Crystal self-organization in microclines from granitic pegmatites

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ABSTRACT

Microclines from granitic pegmatites are complex crystals formed in evolutionary open systems during the subsolidus stage. Si/Al ordering governed by local charge distribution acts in synergy with long-range elastic interactions, producing transformation avalanches due to positive feedback relationship between the two forces. Global crystal self-organization results if atomic ordering is catalyzed by water species and simultaneously lattice is stimulated by shear stress. In this case, coalescence or juxtaposition of transformation avalanches evolve into regular pseudoperiodic twin-domain patterns.

Keywords: *microcline, pegmatites, self-organization, transformation avalanches, twin-domains, elastic interactions.*

INTRODUCTION

On cooling triclinic K-feldspars, i.e. microcline crystals are locally transformed by Si/Al order in four tetrahedral sites, with a small variation in the local T-O-T geometry, along with the conversion of modulated structures composed of nanodomains with diffuse boundaries (Sánchez-Muñoz et al. 1998) into twinned structures formed by regular macrodomains (Sánchez-Muñoz et al. 2006). Here we show the way these features are linked, using granite pegmatite giant crystals, in which alteration by water rich-fluids at low temperatures is not very strong, and pristine subsolidus structures are well preserved.

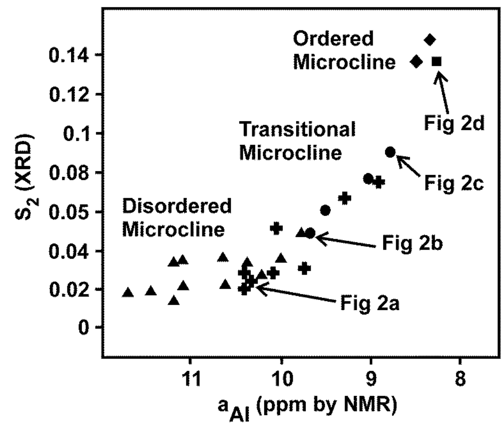

FIGURE 1. "Bulk" structural state and local Si/Al order from the S_2 and a_{Al} parameters by powder XRD and ^{27}Al NMR spectra respectively. Samples: ▲La Isla, +Enio, ●Achio and Fermín; ■Helio and ♦Golconda III.

SAMPLES AND EXPERIMENTAL PROCEDURE

Eighty six microcline crystals in perthitic intergrowths were collected from La Isla pegmatite (Cáceres, Spain), Enio, Achio, Fermín and Golconada III pegmatites in Minas Gerais and Helio pegmatite in Bahía (Brazil). Textures and microstructures were analyzed by optical microscopy and electron microprobe (EPMA) with Na mappings with a SX-50. Powder X-ray diffraction (XRD) was performed using a Siemens D-5000 with Cu $K_{\alpha 1}$ radiation at 40 kV and 30 nA. The S_2 parameter was calculated from the second moment of the diffraction profile in the region of the (131) peak, between 29.50 and 30.66 °2θ, with similar meaning to triclinicity Δ. High resolution ^{27}Al magic-angle sample spinning nuclear magnetic resonance (NMR) spectroscopy of powdered samples were recorded at 104.24 MHz in a Bruker MSL-400 spectrometer. The a_{Al} parameter is the half width at the middle height in parts per million (ppm) of the NMR signal. Raman microprobe spectra were collected using a Dilor XY 800 spectrometer under an optical microscope in a thin sections parallel to (001) with a x100 magnification. The excitation source was the spectral line at 514.5 nm provided by an argon ion laser. Accumulations lasting from 400 to 600 seconds were performed. The laser power on the sample was 200 mW, with a focus size of ~ 1 μm^3 to collect the signal.

RESULTS AND DISCUSSION

The statistical distribution of the structural state in the samples from XRD shows a tendency to *bimodality* around end member values and also the *coexistence* of many triclinicities inside each crystal. Fig.1 displays a correlation between the "bulk" structural state determined by XRD and the local Si/Al order by NMR, showing a continuum between end members: (i) crystals with a single and intense (131) peak with S_2 = 0.10 and $\Delta \sim 0$, with the high Si/Al disorder with, a_{Al} = 11.73 ppm, equivalent to $\Sigma t_1 \sim 0.74$ in high microcline (HM) or orthoclase X-ray pattern; (ii) crystals with maximum triclinicity, i.e. total (131)-(1-31) peak splitting with S_2 = 0.154 and $\Delta \approx 1.0$, having full Si/Al order a_{Al} = 8.21 ppm, equivalent to $\Sigma t_1 = t_{1o} \sim 1.00$ in low microcline (LM) X-ray pattern. The coexisting structural states are not randomly disposed but forming well organized intergrowths forming *transformation avalanches* that are triggered from non-coherent interfaces like boundaries with Na-veins (Fig. 2). Fig. 3a shows the Raman spectra of microcline end members being distinguished by the splitting between the A and B bands circa 282 and 265 cm^{-1}, with values of 13.4 and 19.0 cm^{-1} for HM and LM respectively. Fig. 3b is a Raman microprobe profile perpendicular to the vein-matrix boundary along a transformation avalanche in the sample of Fig. 2b. A continuous variation in the A-B splitting is found corresponding to intermediate microclines (IMs). The origin of the transformation avalanches is explained by synergy between local forces derived from Si/Al ordering due to local charge compensation and long-range elastic interactions, i.e. from a positive feedback relationship between the two forces. Three types of crystals can be distinguished:

Disordered microclines

Crystals are mainly composed of HM regions and although avalanches can be observed (Fig. 2a) their coverage and interactions have a limited development. Re-equilibration on cooling in these microclines is almost absent because *static regimes* of recrystallization take place. This is because the effect of aqueous fluids is restricted along boundaries and tectonic shear stress is absent during the subsolidus cooling, like in late-post-tectonic environments.

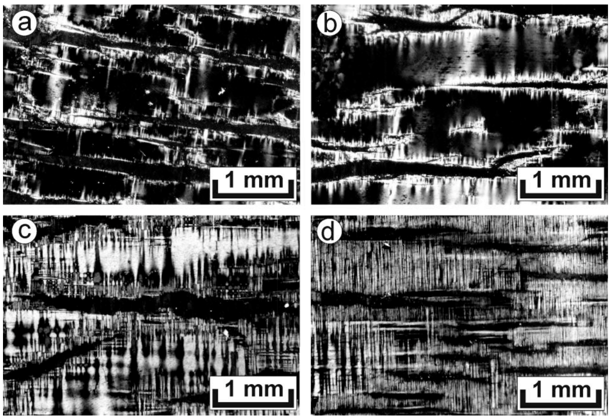

FIGURE 2. Optical micrographs parallel to (001) using transmitted light and crossed nicols. HM regions are in extinction position in (a) and (b). (c) and (d) micrographs are in parallel position to show contrast from different domain orientation variants.

Transitional microclines

When transformation avalanches have short length, they only interact if their nucleating points are close enough (Fig. 2b). In this case, the extension of LM is limited to regions close to the Na/K interfaces. However, when they reach a long development, two distant avalanches of the same orientation variant can overlap, and as a consequence, the transformation is reinforced. Thus, HM can be hardly found and ubiquitous IMs close to LM prevail throughout the crystals (Fig. 2c).

Ordered microclines

Crystals are mainly formed by structural states close to that of the LM end member. Regular pseudoperiodic Albite- and Pericline macroscopic twin patterns are the microstructures resulting from global crystal self-organization by coalescence or juxtaposition of transformation avalanches, that depends on their orientation variant (Fig. 2d). Those elastic microstructures can be observed only if lattice relaxation is avoided, for example by water fluid interaction at low temperatures (Sánchez-Muñoz et al. 2006). They are formed in *dynamic regimes* in which large mineral volumes are totally re-equilibrated. This adaptive behaviour emerges when simultaneous local atomic Si/Al ordering catalyzed by water species and global lattice stimulation by shear stress occur.

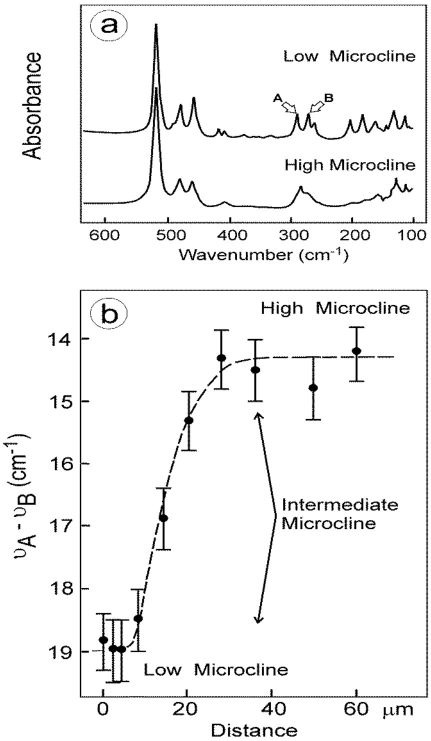

FIGURE 3. a) Raman spectra of HM and LM showing the position of the A and B bands. b) A-B band splitting as υ_A-υ_B in cm^{-1} with distance from a profile along a transformation avalanche in Fig. 2b, exhibiting a region of LM close to the interphase between Na- and K-feldspars, HM far away from the interface and all intermediate structural states in between of IMs.

CONCLUSION

A common line of evolution was proposed from the correlation between the observed features in K-rich perthitic feldspars from many localities (Cerny 1994), known to be dependent mainly on the availability of water and tectonic shear stress (Martin 1988). This evolutionary process is here explained by the extension reached by transformation avalanches and their self-assembly capabilities during the subsolidus stage.

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