

Clues to the formation of the terrestrial planets from highly siderophile elements

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The highly siderophile elements (HSE) are normally strongly partitioned into metal relative to silicate. Yet the abundances of these elements estimated for Earth's primitive upper mantle (PUM) and the martian mantle are only about 200 times lower than those of chondrites. These abundances are considerably higher than would be expected from low P-T metal-silicate partitioning. In contrast, lunar basalts, volcanic glasses and highlands crust suggest that abundances in the lunar mantle may be more than twenty times lower than in the terrestrial PUM. The dominantly chondritic ¹⁸⁷Os/¹⁸⁸Os estimated for the terrestrial, lunar and martian mantles require that their time integrated Re/Os were also within the range of chondritic meteorites. Most HSE in the projected terrestrial PUM appear to be present in chondritic relative abundances, although Ru/Ir and Pd/Ir are slightly suprachondritic. Similarly suprachondritic Ru/Ir and Pd/Ir have also been reported for some lunar impact melt breccias that were created via large basin forming events. This could reflect a nebular signature outside of the range of known chondrites in the sources of the HSE.

Hypotheses to account for the absolute and relative abundances of HSE present in Earth's mantle include inefficient core formation, lowered metal-silicate D values resulting from metal segregation at elevated temperatures and pressures, and late accretion of materials with broadly chondritic bulk compositions after the cessation of core segregation. Synthesis of the large database now available for HSE in the terrestrial mantle, lunar samples, martian meteorites, and possible mantle samples from the HED parent body reveals that each of the main hypotheses has flaws. Although we favour continued accretion subsequent to the cessation of core segregation as the dominant process, other processes must also have had strong influences. Timing of the dominant contributions from late accretion remains poorly constrained. Whether genetic affinities for late accreted materials can be extracted from available rocks also remains to be seen.

Cu isotope systematics of the Butte Mining District, Montana

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We present for the first time Cu isotope values of waters and mineral specimens from the Butte Mining District, Butte, Montana. Our goal is to demonstrate the usefulness of Cu isotopes to determine sources of Cu in stream and ground waters and to assess the degree of Cu-sulfide weathering throughout the mining district.

We collected waters from the Berkeley Pit lake, monitoring wells near the lake, and stream samples from Silver Bow Creek and the Upper Clark Fork River downstream of the Butte mine. In addition, we collected Cu-sulfate salts from within the mine and on the flood plain 30 to 60 km downstream from Butte. Cu-bearing sulfide minerals were collected from within the active mine and from an archived collection of hand samples from the underground workings. The $\delta^{65}\text{Cu}$ values were measured using a Finnigan Neptune MC-ICP-MS. Isotope values have a 2σ error of 0.14‰.

Primary chalcocite (Cu_2S), chalcopyrite (CuFeS_2), and bornite (Cu_5FeS_4) samples from 700 to 1500 meters depth have $\delta^{65}\text{Cu}$ values that range from -0.30 to 0.37‰, whereas supergene chalcocite closer to the surface has values between 5.07 and 5.64‰. $\delta^{65}\text{Cu}$ values of Berkeley Pit waters and groundwater samples surrounding the pit lake range from 1.56 to 2.32‰. A stream water sample approximately 5 km downstream from the Berkeley Pit has a value of 1.22‰ and surficial Cu-salt samples from weathered mine tailings deposited along the stream approximately 30 km and 60 km below Butte have values of 0.40‰ and 0.32‰ respectively.

Applying published fractionation factors from previous studies to our isotope results, we conclude that the dominant source of aqueous Cu in the immediate mine district is from rapid oxidative weathering of primary sulfide minerals. The isotopic value of the water sample 5 km downstream from Butte may indicate Cu scavenging by sorption to Fe oxides. The source for Cu-rich salts in the flood plain is likely the highly weathered mine tailings deposits from which most of the isotopically heavy Cu (⁶⁵Cu) has been leached away.