Diffusion-driven lithium isotope fractionation: models and implications

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The large mass difference between ^{6}Li and ^{7}Li gives rise to significant isotopic fractionation associated with low-temperature weathering and water-rock interactions, while isotopic fractionation at high temperature is expected to be insignificant. However, recent studies using both laboratory experiments and natural rocks have demonstrated extremely large isotopic fractionation at high temperature, due to different diffusivities of ^{6}Li and ^{7}Li in melts, minerals and rocks [1-3]. These studies indicate that diffusion-driven isotopic fractionation can happen in different media, at variable but high temperatures and at different scales from millimeters to tens of meters.

Here we model how diffusion-driven isotopic fractionation can affect Li isotopic systematics of igneous and metamorphic rocks. We find that 1) large differences in both Li concentration gradient and diffusivities of ^{6}Li and ^{7}Li can lead to significant Li isotopic fractionation, however, it is also possible to observe large isotopic variations with constant Li contents if only a portion of the diffusion profile is sampled. Thus relatively constant Li concentration profile cannot be used to rule out the possibility of diffusion-driven isotopic fractionation. 2) Homogeneous δ^7Li in minerals from lower crustal or upper mantle xenoliths indicates the absence of alteration by host magma and reflects the initial Li isotopic composition of xenoliths. In contrast, heterogeneous δ^7Li in minerals implies open system behavior and/or diffusional exchange. 3) Intra-mineral isotopic variation is a function of time, diffusion coefficient and the diffusion radius. For mineral pairs having similar size, intra-mineral isotopic fractionation changes sign with time. Thus, Li isotopic fractionation between minerals can be used as a speedometer to constrain the duration of a geological event such as heating or cooling, or Li infiltration. 4) The maximum scale of volume diffusion for Li is ≤ 1 m. In contrast, fluid-assisted grain boundary diffusion can reach more than hundreds of meters, which can explain the homogenous δ^7Li in high-grade metamorphic terranes. These different diffusion scales for Li make it a powerful tracer of fluid-rock interactions.

References

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