour required. Obviously, where microstructure is to be related to the petrofabrics, or where petrofabrics of small regions are required (e.g. crystallographic relationships between adjacent grains) then only SEM/EC is applicable.

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