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Refractory peridotites at ultraslow-spreading ridges record ultra-low oxygen fugacity

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The oxygen fugacity (f_{O2}) of the upper mantle has important implications for magma redox, the degassing of volatiles to the atmosphere, and the geodynamic history of the mantle. While both mid-ocean ridge basalts and peridotites are useful probes of mantle f_{O2}, basalts homogenize the geochemical variability of their sources and preferentially sample fertile mantle material [1]. Thus, ridge peridotites, while less abundantly exposed, provide insight into mantle heterogeneity that cannot be gleaned from volcanics alone.

Much of the compositional variability observed globally in mid-ocean ridge peridotites can be generated beneath the ridge via processes such as melting and melt-rock interaction. However, there is no evidence that these processes generate significant variability in f_{O2} [2], suggesting that variations in ridge peridotite f_{O2} may instead reflect pre-existing source heterogeneity.

We report new f_{O2} measurements for a set of peridotites from the Gakkel Ridge (n=10) and Hess Deep (n=6) and interpret the samples in the context of previous measurements from the Southwest Indian Ridge [3] (SWIR). Residual lherzolites from SWIR and Gakkel, which reflect low to moderate degrees of melting beneath an ultraslow-spreading ridge, record f_{O2}s slightly above the QFM buffer, consistent with the f_{O2} of ambient sub-ridge mantle as implied by global MORB. Refractory harzburgites from Hess Deep, which reflect large degrees of melting at the fast-spreading East Pacific Rise, also record f_{O2}s in this range, consistent with previous observations that melt extraction does not significantly alter peridotite f_{O2}. In contrast, refractory harzburgites from SWIR and Gakkel record significantly lower f_{O2}s (<QFM -2) that are inconsistent with generation during modern ridge processes.

These excursions to ultra-low f_{O2} were likely generated during ancient melting events, prior to emplacement beneath the modern ridge. We use thermodynamic modeling to demonstrate that the generation and preservation of low-f_{O2} peridotite reservoirs requires melting to initiate within the garnet field at high potential temperature and continue to relatively shallow pressures. Our results indicate that rafts of ancient, refractory, ultra-reduced mantle circulate in the modern upper mantle while contributing little to modern ridge volcanism.

[1] Stracke et al., 2019
[2] Birner et al., 2021
[3] Birner et al., 2018