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Ultra-Low Oxygen Fugacity Recorded by Refractory Mid-Ocean Ridge Peridotites Reflects Deep, Ancient Melting Events at High Potential Temperature

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The oxygen fugacity (fO_2) recorded by mid-ocean ridge peridotites varies by over four orders of magnitude [1-3], suggesting a heterogeneous sub-ridge mantle. However, modern ridge processes such as melting and melt-rock interaction do not generate significant redox heterogeneity [4], indicating that variations in ridge peridotite fO_2 instead reflect pre-existing source heterogeneity.

In this contribution, we focus on the geochemistry and oxygen fugacity of refractory harzburgites – peridotites that record large degrees of melt extraction – from the Gakkel Ridge, Southwest Indian Ridge (SWIR), and East Pacific Rise [2,5]. We find that refractory harzburgites from Hess Deep, associated with the fast-spreading East Pacific Rise, record fO_2 consistent with average fertile mantle. The consistency in fO_2 between fertile ridge peridotites and the Hess Deep refractory samples provides further evidence that modern ridge melting in the spinel stability field does not strongly affect fO_2. In contrast, refractory harzburgites from ultraslow-spreading ridges (SWIR + Gakkel) record f_{O2} significantly lower than the mantle average [5]. These samples do not represent modern ridge melting and instead likely experienced high degrees of melting in the Earth's ancient past [6-7].

We use thermodynamic modeling and a new empirical mineral-partitioning model to demonstrate that the excursions to ultra-low fO_2 recorded by the SWIR+Gakkel refractory samples can be produced by large degrees of melting at high potential temperature, beginning in the garnet field and continuing into the spinel field. These conditions would be met during generation of ancient komatiites, providing a mechanism for the production of both low-fO_2 mantle residues and low-fO_2 lavas from a mantle with the same initial bulk Fe^{3+}/tFe ratio as today. The residual rafts of ancient, refractory, reduced mantle continue to circulate in the modern mantle while contributing little to modern ridge volcanism.

[1] Bryndzia and Wood, 1990
[2] Birner et al., 2018
[3] Cottrell et al., 2022
[4] Birner et al., 2021
[5] Birner et al., 2024
[6] D'Errico et al., 2016
[7] Liu et al., 2008