Stable isotope evidence for planetesimal evaporation

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There is great interest in major-element stable isotope fractionation evidenced by comparing bulk Earth with various meteorite groups. In particular, Si and Mg in differentiated rocky bodies, and Fe in iron meteroties, exhibit heavy isotope enrichments compared with chondrite groups that have been attributed to evaporation of partially or entirely molten planetesimals. We evaluate the mechanisms of planetesimal evaporation in the early solar system and the conditions that controled attendant isotope fractionations.

Energy balance at the surface of a body accreted within 1.5 Myr of CAI formation and heated from within by ^{26}Al decay results in internal temperatures exceeding the silicate solidus, producing a transient magma ocean with a thin surface boundary layer of a few cm that would be subject to foundering. We consider evaporation of planetesimals too small to retain an indigenous vapor ($< ½\ M_{Pluto}$) but enveloped by H_2-rich gas of the protoplanetary disk as well as larger bodies ($> ½\ M_{Pluto}$) that retain hot rock vapor even in the absence of ambient nebular gas. In the latter case, a steady-state rock vapor forms within hours and results from a balance between rates of magma evaporation and Jeans escape.

We find that vapor pressure buildup adjacent the surface of the evaporating magmas would have led inevitably to near-equilibrium isotope partitioning between the vapor phase and the silicate melt. Numerical simulations of this near-equilibrium evaporation process show that for a steady-state far-field vapor pressure of 10^{-8} bar, the vapor pressure at the surface of an evaporating body with a radius of ~ 700 km is 10^{-4} bar, corresponding to 95% saturation.

We model the Si and Mg isotopic composition of bulk Earth as a consequence of accretion of planetesimals that evaporated subject to the conditions described above. Accounting for the small effects of Si in the core (~0.03 ‰ in $\delta^{29}Si$) and fractionation of olivine to form basalts (~ 0.02 ‰ in $\delta^{25}Mg$), our results show that the best fit to bulk Earth is for an ordinary or carbonaceous chondrite source material with about 10% loss of Mg and 15% loss of Si resulting from evaporation into protoplanetary disk H_2 on timescales of 10^4 years. Enstatite chondrite starting materials do not fit the combination of isotope ratios and mass losses evidenced by the bulk composition of Earth.