**MODELING THE ELEMENTAL AND ISOTOPIC FRACTIONATIONS IN THE NON-CARBONACEOUS CHONDRITES.** C. M. O'D. Alexander[1], Dept. Terrestrial Magnetism, Carnegie Institution for Science, 5241 Broad Branch Road, Washington, DC 20015 (calexander@carnegiescience.edu).

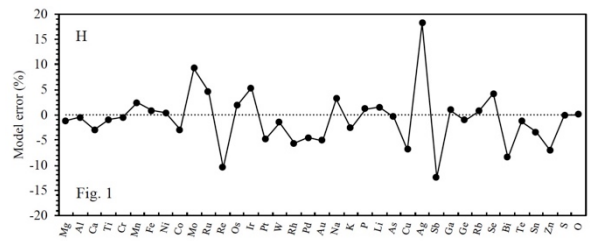
**Introduction:** The bulk compositions of the chondritic meteorites exhibit elemental and isotopic variations that may help identify important processes that were operating in the early Solar System. Recently, it has been suggested that the formation of Jupiter's core < 1 Ma after Solar System formation created a barrier that impeded 'communication' between the inner and outer Solar System, with the carbonaceous chondrites (CCs) having formed beyond the orbit of Jupiter and all other chondrites (non-CCs) having formed inside of it [1, 2]. Since the non-CCs formed in the inner Solar System, their fractionations may hold clues to understanding the bulk compositions of the terrestrial planets.

The basic features of the elemental fractionations amongst the chondrites have been understood for some time, but not quantitatively. The need for quantitative models has acquired greater urgency with the discovery of nucleosynthetic isotopic anomalies in bulk meteorites either produced by an unmixing of a homogeneous nebula or are evidence of a spatially and/or temporally more heterogeneous nebula than previously recognized [e.g., 2, 3, 4-8]. These nucleosynthetic anomalies are arguably the clearest evidence for a fundamental division between the CCs and non-CCs [9].

[10, 11] has proposed a quantitative model that successfully reproduces the elemental and isotopic fractionations amongst the CC groups. It involves variable fractionations of just four components: (1) A refractory component, CC-RI, responsible for the refractory enrichments and nucleosynthetic anomalies, (2) a chondrule or chondrule-precursor component that experienced some volatile and metal loss, (3) CI-like matrix, and (4) water. However, these CC components are not able to reproduce the fractionations amongst the non-CCs. Two non-CC models are explored by [12], only one of which is described here, but the qualities of both fits are similar.

**Samples and Methods:** A reduced $X^2$ fitting procedure was used to determine the minimum number of components that can explain all aspects of the bulk chemical and isotopic compositions of the non-CC groups. These components are: (1) An anhydrous and reduced (little FeO, etc.) material (NCC-CI) that is CI-like elementally but not isotopically. (2) Volatiles. (3) Refractory-siderophile-poor (M1) and -rich (M2) metal. (4) The Si-depleted NCC-RI component responsible for most refractory and volatile lithophiles fractionations. (5) Matrix with a NCC-CI composition that is primarily responsible for the contents of the most volatile elements used in the fits (e.g., S, Zn and Se). (6) Water that influenced both oxidation states and O isotopes.

**Results and Discussion:** Despite the components used oversimplify what are complex aggregates, the fit reproduces the bulk elemental compositions of the non-CCs to within the uncertainties (e.g., Fig. 1). The bulk com-




positions of the OCs and RCs can be explained by variable fractionations of the same components. They should, therefore, be considered as members of the same chondrite class. Slightly different compositions are needed for the NCC-RI, metal and volatile components that were fractionated from ECs. This not very surprising given the much more reduced nature of the ECs.

When and where the identified components formed is not certain. However, the need for two independent metal components with distinctly different compositions suggests that they formed prior to chondrule formation. Similarly, the compositions of the NCC-RI components do not resemble any recognized type of chondrule in the non-CCs, although the fact that they are enriched, relative to Si, in both refractory and moderately volatile lithophiles suggest that they may be composites of at least two distinct materials. Volatility, particularly for the lithophiles, played a much more minor role in shaping the compositions of the non-CCs compared to the CCs.

Unlike for the CCs, the chondrule compositions (NCC-CI minus volatiles, M1, M2 and NCC-RI) are predicted to vary somewhat. The model LL chondrule composition reproduces quite well the average major/trace element abundances for separated Semarkona chondrules taken from the literature, although predicted alkali abundances are slightly too high.

The NCC-CI reservoir from which the non-CCs evolved is not CI-like for its O, Ca, Ti, Ni and Cr isotopes. The necessity for invoking this is illustrated in Fig. 2. The CC compositions in Fig.2 can be explained

by the addition of the CC-RI component to CI. However, the non-CC $\varepsilon^{50}$Ti vs. Al/Si/CI trend is almost orthogonal to the CC trend and cannot be explained by subtraction of the CC-RI component from CI. Perhaps even more compelling is the fact that subtraction of the CC-RI component would increase the $\varepsilon^{54}$Cr rather than reduce it as the non-CCs require.

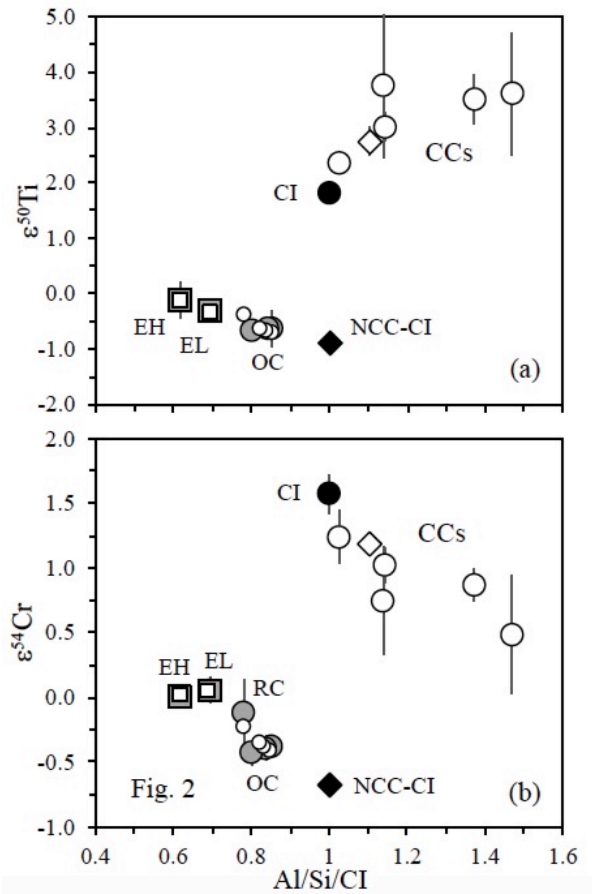
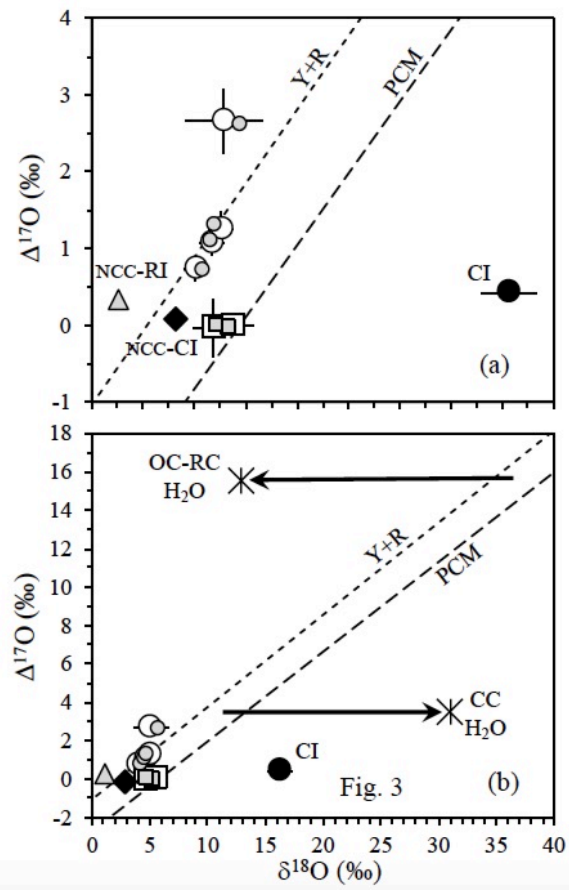



*Figure 2. The nucleosynthetic isotope anomalies in Ti and Cr vs. bulk Si- and CI-normalized bulk compositions of the CCs (large open symbols, except CI) and non-CCs (large shaded symbols). The small open symbols are the model non-CC compositions.*

The difference between the CCs and the non-CCs extends to the O isotopes of water. The inferred water composition of the water accreted by the non-CCs has a significantly higher $\Delta^{17}$O and is mass fractionated in the opposite direction, relative to the PCM and Y+R lines (Fig. 3). If $\Delta^{17}$O is a function of outer Solar System or presolar water fraction, this would imply, counterintuitively, that inner Solar System objects accreted more outer Solar System water than outer Solar System objects. However, the inferred $\Delta^{17}$O of the non-CC water is still much lower than that of cosmic symplectite in




Acfer 094 [13] that is often taken to be close to that of the outer Solar System or presolar water.

Whether the dichotomy between the CCs and non-CCs is due to the growth of Jupiter's core is beyond the scope of this study. However, the elemental and isotopic differences between the OC-RCs and ECs point to regional and/or temporal variations even with the inner Solar System. Nor is it clear that the components responsible for the fractionations amongst the non-CCs can account for the compositions of all the achondrites or the Earth, suggesting that there may have been even greater heterogeneity in the inner Solar System than recorded by the non-CCs.

**References:** [1] Kruijer T.S. et al. (2017) *PNAS, 114*, 6712-6716. [2] Budde G. et al. (2016) *EPSL, 454*, 293-303. [3] Trinquier A. et al. (2009) *Science, 324*, 374-376. [4] Qin L. et al. (2010) *GCA, 74*, 1122-1145. [5] Regelous M. et al. (2008) *EPSL, 272*, 330-338. [6] Fischer-Gödde M. et al. (2015) *GCA, 168*, 151-171. [7] Van Kooten E.M.M.E. et al. (2016) *PNAS 113*, 2011-2016. [8] Schiller M. et al. (2015) *GCA, 149*, 88-102. [9] Warren P.H. (2011) *EPSL 311*, 93-100. [10] Alexander C.M.O'D. (2019) *GCA* In press. [11] Alexander C.M.O'D. (2019) *LPSC, 50*, submitted. [12] Alexander C.M.O'D. (2019) *GCA,* In press. [13] Sakamoto N. et al. (2007) *Science, 317*, 231-233.