Incommensurately modulated structures and subsolidus phase relations of intermediate plagioclase feldspars

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Plagioclase feldspars are the most abundant mineral in the Earth's crust. Intermediate plagioclase feldspars commonly display incommensurately modulated structure or aperiodic structure. Both fast-cooled and slow-cooled plagioclase feldspars display the incommensurately modulated structures. The ordering pattern in the incommensurately modulated structures of e-plagioclase (characterized by the satellite diffraction peak called e-reflections) are the most complicated and intriguing. The modulated structure has a superspace group symmetry of $X^{-1}(αβγ)0$ with a special centering condition of $(1/2 1/2 1/2 0)$, $(0 0 1/2 1/2)$, $(1/2 1/2 0 1/2)$, and the $q$-vector has components (i.e., $δh$, $δk$, $δl$) along all three axes in reciprocal space. Displacive modulation, occupational modulation, and density modulation are observed in slowly cooled labradorite feldspars. Z-contrast images show both Ca-Na ordering and density modulation. Local structure of lamellae domains has $I1$ symmetry. The neighboring lamellae domains are in inversion twinning relationship. The results from Z-contrast imaging and low-temperature single XRD provide consistent structure with density modulation. The amplitudes of the modulation waves are new parameters for quantifying the ordering state of plagioclase feldspars. Iridescent labradorite feldspars display exsolution lamellae with average periodicity ranging from ~150 nm to ~350 nm. Compositional difference between the lamellae is about 10 to 15 mole % in anorthite component. Areas or zones with red iridescent color (i.e., long lamellae periodicity) always contain more Ca (~1 to 3 mole %) than the areas with blue (or green) iridescent color within the same labradorite crystal. We proposed that the solvus for Bøggild intergrowth has a loop-like shape ranging from ~An$_{44}$ to ~An$_{63}$. The Ca-rich side has higher temperature than the Na-rich side. The shapes of satellite peaks, the distances between e-reflections (modulation periods), and even the intensity of c-reflections may also be used evaluate the ordering state or cooling rate of the plagioclase feldspar. Both modulated structure and the exsolution lamellae can be used as proxies for quantifying cooling rate of a labradorite and its host rock.