The compositions of coherent exsolution lamellae in alkali feldspar measured with atom probe tomography

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In the past, the compositions of experimentally produced coherent exsolution lamellae in alkali feldspars had to be determined indirectly from the “distorted” lattice parameters, because their small size prevented direct in-situ composition measurements. This indirect approach is based on strain models hinging on elastic constants, which are, however, subject to considerable uncertainties, especially for alkali feldspars with intermediate compositions (Robin 1974; Sipling & Yund 1976). In this study, we directly measured the compositions of experimentally produced exsolution lamellae using atom probe tomography (APT), a technique with near-atomic resolution which became available for non-conductive materials in the last decade.

At first, two K-rich gem quality alkali feldspars (Madagascar orthoclase and Volkesfeld sanidine) were shifted to intermediate Na-K-compositions by cation exchange with NaCl-KCl salt melt at 900 °C and subsequently annealed at ambient pressure and temperatures between 440 and 560 °C. Annealing conditions were within the miscibility gap of disordered alkali feldspar solid-solution and the initial compositionally homogeneous feldspars exsolved into a coherent lamellar intergrowth. Transmission electron microscopy (TEM) investigation of the exsolved feldspars revealed fully coherent exsolution lamellae subparallel to (-801) with lamellar widths of 5-30 nm. As the cell parameters of alkali feldspar exhibit considerable compositional dependence, the lattices of the more Na-rich and the more K-rich lamellae must be distorted in order to maintain coherency across the lamellar interfaces. In electron diffraction patterns this lattice distortion is evident from a splitting of the reflections corresponding to lattice planes sub-parallel to the lamellar interfaces.

APT revealed compositionally distinct domains corresponding to the expected Na-rich und K-rich lamellae. Time series experiments with different annealing durations were done at a given temperature to check when the lamellar compositions become stable, i.e. when thermodynamic equilibrium between the Na-rich and the K-rich lamella is reached. Even at the lowest applied temperatures equilibrium was reached within a few days, and lamellar compositions may be regarded as binodal points. The binodal points obtained at different temperatures delineate the coherent binodal curves. The results were compared to previously determined coherent solvi from the literature. Interestingly, Volkesfeld sanidine and Madagascar orthoclase show similar Na-K element partitioning and thus similar thermodynamic non-ideality of the alkali feldspar solid-solution in feldspar-salt melt cation exchange experiments at ambient pressure and temperatures between 800 and 1000 °C, but the coherent solvus of Volkesfeld sanidine lies well below the one of Madagascar orthoclase.

This apparent discrepancy may either be due to different degrees of thermodynamic non-ideality of the alkali feldspar solid-solution at the comparatively low temperatures of exsolution. Alternatively, this may be explained by different elastic properties of Volkesfeld sanidine and Madagascar orthoclase, which feed into the Gibbs energy of the soldi-solution via the elastic energy associated with coherent lamellar intergrowth.

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