Experimental constraints on the evaporation of moderately volatile elements during planetary formation

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Moderately volatile elements (MVEs) condense between the major components (Fe, Si and Mg; ≈1300 K) and FeS (≈650 K), where condensation temperatures (T_c) are calculated for a gas of nebular composition at 10^{-4} bar [1]. The adundances of MVEs in chondritic meteorites vary as a smooth function of their T_c. However, MVE patterns in differentiated bodies, such as the Earth, are variably depleted and do not behave systematically with T_c [2]. This is because, unlike in chondrites, volatile depletion in planetary bodies may arise during or post-accretion by evaporation and collisional erosion. These processes occur at more oxidising conditions and at higher pressures to that of the solar nebula. Thus, T_c is inappropriate for understanding the behaviour and origin of moderately volatile elements in terrestrial planets.

In order to quantify element volatility under conditions relevant to planetary formation, we performed a series of experiments in 1 atm CO-CO_2 gas-mixing furnaces at oxygen fugacities (fO_2), bracketing that of planetary mantles, from logfO_2 = -10 (IW) to -0.7 (air). Time- and temperature series were conducted for 15 to 1000 minutes and 1300-1550°C, above the liquidus for a synthetic composition in the FCMAS system, to which ~15 MVEs, each at 1000 ppm, were added.

Refractory elements (*e.g.*, Ca, Sc, V, Zr, REE) are retained in the melt under all conditions. MVEs show highly redox-dependent volatility, where the extent of volatile loss as a function of fO_2 depends on the stoichiometry of the evaporation reaction; $M^xO_{x/2} = M^{x-n}O_{(x-n)/2} + n/4O_2$. Where *n* is positive (as in most cases), the element in the gas is more reduced than in the liquid, meaning lower oxygen fugacity promotes evaporation. Elemental volatility is fit at a given run duration to T and fO_2 to derive the enthalpy and entropy of vaporisation. These equations yield relative vapour pressures, (pM_1/pM_2), which can fingerprint the effect of evaporation in determining the MVE budgets of terrestrial bodies.

[1] Lodders (2003) *Astrophys.J., 591,* 1220-1247. [2] O'Neill & Palme (2008) *Phil.Trans.R.Soc., 366*, 4205-4238.