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Preservation of oscillatory zoning in plagioclase inclusions from the Western Gneiss Region, Norway

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For many minerals, chemical diffusion is sufficiently fast on the geological time scale to homogenize chemical heterogeneities at temperatures exceeding 700°C. Therefore, the observation of preserved chemical zoning at high temperatures is difficult to explain. This is particular problematic for oscillatory zoned minerals with sharp compositional steps experiencing high-temperature metamorphic conditions for several million years.

Here we investigate a rock specimen from the Western Gneiss Region (WGR) that experienced Caledonian ultra-high pressure (UHP) metamorphism with peak metamorphic conditions of ~800°C and 3.2 GPa, and a post UHP overprint (with T >750°C and 1.2 GPa) during exhumation.

Polymineralic inclusions in garnets encompass amphibole, biotite and oscillatory zoned plagioclase of 150 x 200 μm size with thin compositional lamellae of 1-10 μm alternating from core towards the rim. The zoning of the plagioclase grain is reverse with increasing anorthite content from the inclusion core to the rim. We conducted a detailed microstructural characterisation utilizing a combination of electron microprobe analysis (EPMA), electron backscatter diffraction (EBSD) measurements and analytical transmission electron microscopy (A-TEM). The high-resolution analyses show that the compositional profile has sharp contacts between each lamella. Such sharp contacts exclude the possibility of pervasive diffusional modification.

In order to understand how such a high-temperature microstructure with sharp chemical zoning can be preserved on the million years' time scale, we apply conventional and unconventional diffusion quantification methods. It is shown that conventional (Fickian) diffusion would have equilibrated this microstructure within thousands of years. In contrast, we apply the newly developed approach where chemical diffusion is coupled to mechanical deformation (Zhong et al. 2017). We show that the preservation of such a compositional zoning in minerals can be strongly influenced by this coupling. A significant pressure gradient is developed inside the grain due to the chemical diffusion at the very early stage of the chemical re-equilibration. Due to slow viscous relaxation, this pressure gradient is then able to inhibit further concentration homogenization, explaining the preservation of the oscillatory zoning.

Zhong X, Vrijmoed J, Moulas E, Tajcmanova L, (2017) A coupled model for intragranular deformation and chemical diffusion. Earth and Planetary Science Letters