

Geochemical constraints on residual metal and sulfide in the sources of lunar mare basalts

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ABSTRACT

Low oxygen fugacity (f_{O_2}) in the lunar interior (one log unit below the iron-wüstite buffer [IW-1]) offers the possibility that stable Fe-metal and sulfide phases exist as restites within lunar mare basalt source regions. Metal and sulfide phases have high metal-melt and sulfide-melt partition coefficients for chalcophile, siderophile (>100), and highly siderophile elements ($>>100000$; HSE: Os, Ir, Ru, Rh, Pt, Pd, Re, Au). If these phases are residual after mare basalt extraction, they would be expected to retain significant quantities of these elements, likely generating non-chondritic HSE inter-element ratios, including Re/Os in the silicate magma. If such phases were present, then the estimated HSE abundances of the bulk silicate moon (BSM) would be proportionally higher than current estimates ($0.00023 \pm 2 \times$ CI chondrite), and perhaps closer to the bulk silicate earth (BSE) estimate ($0.009 \pm 2 \times$ CI chondrite). Here I show that relationships between elements of similar incompatibility but with siderophile (W), chalcophile (Cu), and lithophile tendencies (Th, U, Yb) do not deviate from expected trends generated by magmatic differentiation during cooling and crystallization of mare basalts. These results, combined with chondrite-relative HSE abundances and near-chondritic measured $^{187}\text{Os}/^{188}\text{Os}$ compositions of primitive high-MgO mare basalts, imply that lunar mantle melts were generated from residual metal- and sulfide-free sources, or experienced complete exhaustion of metal and sulfides during partial melt extraction. Evidence for the loss of moderately volatile elements during lunar formation and early differentiation indicates that the BSM is >4 to 10 times more depleted in S than BSE. Because of an S-depleted BSM, mare basalt melts are unlikely to have reached S saturation, even if sulfide concentration at sulfide saturation (SCSS) was lowered relative to terrestrial values due to low lunar f_{O_2} . In the absence of residual sulfide or metal, resultant partial melt models indicate that a lunar mantle source with 25 to 75 $\mu\text{g/g}$ S and high sulfide-melt partition coefficients can account for the chondritic-relative abundances of the HSE in mare basalts from a BSM that experienced $<0.02\%$ by mass of late accretion.

Keywords: Moon, siderophile elements, sulfide, metal, saturation, partial melting; Planetary Processes as Revealed by Sulfides and Chalcophile Elements