

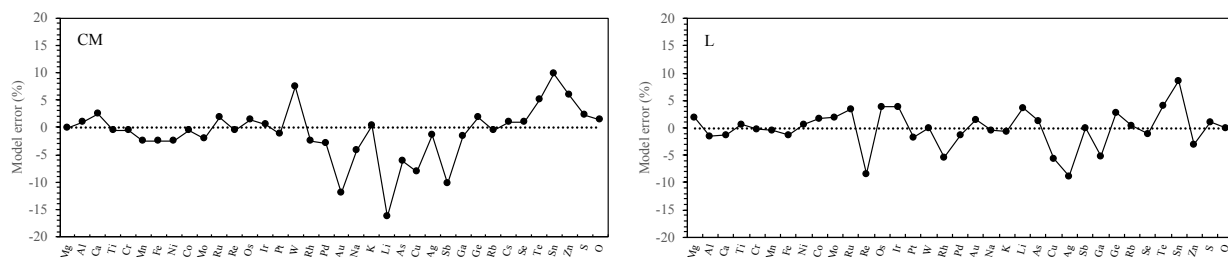
## QUANTITATIVE MODELING OF THE ELEMENTAL AND ISOTOPIC FRACTIONATIONS IN CHONDRITES

C. M.O'D. Alexander, DTM, Carnegie Institution of Washington, 5241 Broad Branch Road, Washington, DC 20015, USA (calexander@carnegiescience.edu).

**Introduction:** The chondrites accreted from the dust present in their formation regions. Hence, they provide snapshots of the dust evolution in the nebula in space and time. Key to understanding this evolution are the elemental and isotopic fractionations in chondrites. Qualitatively, the basic outlines of the elemental fractionations have been understood for many years. However, developing a quantitative understanding of the fractionations has taken on added urgency with the discovery of variations in bulk isotope anomalies in chondrites for many elements (e.g., O, Ca, Cr, Ti, Mo, Ru). These isotopic variations indicate that the chondrites formed from two or more isotopic reservoirs that may have been created by the formation of Jupiter's core [1, 2].

Here a model is described that is able to quantitatively account for most bulk elemental and isotopic features of chondrites. The model assumes that the compositions of chondrites have been shaped by four basic components that are common to each of the chondrite classes but may differ between classes: (1) Chondrules whose precursors were ultimately CI-like but at some stage lost material through volatile loss and Fe-Ni-metal fractionation; (2) refractory inclusions; (3) matrix with a CI-like composition; and (4) water. The CI-like material in matrix and chondrule precursors was assumed to be anhydrous, with all S in FeS and all remaining Fe in metal. With these assumptions, a best fit routine was applied separately to best estimates of the compositions of (i) the CC groups (excluding the CB/CHs and Tagish Lake), and (ii) the OC, RC and EC groups.

**Results:** The model is able to reproduce a broad spectrum of measured elemental abundances to within the as-



sumed  $1\sigma$  relative uncertainties; 3% for major elements, 5% for minor elements and 10% for trace elements. There appear to be no systematic deviations with condensation temperature or chemical affinity.

Volatility has played an important role in the formation of the CCs, with relative losses that are consistent with expectations from condensation calculations [3]. However, the major controls on the differences in elemental and isotopic compositions amongst the CCs are the relative abundances of refractory inclusions and matrix. The abundances of refractory inclusions control the levels of isotope anomalies in the bulk CCs, except for O where water was also important. In general, the inferred mean isotopic compositions of the inclusions is consistent with their reported compositions. The only exception is Cr whose inferred mean  $\epsilon^{54}\text{Cr} \approx -12$  is quite different from typical values of  $\epsilon^{54}\text{Cr} \approx 6-10$  for CAIs [4], but is required by negative correlations for bulk  $\epsilon^{54}\text{Cr}$  vs. Al/Si or  $\epsilon^{50}\text{Ti}$  [5]. This isotopically light Cr may be associated with ferromagnesian minerals in AOA or the accretionary rims of CAIs.

The OCs and RCs appear to form a coherent set, although the RCs accreted significantly more matrix and water. In some ways, the ELs share more in common with the OC-RCs than with the EHs. Nevertheless, in this preliminary modeling the ELs and EHs were assumed to be distinct from the other two classes. All three classes seem to have lost to varying degrees a similar refractory component that was distinct from the component gained by the CCs. However, fractionation of this component from CI cannot account for the isotopic variations amongst the non-CC groups. It seems likely that the non-CC groups evolved from a primordial material with CI-like elemental compositions but distinctly different isotopic compositions. Indeed, it is possible that the ECs and OC-RCs evolved from slightly different materials. The water accreted by the OC-RCs had a higher  $\Delta^{17}\text{O}$  and was less mass fractionated than that of the CCs. Water/matrix ratios in the OC-RCs were slightly lower than in the CCs, except the COs. The ratios of groups were much lower than one which is often cited for nebular dust with a solar composition [3]. However, this ratio of one assumes that all CO/CO<sub>2</sub> was converted to CH<sub>4</sub>, freeing up O to form water. Clearly this was not the case.

**References:** [1] Budde G. et al. (2016) *Earth and Planetary Science Letters*, 454:293-303. [2] Kruijer T.S. et al. (2017) *Proceedings of the National Academy of Science*, 114:6712-6716. [3] Lodders K. (2003) *The Astrophysical Journal*, 591:1220-1247. [4] Trinquier A. et al. (2009), *Science*, 324:374-376. [5] Warren P.H. (2011) *Earth and Planetary Science Letters*, 311:93-100.