

High-Grade Crustal Melting: Stable and Radiogenic Isotope Disequilibria

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Radiogenic isotopes are used as fingerprints for the source of magmatic rocks and to estimate, by mass balance, the contributions of different geochemical reservoirs in magma mixing and assimilation processes. An implicit assumption in this approach is that upon melting, the isotopic composition of the melt is identical to that of the protolith. This assumption does not agree well with observations.

The Sr, Nd, and Pb isotopic compositions of leucosome (melt) and melanosome (restite) pairs in metasedimentary-derived migmatites differ because of three reasons: (i) different parent (P) to daughter (D) ratios (e.g. Rb/Sr, Sm/Nd, and U,Th/Pb) in different minerals, (ii) time, and (iii) nature of the melting reactions. Phases with contrasting P/D ratios develop, with time, different isotopic compositions. As partial melting is controlled by mineral reactions (e.g. muscovite- and biotite-dehydration melting), the isotopic composition of the melt depends on the phases involved in the specific melting reactions. As a result, melt and restite commonly have distinct Sr, Nd, and Pb isotopic compositions. Thus, melts also have different isotopic compositions compared to their protoliths and these differences are preserved if melts are extracted. Extraction of early melt leaves an isotopically modified restite, resulting in distinct isotopic and trace element signatures in subsequent melts due to the different minerals involved in later melting reactions. Depending on protolith age, differences between melt and restite may reach several ϵNd -units and up to 100 ϵSr -units. Discrete melt batches from one source may show considerable isotopic variation that may be erroneously interpreted to reflect variable contributions of material from different sources.

Similar to the radiogenic isotopes, Li and B isotopes also show significant fractionation between melt and restite during partial melting, largely depending on melting temperature and on contrasting coordination in host minerals and melt. Isotopic compositions over a cm-scale melt-restite profile show a step in $\delta^7\text{Li}$ (5 δ -units) at the contact, whereas $\delta^{11}\text{B}$ shows little variation and a smooth pattern across the contact. The contrasting isotope distribution patterns of Li and B imply that these two systems are decoupled as the elemental budget (and, thus, the isotopic budget) is controlled by different minerals. The sharp contrast in $\delta^7\text{Li}$ on a cm-scale questions the importance of diffusion to explain $\delta^7\text{Li}$ variation on larger scales.