TWINNING IN K-FELDSPARS FROM THE INTERPLAY BETWEEN THE IONIC AND ELECTRONIC LATTICES

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ABSTRACT

Ordinary and diagonal Albite and Pericline twins are studied in a transitional microstructure from orthoclase-microcline recrystallization in the K-feldspars of the Fermín pegmatite (MG, Brazil) using polarized light microscopy (PLM), Raman microprobe (RMP) spectroscopy, scanning and transmission electron microscopies (SEM and TEM). Our data suggest that twin patterns obey to a fundamental behaviour of crystalline matter in which large volumes can act cooperatively as a whole in order to decrease the lattice elastic strain throughout “long-range” interactions. It is proposed that this essential information is propagated via the electronic lattice or a network system formed by the bonding electrons. Twin-structures result from correlations between many distant interacting variants. Changes in the symmetry of the sensitive electron lattice promote subsequent local atomic readjustments in the ionic lattice.

INTRODUCTION

An evolution process by mineral self-organization could explain polysynthetic and chess-board patterns composed of *ordinary* Albite and Pericline twins in microcline (Sánchez-Muñoz et al. 2008). Self-assemblage of twin units occurred by a solid-state recrystallization process that is controlled not only by “short” range forces (i.e. Si/Al ordering) but also by “long-range” elastic strain accommodation. Twin-structures are not just random configurations from more or less accidental local atomic readjustments neither the product of an erratic coarsening process, but the consequence of a fundamental feature derived from the overall strain distribution throughout the entire crystalline lattice. If this is a general process, it should explain also microcline structures with *diagonal* Albite and Pericline twinning (Smith 1974). Here, diagonal twining is investigated as well the nature of the “long-range” interactions.

SAMPLES AND EXPERIMENTAL PROCEDURE

Samples were collected in Fermín pegmatite (Linópolis, MG, Brazil). (001) sections were studied by PLM, RMP spectroscopy, SEM and TEM. The RMP spectra were obtained using a Renishaw InVia Raman microscope equipped with an ultra-low noise charge-couple device (CCD) detector, 1 μm of spatial resolution and a laser source at 514.5 nm (25 mW). SEM work was performed in an Inspect-S ESEM of the FEI Company. TEM images along the [001] zone axis were obtained with a Tecnai 20T (PHILIPS) working at 200 kV (UJCI, Madrid).

RESULTS AND DISCUSSION

Figure 1 shows PLM images where the orthoclase-to-microcline recrystallization occurs by many coexisting discrete inputs following four variants, i.e. left- and right-handed Albite and Pericline twin orientations (±A and ±P) as avalanche-like events starting at the interfaces with Na-feldspar veins and propagated inside the orthoclase (at extinction). Coalescence of two variants with the same orientation occurs (arrow 1) if the their nucleating points are close forming twins with homogeneous δ or extinction angles in (001) at ± 18º (i.e. "low microcline") and sharp boundaries (Sánchez-Muñoz et al. 2008). However, distances between those nucleating sites are well separated and K-feldspars with 0º < δ < ±18º are observed in most cases. It was found that similarly oriented twin units can show correlations at distances as long as ~700 μm ! (arrow 2), as revealed by regions with the same orientation as "bridges" but with 0º < δ> ~ 4º. These low δ regions gradually merge into the "extinct" orthoclase matrix if long-distant interactions with another recrystallization event do not occur as in the example shown in Fig. 1b. Twin units along ± A/P orientation occur in orthoclase at extinction. Orthogonal interactions between +A and +P (or –A and –P) twin units can create local volumes of microcline at their intersection with a higher δ (arrow 3) by an effect of "positive interference". Conversely, +A and –P or –A and +P intersections forms optically monoclinic microcline with δ close to 0º (arrows 4) as an optical effect by "negative interference".

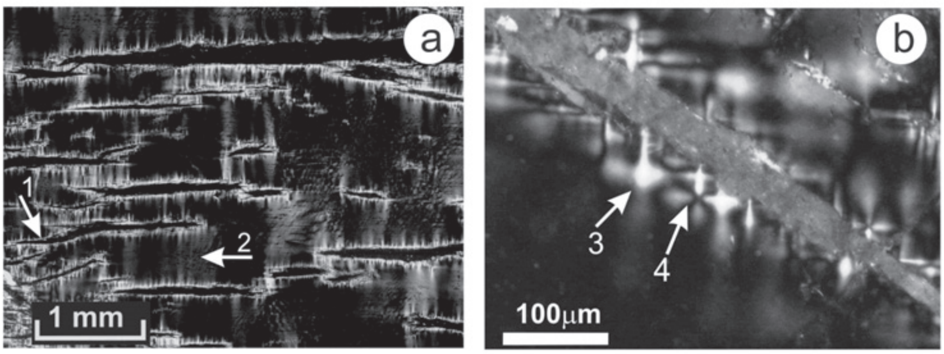

Figure 1 - PLM (001) images at parallel position (a) and some degrees away from that in (b).

Figure 2 shows the origin, propagation directions and extinction behaviour of many single recrystallization events forming a microstructure in *petals* around small albite veins, in which the disposition of the variants is not random but forming precise pattern of minimum elastic strain. At the parallel position (a) is seen the size and orientation of petals (see scheme in b). Fig. 2c), d), e) and f) are PLM images where the samples are rotated -4º, +4º, -9º and +9º away from the parallel position respect to the extinction behaviour of the NW and SE quadrants (δ = 0º). Conversely, the NW and SW quadrants have a very small deviation from 0º. *Ordinary* (numbers 1, 2, 5 and 6 in Fig. 2b) and *diagonal* (3, 4, 7, and 8 in Fig. 2b) variants are clearly resolved, with diagonal ones only in the NE and SE. Observe that albite films in quadrant NW shows signal of water interaction (coarsening and porosity), but the quadrant NE has an obvious pristine character (Fig. 2g). The variants following 1 and 5 ordinary Albite orientations are complementary, i.e. –A and +A or left- and right-handed, related by opposite extinction on sample rotations, like 2 and 6 ordinary Pericline (+P and –P). 7 and 3 diagonal Albite (-dA and +dA*), 4 and 8 diagonal Pericline variants (+dP and –dP*) have also opposite extinctions. Only ± A variants can show regions with δ > 4º. Additionally, 1', 2 and 2' variants display δ > 0º because of negative interference with the matrix in quadrant NW and SW, while 1' and 2' variants show positive interference at their crossover (arrow "a"). A RMP profile was recorded between *i* and *f* points along a +A variant (Fig. 2a, 2g and Fig. 3), and spectra were compared with that at Or point where δ = 0º (Fig. 2g). Peak positions and area ratio of the A and B bands (A-B band splitting is the □ parameter of Sánchez-Muñoz et al. 2008, A/B is Area A/Area B in (001) section with A-twin in N-S orientation) along the *i-f* profile (Fig. 3b) are related to the schemes of local Si/Al order in the ions lattice of the K-feldspars. Four types of K-feldspars can be distinguished: i) "low microcline": δ ~ 18º, □ ~ 19 cm^{-1}, A/B ~ 1.7 only close to *i*, ii) "intermediate microcline" of two types: between *i* and 1 where 9 < δ < 18º, □ > 14 cm^{-1}, A/B > ~ 0.4, and between 1 and 2 where 4 < δ < 9º, □ ~ 14 ± 0.5 cm^{-1}, A/B < ~ 0.4, iii) "anomalous orthoclase": from 2 to *f*: 0º < δ < ~ 4º, □ ~ 14 ± 0.5 cm^{-1} and A/B ~ 0.3 ± 0.1; and iv) "orthoclase": δ = 0º, □ ~ 14 ± 0.5 cm^{-1} and A/B ~ 0.3 ± 0.1. The position of the Raman lines in anomalous orthoclase are the same at the present level of resolution and experimental uncertainties than in Or point. Similar results were obtained in diagonal and Pericline variants with δ < 4º. Thus, the local structure related to the Si/Al ion lattice is similar in both types of regions. However, the optical symmetry, which is related to weakly bound outer or bonding electrons (Shubnivok, 1960) is different, being triclinic only in anomalous parts.

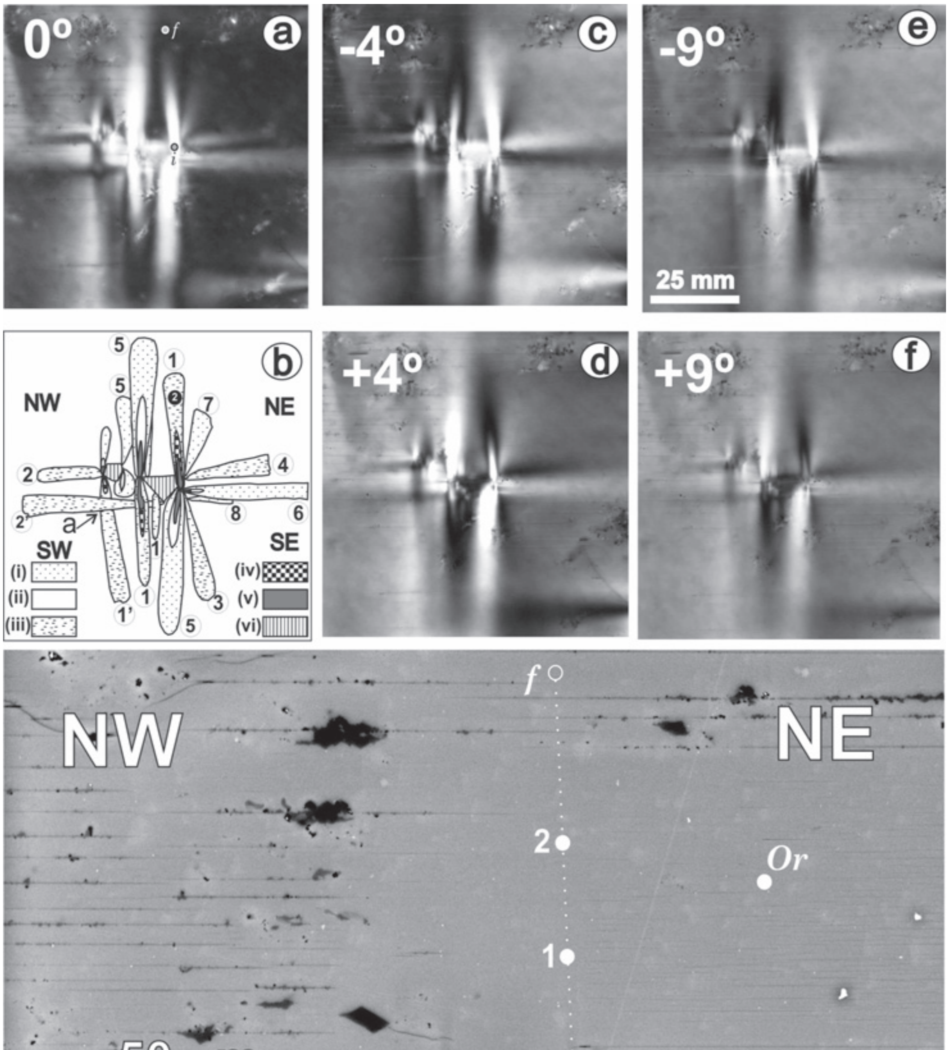

Figure 2 - a) to f) PLM images with – and + signs for anti-clockwise and clockwise sample rotations. b) Scheme of twin orientations, i) and iii) δ>4º; ii) and iv) 4º<δ<9º; v) δ < 9º; vi) albite. g) SEM-BSE image with the i-f profile, point 1, 2 (see also 2b) and Or reference.

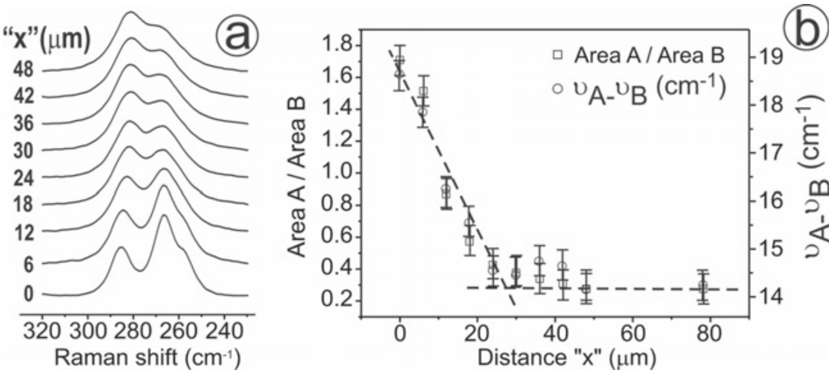

Figure 3 - a) Profile i-f by RPM showing the A-B band spectral region with distance "x" in μm and b) Δ parameter (o) and A/B area ratio (□) with "x". Uncertainties: υ = 1cm^{-1}, A/B = 0.2.

Fig. 4 shows TEM images in a scheme a typical recrystallization A-unit with untwined (Um), regular (Rm) and irregular (Irm) microcline, terms of Bambauer et al 1989, in sharp contact with tweed orthoclase (Tw). Albite films show semi-coherent boundaries (arrow 1) with dislocation pairs, in areas where tweed contrast is not clear (S in Fig. 4e), in sharp contact with areas showing corrugated boundaries (Fig. 4f). Microcline is formed at vein interfaces (arrow 2). It was not possible to correlate anomalous orthoclase with any TEM variety.

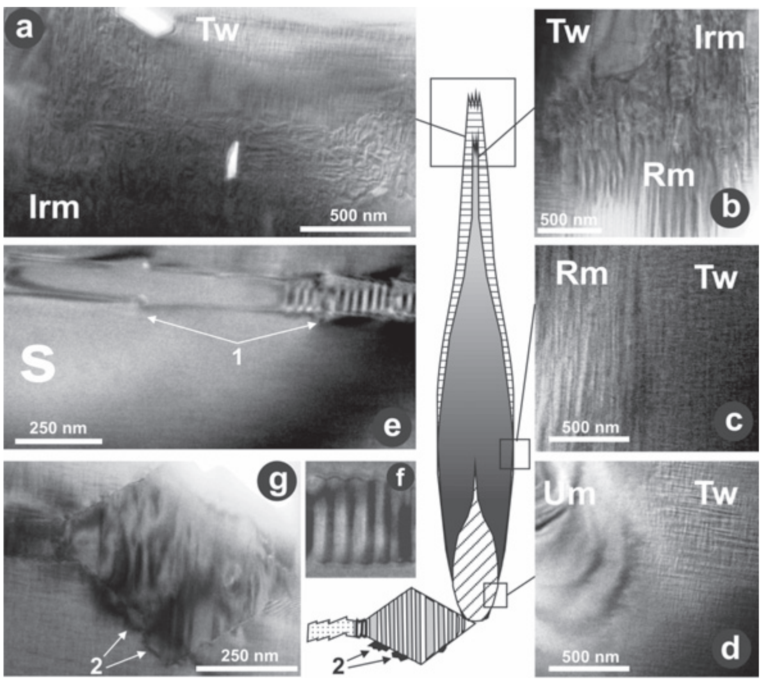

Figure 4- Idealized scheme of a recrystallization unit and details on Albite film by TEM.

In conclusion: *i)* optically triclinic orthoclase ("anomalous orthoclase" with $\delta < 4^{o}$) is not the result of submicroscopic twinning, but the symmetry build up by the electronic lattice formed by bonding electrons; *ii)* recrystallization occurs because the ionic lattice is adapted to the changes occurring firstly in the more sensitive electronic lattice, that promote short-range atomic re-arrangements because of local electric charge requirements; *iii)* diagonal variants are "irrational" with the ion lattice and could be explained in the context of the electron lattice as the relevant reference system; *iv)* K-feldspars show that large volumes of crystalline state can behave as a whole, because the information is propagated via the electronic lattice, under the effect of *certain external stimulations*, in this case probably tectonic changes on cooling.

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