WHAT IS A TWIN-STRUCTURE? AN ANSWER FROM MICROCLINE MINERALS FROM PEGMATITES

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ABSTRACT

Twin-structures in microcline specimens from granite pegmatites were studied by polarized light microscopy (PLM) and Raman microprobe (RMP) spectra. Ordinary and diagonal Albite-Pericline orientation variants from transformation twinning (after a monoclinic precursor) and subsequent solid-state recrystallization twinning were observed. They exhibit a "complexity", related to the particular organizations of the twin units, that is totally expected from traditional crystallographic and equilibrium thermodynamic views. They evolve as global entities with adaptation capabilities to the geological environment. Twin-structure formation involves the active participation of the electron lattices as a fundamental feature of the crystalline state.

INTRODUCTION

Laves (1962) proposed that feldspars are useful to examine basic subjects in mineralogy and crystallography: *What is a mineral, what is a crystal and what is a phase*, are central questions involving the crystalline state. The traditional definition of a mineral (based on homogeneity, atomic order, and defined composition) has been recently revised by IMA: "a mineral is an element or chemical compound that is *normally crystalline* and that has been formed as a result of geological processes" (Nickel, 1995). For Bragg, "a *crystal* is essentially a pattern; the atoms are arranged according to a plan, such that the same configuration is repeated at regular intervals in all three dimensions". Microcline (as many other crystalline substances) shows twinning, a feature ignored in definitions, often seen as insignificant or as a "dirty" phenomenon and historically compared with "demons" and "natural monsters". Here is shown that exceptional regularities are found in the twin patterns of microcline, and hence, *what is a twin-structure* is a relevant question to describe the nature of the crystalline state.

EXPERIMENTAL METHODS

GcF4 and GcF5 (Golconda pegmatite, MG, Brazil), R6 (Wray Mine, North Carolina, USA); BLIR (Ploskaya pegmatite, Kola Peninsula, Russia), KOΛ-16 and KOΛ-18 (Parusny pegmatite, Kola Peninsula, Russia), Dlr1 (Helio pegmatite, Itambé, Bahía, Brazil), 9544 (Pikes Peak, Colorado, USA) microcline specimens were studied. Those from Kola Peninsula and Pikes Peak are green amazonites. PLM images were obtained on (001) section with the help of a red plate. The RMP spectra and hyperspectral 2D and 3D plots were obtained using a ThermoFischer Microscope with ~1 μm spatial resolution and a laser surce at 532 nm.

RESULTS AND DISCUSSION

It was found that twin development in microcline is consistent with avalanche-type mechanisms, Sánchez-Muñoz et al (2008). Fig. 1a is a PLM image of BLIR microcline close to the parallel position showing left- and right-handed Albite twins (N-S) with δ extinction angle in (001) section at ~ -18º and +18º respectively, and left- and right handed Pericline twins (E-W) with δ at ~ -21º and +21º respectively, i.e. -A, +A, -P and +P *transformation twins*. They configure rectangular regions of optically monoclinic microcline δ ~ 0º with a fine cross-hatched (ch) contrast. Subsequent zig-zag patterns formed by two complementary diagonal Pericline twins (dP and dP*) have been nucleated at the surface boundary with the -A twin at the left side, but serrated boundaries are produced by intersections with +A twins at the right side (observe that the -A twin is almost erased at the joint). Fig. 1b is the same area but observed with a *red plate* resulting into "red and blue twins" from subtraction and addition effects when having – or + extinction sense. The interference colours in serrated twins and at twin intersections change respect to pristine areas because of different optical orientations.

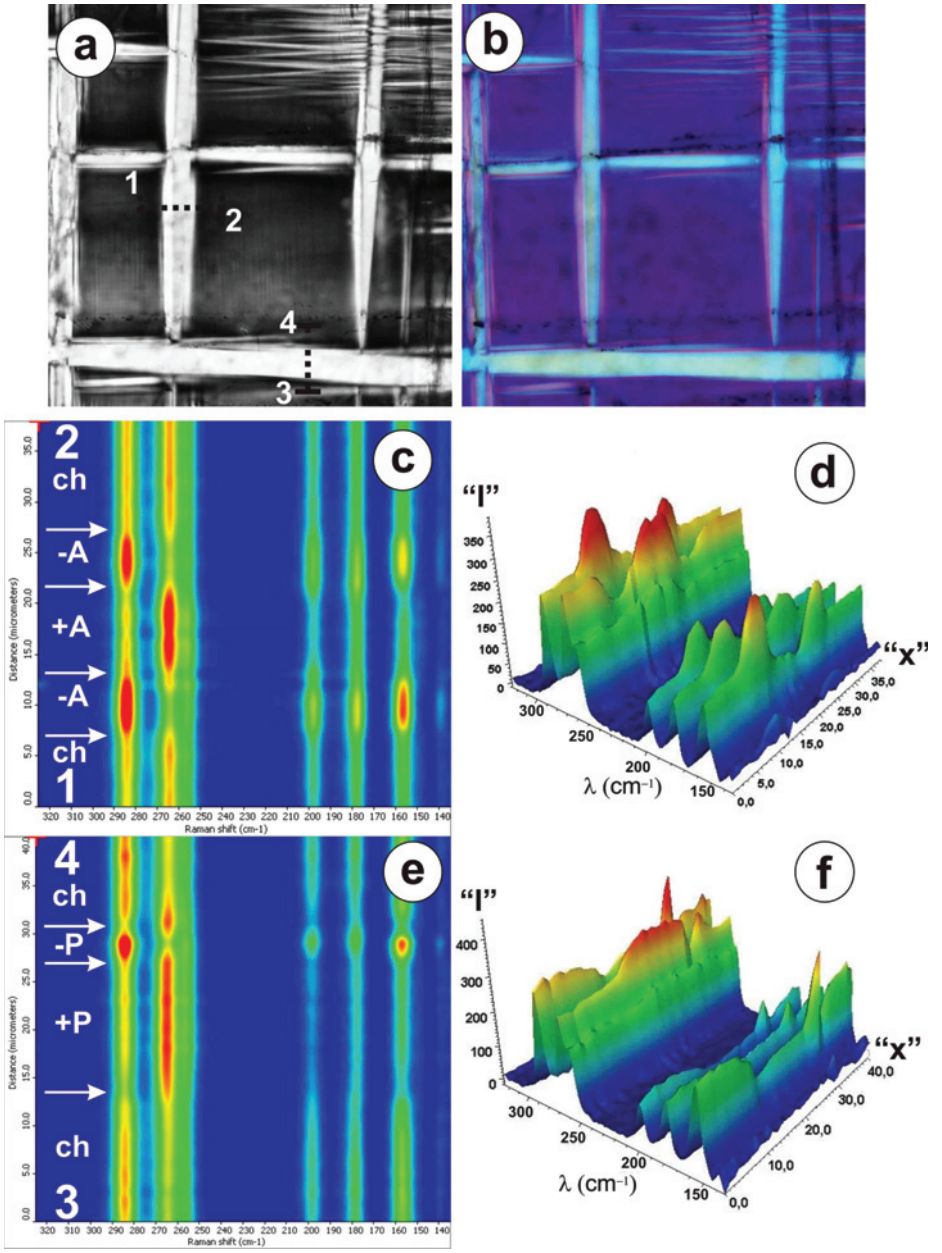

*Figure 1. a) PLM image in (001) section, crossed nicols, b) idem with a red plate. c) and d) Hyperspectral 2D and 3D RMP line-scans along 1-2 across ± A twins, e) and f) idem along **3-4** across ± P twins, Raman shift λ (cm^{-1}), "x" μm (equidistance 1 μm), "I" as relative intensity.*

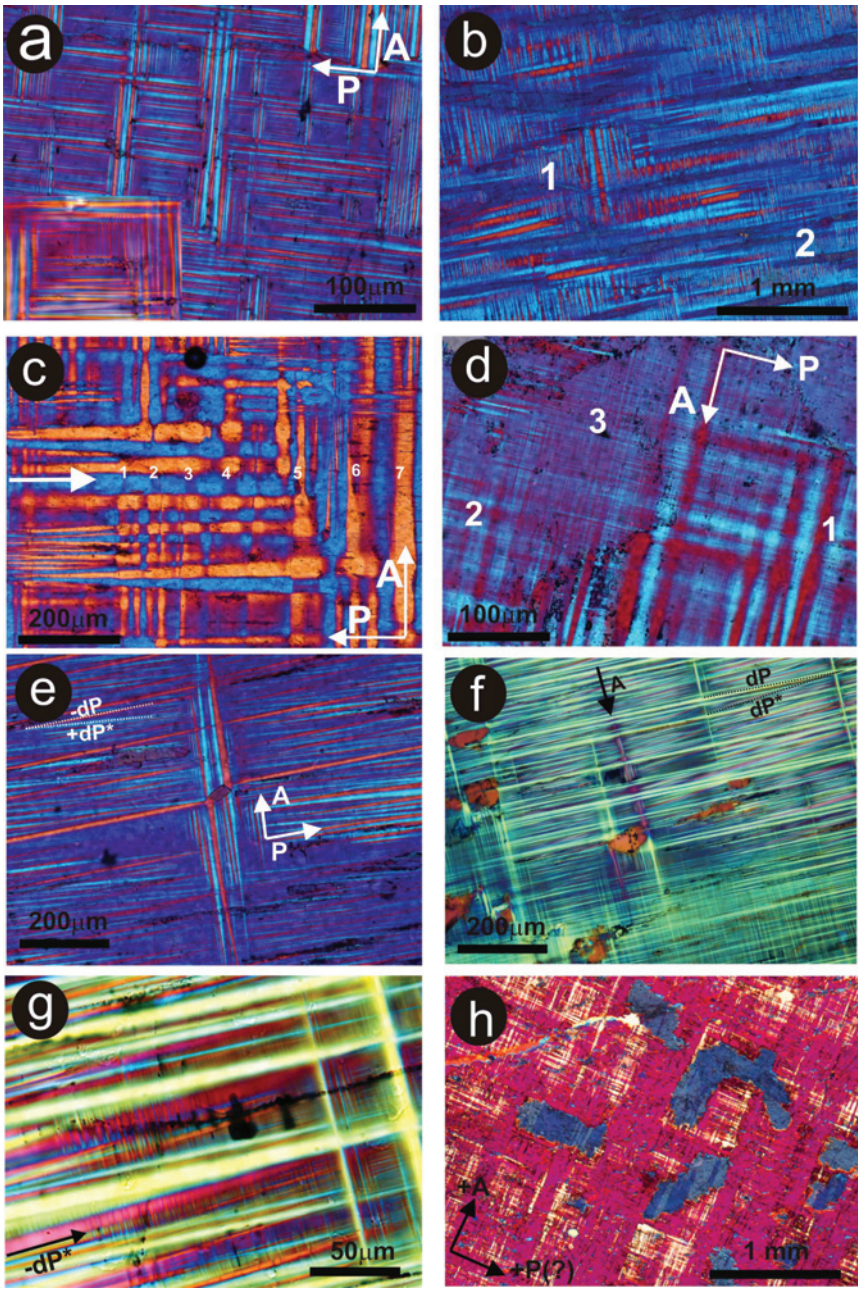

Figure 2 - PLM images with a red plate of a) Specimen KOΛ-18; b) Specimen Dlr-1, c) Specimen GcF4, d) Specimen GcF5, e) Specimen KOΛ-16, f) Specimen BLIR, h) Specimen R6. All cases were taken with crossed nicols except h) which was rotated at 80º. The Raman □ parameter was homogeneously distributed in all samples at ~ 19.2 ± 0.5 cm^{-1}, being consistent with the "low microcline" scheme of Si/Al order in the K-feldspars.

Two RMP line-scans were obtained along 1-2 across ± A-twins (Fig. 1c) and 3-4 across ± P-twins (Fig. 1d) and the areas with ch contrast, showing a *homogeneous* distribution of parameter from the positions of the A- and B-bands at ~286 and 267cm^{-1} (Sánchez-Muñoz et al 2008). Thus an invariable local structure of "low microcline" occurs but regular changes in line intensities are detected from the different lattice orientation in the twin units. Once it is known the correlation between the local structure from the RPM spectra and the δ values in (001) sections, the interference colours (with the red plate) are very useful to discriminate twin orientations as well as the resulting elastic strain fields, consequently, the classic PLM becomes an exceedingly "powerful technique" studying twin-structures.

Figure 2a shows a *rectangular cross-hatched microstructure* formed by ± A-P twinning with few twin intersections. Consequently, the size of the newly formed twins is limited by those formed before, resulting in a progressive decrease of the twin size (see inset) as the monoclinic precursor is gradually transformed. In Fig. 2b this microstructure is partially conserved in the "1" region but it is replaced by a fine polysynthetic ± A twinning in the "2" region with serrated boundaries from deformational origin. Fig. 2c exhibit a coarse chess-board (cb) pattern by multiple A-P intersections, but a sharp dichotomy between "mixture" and "window" areas, i.e. the "black" and "white" tiles of the chess-board, is absent because different amount of mixtures are found, as recognized by Fitz Gerald and McLaren (1982). However, this pattern is more than a intersection of twins, A- and P-twins are hybridizing: the arrowed +P twin is almost unaffected at "1" but the amount of mixture with –A variants changes progressively up to "7" where the former can not be appreciated. Fig. 2d shows a hybrid pattern in "1", partially replaced in "2", almost completely substituted in "3" by another much finer pattern that implies a huge increase in surface energy of the mineral system with the augment of the total area of twin boundaries per unit volume. Obviously external extra energy must be supplied from the geological environment, e.g. from tectonic causes, forming non-equilibrium twin structure that absorbed that energy to adapt the twinning setting to the new milieu. Fig. 2e and 2f show *petals* associated to the wedge terminations of an albite lozenge. In Fig. 2e the blue +dP* and red –dP twins form also a regular pattern. In Fig. 2f, the ± dP* twin are locally replaced by +dP (yellow). In the lower part a fine twining replaces the previous patterns. Fig. 2g shows details of several P twins being serrated by later A twins (observe the gradual colour conversion from rose to red because of lattice orientation changes along the arrowed -dP* twin). Thus, the monoclinic symmetry seen optically and the gradual changes in interference colours respond to optical effects linked to the electronic lattice that is strongly modified by the elastic strain fields from fine twinning arrangements and lattice misorientation. In Fig. 2h, +A and apparent +P twins having δ=+18º occurs in a pattern with forcedly squared albite veins (in blue).

In conclusion: i) pristine microcline is not just a pseudomorph from a monoclinic precursor, formed by randomly distributed transformation and recrystallization twins; ii) the definition of microcline with a triclinic unit cell from atomic positions as its essential character seems a very limited conception of that the crystalline state is; iii) if the electronic structure is attended, a extraordinary richness of twin-structures emerges, iv) twin-structures respond to the

overall elastic strain where a mineral acts a global entity; v) each mineral specimen is unique from their own history; vi) long-range interactions via the electronic lattice explain structural features (and electromagnetic properties) impossible to understand by taking into account the crystalline state in term of atomic or ionic order only.

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