

Stable isotope geochemistry of the Varuträsk rare-element pegmatite (northern Sweden)

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The Varuträsk pegmatite, located in the Skellefte district in northern Sweden, is a classical representative of highly fractionated LCT-type rare-element pegmatites [1,2]. The Varuträsk pegmatite shows a typical primary zonation pattern, composed of well-developed border, wall and intermediate zones and a quartz core [3]. Major rare-element enrichment is mainly related to late-stage assemblages such as albite-lepidolite and pollucite units. Previous work [4] has focused on the major and trace element characteristics of key minerals (feldspars, micas, tourmaline, columbite-tantalite), demonstrating progressive magmatic fractionation trends in the primary pegmatite zones. Significant compositional changes observed in the late-stage mineral assemblages (reversals of magmatic fractionation trends, depletion in elements typically enriched in aqueous fluids) indicate that a magmatic fluid exsolved after the development of the primary pegmatite zonation.

The results of the present stable isotope (B, H, O) study further constrain the role of a magmatic fluid phase in formation of rare-element enrichment. Stable isotope analysis (O, H, B) has been performed on quartz, mica and tourmaline from all principal mineral assemblages in the pegmatite body. Boron isotope data of tourmalines using SIMS microanalysis are in the range between -14.6 and -6.2 ‰. The $\delta^{11}\text{B}$ data of different tourmaline types conforming to the primary pegmatite zonation show a clear magmatic fractionation trend. By contrast, tourmalines related to late-stage assemblages show a reversed fractionation that is correlated with the behavior shown by several major and minor elements in the tourmaline (Na, Fe, Mn, F). The B isotope evolution cannot be modeled by purely magmatic melt-tourmaline fractionation, but requires fluid-tourmaline partitioning to be operative for the late-stage assemblages. Hydrogen isotope data of micas indicate a substantial increase in δD from -76 to -53 ‰ from the wall to the innermost zones, requiring closed-system fractionation processes that involved melt and fluid. Taken together, the stable isotope data demonstrate that rare-element enrichment in the most fractionated assemblages is related to the transition from purely magmatic crystallization to conditions where a magmatic fluid phase was important.

[1] Cerny, P. 1991: Rare-element Granitic Pegmatites. Part I: Anatomy and internal evolution of pegmatite deposits. *Geosci. Canada*, 18, 49-67 [2] Cerny, P., Ercit, T.S. 2005: The classification of granitic pegmatites revisited. *Can. Mineral.*, 43, 2005-2026 [3] Quensel, P. 1952: The Paragenesis of the Varuträsk Pegmatite. *Geol. Mag.*, 89, 49-60 [4] Matalin, G., Wagner, T., Jonsson, E., Wälle, M., Heinrich, C.A., 2012. Evolution of the Varuträsk LCT-type rare-element pegmatite (N Sweden): mineral chemistry constraints. *Contrib. Mineral. Petrol.* (submitted)

Deep ocean mixing, the bipolar seesaw, and polar ocean biogeochemical change

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At the scale of the global ocean, deep water formation is coupled to processes – most notably, vertical mixing and wind-driven upwelling – that reduce the density of deep water or otherwise remove dense water from the deep ocean. This formation/removal coupling may play a critical role in glacial/interglacial changes in polar ocean circulation and in atmospheric carbon dioxide. Considering the two regions of modern deep water formation, the North Atlantic and the Antarctic, if deep water formation ceases in one region but the loss of dense deep water does not decrease equivalently, then the other polar region must increase its deep water formation rate. This is one proposed physical mechanism behind the observed “bipolar seesaw” in high latitude temperatures on millennial time scales. Since deep water formation in the North Atlantic and the Antarctic have opposite effects on the efficiency of the global biological pump, any tendency for anti-correlation in their rates has a major effect on atmospheric CO₂. Accordingly, there is intense focus on an ocean seesaw mechanism for the CO₂ rises at the end of ice ages. However, there are divergent views as to the importance of deep ocean mixing *versus* the winds in driving such a North Atlantic/Antarctic seesaw. If the biogeochemical conditions of the polar ocean surface can be reconstructed back through time, we will have greater insight into how the polar regions have changed in their ventilation of the ocean interior and their impact on deep ocean carbon storage. In this talk, in addition to drawing upon numerical model experiments to lay out the arguments above, we will describe new diatom- and foraminifera-bound nitrogen isotope data from the Antarctic and the North Atlantic that support the view of seesaw-like behaviour between the two regions over major glacial/interglacial transitions and on millennial time scales. In this context, we will revisit the question of deep mixing *versus* the winds as driving this pattern.