Goldschmidt 2024 Abstract
https://doi.org/10.46247/gold2024.24736

Deformation, Mixing, and Decoupling of Nd-Hf Chemical Heterogeneities at Mid-ocean Ridges

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Mantle rocks representing the residue of melting are petrological probes of the interior of the Earth. A common assumption in the interpretation of Nd-Hf isotope ratios of residue samples is that the residue retains the isotope ratios in the source. However, this assumption is debated because melt and solid of different isotopic compositions could undergo chemical exchange, altering the isotopic signature of the source. By modeling the transport of chemical heterogeneities in the melting region beneath mid-ocean ridges, we show that the chemical heterogeneity marked by Nd or Hf isotope ratio is deformed and its isotopic signals could be damped and decoupled.

At fast-spreading ridge, a maximum melt fraction of 1% has been observed. Our model shows that original circle-shaped heterogeneity is dispersed in between the solid flow and the effective transport velocity assuming chemical equilibrium. The Nd isotope ratio in the center of the chemical heterogeneity tends to decay to the value of background mantle. The amount of decay depends on the strength of dispersion, which itself is strongly dependent on the melt fraction. The melting region beneath a slow or ultraslow-spreading ridge have smaller or even zero melt fraction, which resulted in much weaker or no dispersion. Therefore, chemical heterogeneities beneath ultraslow and slow ridges can preserve larger isotopic variability in the source compared to fast ridges, which is consistent with observed Nd isotopic variability in residues of ultraslow and slow ridges compared to fast ridges.

Current simulations also demonstrate that 2D mantle flow and melt migration at fast-spreading ridge produce chromatography fractionation of Nd with respect to Hf, causing their isotope ratios to decouple. Nd-Hf isotope ratios in the residue at ultraslow-spreading ridge stay coupled Spatial sampling of Nd and Hf isotope ratios is required to validate the effect of chromatography fractionation on Nd-Hf isotope ratios.