The inventory of high field strength elements in CAIs and its implications for short-lived chronometers

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Ca, Al-rich inclusions (CAIs) provide an important vestige of processes active during the initial stages of the solar system, when the first solid matter condensed. Typically, CAIs are enriched in refractory elements, and amongst these elements rare earth elements (REE) have commonly been used to classify CAIs and to investigate processes active during their formation. Here we report a comprehensive dataset for the refractory group of extended high field strength elements (HFSE, W-Mo-Nb-Ta-Zr-Hf) and for U-Th in 16 CAIs from CV3 chondrites. All elements except for Nb and Mo were measured at high precision by isotope dilution. Beyond adding new information on early condensation processes, the HFSE also include two important short-lived decay systems, namely ^{182}Hf-^{182}W and ^{92}Nb-^{92}Zr.

Our HFSE data reveal that the relative abundances of HFSE in CAIs are often not chondritic, similar as observed for REE. In particular group II CAIs exhibit strong depletions in Zr-Hf, and Mo and moderate depletions of W and Nb relative to Th or Ta. This is in marked contrast to thermodynamically predicted condensation temperatures [1]. We explain this discrepancy by prior condensation of ultra-refractory material (Zr-Hf), oxidation of metal phases (W-Mo) [2], and mineralogical control (Nb-Ta). Variable U/Th reflect U mobility during parent body or terrestrial alteration.

With respect to short-lived chronometers, our data indicate that the fractionated Hf-W and Zr-Nb found in some CAIs were already established by selective processing of metal and silicate components and multiple episodes of condensation during CAI formation. Both chronometers therefore provide reliable estimates of the initial abundances of ^{182}Hf and ^{92}Nb in the solar system. A subset of the CAIs with extreme Nb/Zr was therefore also analysed for Zr isotopes to obtain a direct estimate of the initial solar system abundance of extinct ^{92}Nb. The CAIs define a statistically significant isochron yielding an ^{92}Nb/^{93}Nb of $2.3\pm0.5*10^{-5}$. This value is slightly higher but still within error of a previous estimate based on basaltic achondrites [3].

[1] Lodders et al. (2003) *Astroph. Journ.* **591**, 1220-1247 [2] Fegley & Palme (1983) *Earth Planet. Sci Lett.* **439**, 172-181. [3] Iizuka et al. (2016) *Earth Planet. Sci Lett.* **72**, 172-181.