Iron and oxygen isotope fractionation between eclogite minerals of the Münchberg Massif (Germany)

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In the absence of significant fluid-rock interactions, stable oxygen ($\delta^{18}O_{V\text{-}SMOW}$) and iron isotopes ($\delta^{56}Fe_{IRMM\text{-}524a}$) are thought to behave conservatively during subduction zone metamorphism. High-$Fe^{3+}/\Sigma Fe$ minerals tend to enrich heavy Fe isotopes compared to coexisting low-$Fe^{3+}/\Sigma Fe$ minerals, but Fe coordination can also play an important role. The relative contributions of these two factors are poorly known for high-pressure minerals, as well as the degree of retrograde diffusive re-equilibration. Here, we investigate the Fe and O isotope systematics of eclogites (without metamorphic vein networks) from the Variscan Münchberg Massif.

All minerals in the eclogites are homogeneous in major elements, except garnet, which usually shows rimward enrichment in MgO and depletion in CaO, whereas FeO and MnO zoning is often weak or absent. Spatially resolved analyses of garnet were obtained by SIMS ($\delta^{18}O$), and microdrilling followed by solution ICP-MS ($\delta^{56}Fe$). Other minerals were conventionally separated and analyzed by laser fluorination mass spectrometry ($\delta^{18}O$) and MC-ICP-MS ($\delta^{56}Fe$).

Within ca. ±0.2‰ uncertainties (2σ), garnet is homogeneous in $\delta^{18}O$ values, except for two samples, where the rim $\delta^{18}O$ values are ~0.5‰ higher than those of the cores. The $\delta^{18}O$ values of garnet, omphacite, amphibole, kyanite, zoisite, phengite, and quartz mostly agree with predicted equilibrium values at ca. 700°C. In contrast, $\delta^{18}O$ values for rutile are always ~3‰ lower than predicted. Garnet is often zoned in $\delta^{56}Fe$ values, with an increase of up to 0.3‰ from core to rim. Being the most reduced mineral in the assemblage ($Fe^{3+}/\Sigma Fe \leq 0.03$), garnet yielded $\delta^{56}Fe$ values 0.1-0.3‰ lower than those of coexisting omphacite ($Fe^{3+}/\Sigma Fe = 0.07–0.56$) and amphibole ($Fe^{3+}/\Sigma Fe = 0.07–0.28$), but 0.1-0.3‰ higher than pyrrhotite ($Fe^{3+}/\Sigma Fe = 0.29$ as Fe_7S_8).

It seems that the eclogites essentially retained inter-mineral oxygen isotope equilibria, except for diffusional resetting of rutile. $\delta^{18}O$ and $\delta^{56}Fe$ zoning in garnet can be mostly ascribed to Rayleigh fractionation, and the remaining variations may be due to (1) changing matrix assemblages and/or temperature increase during garnet growth, (2) retrograde diffusion, and/or (3) potential influx of external fluids. The Fe isotope system may possibly undergo faster diffusion than the oxygen isotope system, but at least the qualitative $\delta^{56}Fe$ differences between the minerals are probably preserved. Iron isotope fractionation between garnet, omphacite, and amphibole appear to result mostly from $Fe^{3+}/\Sigma Fe$ differences, whereas the low $\delta^{56}Fe$ values of pyrrhotite reflect its low Fe-S bond strength.