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A new Melt Contamination Model for the Generation of “I-type” granitic rocks by melting heterogeneous lower crust

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The formation of the hornblende-bearing "I-type" granitic rocks that dominate convergent margin batholiths is controversial. The metaluminous, often calc-alkaline composition implies derivation of these rocks by the remelting of infracrustal source rocks, or by crystallisation of mantle-derived magmas. The generation of “I-type” granitic rocks is often explained by models, which consider the transformation of juvenile mafic precursors into new felsic continental crust. Such models, however, do not explain the radiogenic and stable isotope variations often found in these rocks. While the assimilation of supracrustal components, such as sedimentary or volcanogenic rocks, might explain isotope heterogeneity in I-type granitic rocks, complications arise when such mixing models are applied to explain whole rock geochemical trends together with whole rock isotope variations.

In situ analysis of Hf, Nd, and O isotopes in critical accessory minerals such as zircons, apatite and monazite can help to unravel granite formation and evolution processes. However, most studies have focused on the end-product, i.e, granitic rocks emplaced in the middle and upper crust. There is a lack of studies, which monitor the geochemical evolution and modification of magma from the source to the emplacement site. In this study, we investigate granite magma formation in the granulitic lower crust. Based on detailed studies of melt-rock interaction in migmatitic mafic granulites and granitic rocks from the mid- and upper crust from the Hidaka Metamorphic Belt (HMB) (Japan), a new Melt Contamination Model is presented to explain the geochemical fingerprint of I-type granitic rocks. Nd and Hf Isotope analyses of apatite and zircon from leucosomes and mesosomes of HMB mafic granulites reveal grain-scale isotope heterogeneities of >10 epsilon units, inconsistent with closed-system anatexis. This strong isotopic contrast reflects hybridisation between partial melts derived from metasedimentary rocks and interlayered mafic granulite horizons during extraction of silicic melt from the lower crust. Such open system melt-rock interaction results in local isotopic modification of the mafic granulites and shifts the Hf isotope signature of the anatectic melt to more radiogenic values, similar to those of hornblende-bearing ("I-type") granites emplaced into the HMB at higher crustal levels. Our study implies that the generation of broadly "I-type" granitic magmas does not require extreme temperatures to extensively melt meta-igneous (infracrustal) rocks, nor is the direct input of mantle magma important. Isotopic heterogeneities in such magmas on a mineral and sub-mineral scale reflect derivation from contrasting crustal sources where the rate and mechanism of magma transfer through the granulitic lower crust is critical.