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Oxygen Fugacity Across Tectonic Settings

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Petrologists have developed and applied oxybarometers for more than half a century. With time, activity models that yield fO2 from mineral, melt, and vapor compositions have evolved, and new analytical methods have opened new sample categories to oxybarometric interrogation. We compiled published compositional data [1,2] from lithologies that constrain fO2 (n=860 volcanic rocks and n=326 mantle lithologies) from ridges, back-arcs, forearcs, arcs, and plumes (Fig. 1). We re-calculated fO2 for each dataset, applying a consistent set of modern activity models. We also compiled trace element concentrations (e.g., vanadium) as additional fO2-proxies for comparison. Volcanic and mantle rocks from the same tectonic setting yield similar fO2s, but mantle lithologies record larger ranges in fO2 than volcanic rocks. The fO2s recorded by multiple Fe-based oxybarometers and vanadium partitioning vary as a function of tectonic setting, with fO2 recorded at ridges < back-arcs < arcs (Fig. 1). The fO2s recorded by plume lithologies are broadly similar to ridges, but require nuance in their interpretation. Likewise, effects of subsolidus metamorphism on fO2s recorded by mantle lithologies remain poorly understood. The Earthchem Library [2] therefore provides a useful compendium, but we advise caution in the interpretation of the data. Crystal fractionation has a small effect on the fO2s of residual basaltic liquids, no discernible effect in more evolved compositions, and arc rhyolites record similar fO2s to arc basalts. The effect of degassing depends on tectonic setting, which governs the final pressure at which magmas erupt, the identity and concentration of dissolved volatiles, and the initial fO2 of undegassed magmas. Empirically-based degassing models suggest that the effect of degassing is negligible at ridges, may cause oxidation or reduction of ~0.25 log units at arcs, and universally reduces plume melts by ≥1 log unit (Fig 2). The effects of crystallization and degassing on fO2 are smaller than the differences between tectonic settings; we infer that upper mantle fO2 varies as a function of tectonic setting.

[1] Cottrell et al., (2022) [1] Cottrell et al., (2022) http://doi.org/10.1002/9781119473206.ch3 [2] Cottrell et al., (2021) https://doi.org/10.26022/IEDA/111899

FIGURE 1.

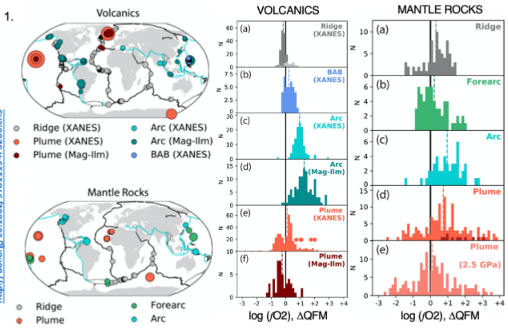

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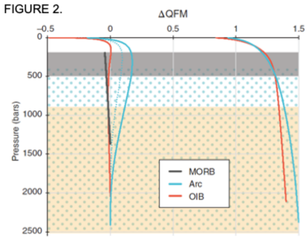
FIGURE 2.



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Progressive degassing of a C-O-H-S vapor in ridge, arc and plume settings using the gas-melt equilibrium model D-Compress of Burgisser et al. (2015). The OIB and arc scenarios were each run at QFM and near QFM+1.5 to demonstrate the impact of initial f_{O_2} on degassing trajectory. Orange, teal-stippled, and gray fields show melt inclusion entrapment (or hydrostatic) pressures for OIB, arc, and MORB. Thus, the "final" f_{O_2} for each model should inferred from the intersection of the model curve with the tectonic-setting-specific minimum pressure. Initial model conditions: MORB at QFM and 1385 bar with 0.2 wt% H2O, 1100 ppm C_{O_2}, and 1425 ppm S (increasing CO_2 to several thousand ppm has no effect on the trajectories shown); OIB at QFM+1.4 and 2115 bar with 1.5 wt% H_2O, 1710 ppm C_{O_2}, and 2430 ppm S; Arc at QFM+1.5 and 2380 bar with 4.5 wt% H_2O, 800 ppm CO_2, and 2050 ppm S. Full details are available in [1].