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Mechanically-controlled chemical zoning and its preservation in high-temperature minerals from the Western Gneiss Region, Norway

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In many mineral phases, chemical diffusion is sufficiently fast to homogenize the chemical heterogeneities on geological time scales at temperatures exceeding 700 °C. However, when chemical zonation in minerals that experienced high temperature conditions for millions of years is preserved, the current knowledge of chemical diffusion rates in minerals may not be sufficient to explain the preservation. Because in such cases, classical chemical diffusion approach predicts complete chemical equilibration. Therefore, in high-temperature metamorphic rocks, the preservation of chemical zoning still remains enigmatic. Interestingly, the development and preservation of compositional zoning in minerals can be strongly influenced by mechanically-maintained pressure variations.

In this contribution, the ability to preserve the compositional zoning is investigated for two minerals – garnet and plagioclase. Samples are chosen from a region that witnessed a long-lasting high temperature metamorphism - the Western Gneiss Region (WGR). The WGR witnessed 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. Results from classical diffusion modelling are compared to newly developed methods that involve chemo-mechanical coupling in order to explain the preservation of chemical zoning during high temperature metamorphism.

Garnets from selected samples have pronounced compositional zoning and Lu-Hf garnet geochronology reveals a Scandian age of 413 +/- 2.6 Ma. This indicates that garnet grew during the pre- ultra-high pressure event in the Western Gneiss Region and that garnets experienced the following decompression without being affected by the long lasting high- temperature metamorphism. Results from diffusion modelling show a too short duration of the high-temperature event which is inconsistent with the existing regional geology data. On the contrary, the new equilibrium approach that predicts compositional zoning as a result of spatially varying pressure has been applied. The results show a good fit with naturally observed chemical zoning in multicomponent systems. This offers an explanation for the preservation of chemical zoning in multicomponent systems, such as garnet, by mechanically induced local pressure variations under high-temperature conditions.

The second example is an oscillatory zoned plagioclase inclusion in garnets that attracted attention because of the preservation of its sharp zoning. The sharp zoning is further characterised by high-resolution techniques. The classical Fickian diffusion model predicts chemical homogenization within thousands of years. In contrast, when chemical diffusion is coupled with mechanical deformation, a significant intragranular pressure gradient is developed at a very early stage of the chemical re-equilibration. Due to slow viscous relaxation, further chemical homogenization is inhibited, which may have contributed to the preservation of the oscillatory zoning.

In this contribution mechanisms are investigated that might be responsible for the preservation of chemical zoning in high-temperature minerals. The presented case studies show more evidence for the preservation of chemical zoning by mechanical effects. This study contributes to a better understanding of chemo-mechanical processes and may contribute to our better understanding of the long-term strength of the lower crust.