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Overcoming Scoria Bias in Arc Systems Through Spinel-Constrained, Path-Independent Restoration of Recrystallized Melt Inclusions

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Melt inclusions are widely used to infer volatile contents and primitive melt compositions in volcanic arcs, particularly in continental settings where primitive lavas are rarely erupted. Most studies preferentially target rapidly quenched scoria, which minimizes post-entrapment modification (PEM) and permits relatively direct analysis. However, mafic olivine-bearing scoria are uncommon eruptive products of long-lived, polygenetic stratovolcanoes, leading many studies to preferentially sample isolated monogenetic cones.

The reliance on melt inclusions from scoria cones can introduce geochemical bias into datasets. A comparison of whole-rock data from Chile, Western Mexico, and Central America shows that small monogenetic scoria cones are systematically distinct from adjacent stratovolcanoes, exhibiting lower slab-derived geochemical signatures that decrease with distance from major volcanic centers. These observations indicate that scoria cones are not necessarily representative of the mature arc systems that dominate volcanic flux.

This discrepancy motivates the development of approaches capable of recovering primary melt information from lava-hosted, often recrystallized melt inclusions erupted from arc stratovolcanoes. We present a spinel-constrained, path-independent correction framework that integrates recent advances in spinel thermometry, spinel oxybarometry, and Fe-speciation–based calibrations of Kd(Fe^T-Mg). Co-entrapped spinel provides independent constraints on temperature, oxygen fugacity, and Fe^{3+}/Fe^T, allowing an analytical solution for the restoration of inclusions with a unique solution for total PEM induced mass change. Because the solution is not path dependent, it avoids assumptions regarding the relative roles of olivine crystallization/dissolution and Fe–Mg diffusive exchange with the host crystal.

Coupled with a recalibrated olivine–melt hygrometer derived from expanded experimental datasets, this framework yields independent estimates of primary volatile contents. Application to high-Mg# lavas from the north flank of Mount Rainier demonstrates that extensively recrystallized inclusions modified by diffusive exchange can be effectively restored. The reconstructed inclusions preserve elevated CO_2 and (via hygrometry) H_2O contents and record entrapment conditions extending to Moho depths. These results show that representative primary arc magmas can be recovered from stratovolcano lavas, reducing reliance on scoria and providing a more direct view of volatile-rich melt generation in mature arc systems.