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Oxidized arc mantle revealed by partitioning of vanadium, titanium and scandium

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Oxidation state of the Earth‘s mantle, often expressed as oxygen fugacity (fO_2), represents the amount of oxygen available in the mantle. fO_2 governs valence state of multivalent elements (e.g. sulfur, carbon, iron and vanadium) and different species of those elements behave differently during magma generation, differentiation and subsequent degassing. Thus, by controlling valence state and geochemical behaviors of multivalent elements, fO_2 of Earth‘s mantle exerts significant effects on the formation of magmatic ore deposits and perhaps secular evolution of Earth‘s atmosphere.
Several approaches had been developed to estimate fO_2 of the upper mantle. One of the most widely used oxy-barometer, which based on the coexistence of olivine, orthopyroxene and spinel (ol-opx-sp oxy-barometer), had been well calibrated and employed to estimate fO_2 of the mantle xenolith and primitive magmas (1-3). In addition to mineral assemblages, Fe^{3+}/Fe_T ratio in silicate glass also had been used to estimate fO_2 of the melts (4). At last, the geochemical behavior of vanadium, which is redox sensitive, had also been used to track mantle fO_2 (5). Oxygen fugacity of the oceanic mantle obtained from different approaches are consistent with each other. However, whether the arc mantle is more oxidized than oceanic mantle remains an outstanding issue. Oxygen fugacity of the arc mantle estimated from ol-opx-sp oxy-barometer, as well as glass Fe3+/FeT ratio demonstrated that mantle wedge is ubiquitously higher in fO_2 than oceanic mantle. But recent study (5) argued that similar V/Sc ratio between MORBs and arc basalts indicate fO_2 similarity in their mantle sources. However, this viewpoint could be problematic since elemental ratios are mainly controlled by partition coefficients (D-values), which are further affected by various parameters. So far, except for fO_2, other effects (temperature, pressure, and phase compositions) on the DV values have not been clearly evaluated.
Here we conducted high temperature and pressure (HT-HP) experiments and determined partition coefficients of vanadium during mantle melting under various fO_2 conditions. In conjunction with published data, we evaluated the effects of fO_2, T, P and phase compositions on the vanadium partitioning by both experimental data and multiple linear regressions. The results indicate that, in addition to fO_2, temperature exerts a significant control on the vanadium partitioning. Since melting temperatures between arc mantle and oceanic mantle are quite different, we estimated fO_2 of the arc mantle via numerical models using pertinent DV values. Our results clarify and reconcile the discrepancy among previous studies and reveal that fO_2 of the arc mantle is generally $\sim$1 log unit high in fO_2 than that of oceanic mantle.

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