Behaviour of the Sm-Nd and Lu-Hf geochronometers in garnet during HT and UHT metamorphism

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Sm-Nd and Lu-Hf garnet geochronology offers a quantitative link between isotopic ages and metamorphic conditions. Most commonly, the link is established on the basis of major element study of a peak metamorphic assemblage. Such an approach is valid only for low to medium grade metamorphism, where both major and trace elements preserve garnet growth conditions. At high temperatures major elements show diffusive profiles and hence are of very limited use for interpretting the dating results, which imposes a necessity for *in situ* studies of trace element distribution. In this study we present Sm-Nd and Lu-Hf garnet dating results along with laser ablation ICPMS trace element data obtained for high and ultra-high temperature rocks.

Migmatitic gneisses from N-Vietnam metamorphosed at ca. 800 °C show high quality Sm-Nd isochron ages spread between 50 and 30 Ma. Lu-Hf data obtained for the same samples failed to deliver tight age constraints but clearly point to much older dates. Both Sm and Nd tend to show decreasing from core to rim concentration gradient with decreasing crystal size, which is interpreted as reflecting variable degree of resetting. Indeed, the youngest Sm-Nd age was obtained for the sample with the smallest garnet crystals. Additionally, the youngest age is associated with the highest strain, which shows that not only temperature but also deformation is a significant factor facilitating resetting of the Sm-Nd, and potentially, Lu-Hf clocks in garnet. Lutetium in most analysed garnets shows Rayleigh-like patterns pointing to the preservation of prograde growth conditions. However, minor resetting of the heavy REE in the smallest crystals is observed.

In ultra high temperature granulites from the Bohemian Massif, Sm-Nd and Lu-Hf systems were decoupled and recorded distinct episodes separated in time by as much as 40 to 70 Ma. The oldest Lu-Hf age correlates with the steep Rayleigh-type Lu zonation profile, which indicates that under dry conditions, garnet can withstand temperature even in excess of 900 °C and preserve the time of prograde growth. In granulite which underwent hydration under amphibolite facies conditions, a younger Lu-Hf age correlates with the partially homogenized Lu zonation trend. In the case of Sm-Nd system in the studied UHT granulites, much younger ages do not reveal any obvious correlations with spatial distribution with these elements in garnet.

The behaviour of $^{234}U/^{238}U$ during experimental granite dissolution

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Weathering of rock minerals has great importance for the natural cycles of elements and other processes on the Earth surface. Lately, several isotopic systems have been employed to study rock weathering. The daughter ^{234}U to the parent ^{238}U ratio can be expressed as an activity ratio ($^{234}U/^{238}U$) equal to one at secular equilibrium. The ($^{234}U/^{238}U$) ratio often deviates from one due to recoil effects of ^{234}U: it is either directly ejected (through ^{234}Th) from a mineral or preferential leached from damaged mineral lattices. These effects result in natural waters mostly having ($^{234}U/^{238}U$) >1 whereas the outer rims of minerals have ($^{234}U/^{238}U$) <1, the latter depending on time, grain size and α-recoil distance. Thus, ($^{234}U/^{238}U$) should be a useful monitor to compare between physical or chemical weathering rates.

Two progressively flow-through laboratory leaching experiments on bulk crushed granite samples were conducted over 1200 hours. Input solutions were kept at pH 1 and output solutions were measured for their ($^{234}U/^{238}U$) and U concentrations. Both experiments show a similar three-step development:
(1) 0-400 hours; ($^{234}U/^{238}U$) above 1 (1.00-1.15)
(2) 400-700 hours; a gradual decrease in ($^{234}U/^{238}U$) reaching <1 (0.90-0.95)
(3) 700-1200 hours; relative constant ($^{234}U/^{238}U$) at ~0.95.
The initial U concentrations in the output solutions were of 800-400 ppt U with a continuous decrease in U concentration below <100 ppt after 1200 hours of leaching.

The observed behavior of ($^{234}U/^{238}U$) in the flow-through experiments suggests that continuous chemical weathering of a granite rock, yields waters with ($^{234}U/^{238}U$)>1 followed by ($^{234}U/^{238}U$) <1. As these experiments are short relative to the ^{238}U decay rate, the initial high ($^{234}U/^{238}U$) cannot stem from *in situ* ^{238}U decay and suggest that the excess ^{234}U are released from damaged lattice sites due to preferential leaching. When the source of the excess ^{234}U has been exhausted, direct dissolution of minerals from rim inwards starts to dominate the U signal and yields output solutions with a surprising ^{234}U deficit. This suggests that under natural high chemical weathering rates, granitic rocks should yield natural waters with ($^{234}U/^{238}U$) <1. However this is rarely observed in nature and suggests that the release rates of ($^{234}U/^{238}U$) during natural chemical weathering, are not fast enough relative to the rates of physical denudation, thereby the ^{234}U-^{238}U system is useful in constraining the relative rates of the chemical and physical weathering.