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Mixing loops, mixing envelopes, and scattered correlations produced by mixing of melts derived from a spatially heterogeneous mantle

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Mixing has been widely used in the interpretation of radiogenic isotope ratios and incompatible trace element variations in basalts produced by decompression melting of a heterogeneous mantle. The binary mixing model is constructed by considering mass balance of endmember components, which is independent of the size and spatial distribution of endmember components in the mantle source. Here we present a new mixing model and a mixing scheme that explicitly consider the size, spatial location, and melting history of enriched and depleted mantle parcels in the melting column. We show how Sr-Nd-Hf-Pb concentrations and isotope ratios of the pooled melt vary as a function of location of the enriched mantle parcel in the melting column. With changing location of the enriched mantle parcel in the upwelling melting column, the number and volume fraction of the enriched mantle parcels in the melting column fluctuate around reference values that are characteristic of the mantle source. Consequently, compositions of the pooled melt do not follow a single mixing curve expected by the binary mixing model. Instead, they define a mixing loop that has an enriched branch and a depleted branch joined by two extreme points in composition space. The origin of the mixing loop can be traced back to four types of enriched mantle distribution in the melting column. The shape of the mixing loop depends on the relative melting rate of the enriched mantle to that of the depleted mantle and the number and spacing of enriched mantle parcels in the melting column. Probabilities of sampling the enriched and depleted branches in the pooled melt are proportional to volume fractions of the enriched and depleted materials in the mantle source. Mixing of pooled melts from one or a bundle of melting columns results in mixing envelopes in the isotope ratio correlation diagrams. The mixing envelope is a useful tool for studying chemical variations in mantle derived melts. As an application, we consider scattered correlations in Sr-Nd-Hf-Pb isotope ratios in oceanic basalts. We show that such correlations arise naturally from melting of a spatially heterogeneous mantle.