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An Improved Empirical Model for Assessing Redox Evolution During Mantle Melting

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The behavior of redox-sensitive elements during melting is critical to magmatic and mantle processes from source to surface. The oxygen fugacity (fO_2) of residual mantle, which in turn sets the fO_2 of low-degree mantle-derived magmas, is a function of pressure, temperature, and compositional variability. As melting proceeds, the evolution of mantle and melt redox involves a complex interplay between the depth/lithology of melting (e.g., garnet-field vs. spinel-field melting) [1] as well as partitioning behavior that is dependent on both temperature and composition [2-3].

Thermodynamic models can assess redox evolution during melting but are slow to update to new data and do not always incorporate ferric iron into all necessary phases. In contrast, empirical models, which rely on a combination of natural and experimental data to constrain partitioning between phases, are significantly easier to adapt to new data and tailor to specific use cases.

We present an improved version of the empirical redox melting model first published in Birner et al., 2024. Our model contains six phases (olivine, orthopyroxene, clinopyroxene, spinel, garnet, melt) and seven components (CaO, FeO, MgO, Al_2O_3, Cr_2O_3, Fe_2O_3, SiO_2). The model calculates ferric iron partitioning between phases during decompression using a combination of experimental data and natural xenolith data. Subsolidus reactions and fractional melting are modeled using empirical reactions in the garnet and spinel fields, and fO_2 evolution is tracked using empirical spinel oxybarometry equations.

The new model offers significant improvements. It runs >10x faster than the previous version and has a new user-friendly interface that allows for easy adjustment of input parameters such as bulk composition, initial redox ratio, and choice of partitioning constraints. The model also incorporates the ThermoEngine thermodynamic package (enki-portal.org), which provides Python-based access to the MELTS family of models and equilibration routines. This allows for integration of thermodynamic parameters, such as the MELTS spinel activity model [4], into our empirical framework. The model is also now accessible via interactive Jupyter notebooks that can be run on a web browser without the need for downloading or installing software.

[1] Birner et al., 2024
[2-3] Davis and Cottrell, 2018/2021
[4] Sack and Ghiorso, 1991ab

