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Decoupling of Fe isotope and $Fe^{3+}/\Sigma Fe$ in arc igneous rocks Implications for sediment recycling and its contribution to mantle redox

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The redox state of subduction zones is pivotal for understanding the geochemical and geodynamic processes of Earth's interior. However, the mechanism behind high oxidation state of arc magmas remains controversial. The possible mechanism is indicated by a combination of Fe isotope and $Fe^{3+}/\Sigma Fe$ ratio for Early Triassic arc igneous from the West Qinling Orogen, China. The studied mafic igneous rocks display arc-type trace element characteristics and enriched Sr–Nd–Hf isotopes, suggesting that their mantle source was metasomatized by substantial sediment-derived hydrous melts, with minor slab-derived aqueous solutions. Additionally, these mafic igneous rocks exhibit lighter Fe isotopes ($\delta^{56}Fe$ = -0.05 to 0.09‰) compared to MORB (0.11 ± 0.06‰). While dehydration of subducting serpentinites at subarc depths can release isotopically light Fe fluids, the lack of co-variation between $\delta^{56}Fe$ and slab-fluid tracers (e.g., Ba/La, Th/Yb, Nd-Hf isotopes) suggests that an alternative mechanism, such as prior melt extraction, is more plausible. This process involves the preferential removal of isotopically heavy Fe^{3+}, leaving a reduced residue with lighter Fe and low $Fe^{3+}/\Sigma Fe$. However, this is inconsistent with the higher $Fe^{3+}/\Sigma Fe$ ratios (0.19–0.33) observed in the mafic igneous rocks compared to MORB (0.16 ± 0.01), leading to a significant decoupling of the $Fe^{3+}/\Sigma Fe$ ratio and $\delta^{56}Fe$ value. Notably, the strong correlations between $Fe^{3+}/\Sigma Fe$ values and sediment melt proxies (Th/Yb, Th/Nd, Th/La, and Hf isotopes) suggest that the addition of sediment melts plays a key role in controlling the high oxidation state of the subarc mantle. Accordingly, the decoupling of $Fe^{3+}/\Sigma Fe$ and $\delta^{56}Fe$ likely results from prior melt depletion of the mantle source, followed by slab fluid metasomatism dominated by sediment melts with high oxidant content (e.g., S^{6+}). Therefore, the observed decoupling of $Fe^{3+}/\Sigma Fe$ and $\delta^{56}Fe$ in arc magmas provides critical insights into the geodynamic controls on subarc mantle melting regimes, sediment recycling, and their effects on mantle oxidation states.