A CHONDRULE EARTH?

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Introduction: The chondrites formed at about the time when the embryo building blocks of the terrestrial building blocks would have been growing. As a result, it is generally assumed that the chondrites are representative of the building blocks' compositions, or at the least the elemental and isotopic fractionations amongst the chondrites provide clues to the processes that controlled the compositions of the terrestrial planets. Recently, it has been suggested that the dichotomy in the isotopic compositions of the non-carbonaceous (non-CC) and carbonaceous (CC) chondrites is a consequence of the formation of Jupiter isolating the inner (non-CC) from the outer (CC) Solar System. Since the Earth and Mars formed in the inner Solar System, it might be expected that they more closely resemble the non-CCs than the CCs. Indeed, the Earth is almost identical isotopically to the ECs. As a result, many researchers have suggested that the building blocks of the Earth were dominated by EC-like objects and/or their differentiated counterparts (aubrites). However, estimates of the Earth's lithophile element composition (i.e., little modified by core formation) more closely resembles those of the CCs. The mixed chemical and isotopic affinities of the Earth's composition is a conundrum that has yet to be resolved. To better understand the fractionations amongst the chondrites, quantitative models of the fractionations in the chondrites are briefly described, and how they might be used to reconcile the conflicting affinities of the Earth's elemental and isotopic compositions are discussed.

The models: While the chondrites were all modelled as mixtures of refractory material, chondrules, matrix and water, it proved necessary to treat the CCs and non-CCs separately. The average compositions of the components in the two models were determined by least squares fitting to the bulk compositions of the respective chondrite groups. The matrix was assumed to be anhydrous and reduced (i.e., its pre-alteration condition), but otherwise CI-like in its elemental composition. The chondrules or their precursors were also assumed to have formed from the same CI-like material, but were subject to loss of moderately volatile elements and metal without fractionating the common and refractory lithophiles. The Mg/Si and Al/Si ratios of the refractory components were fixed by where the two best fit lines to the CC and non-CC groups intersect an AOA-CAI mixing line.

The CCs were reproduced to within the uncertainties of their bulk compositions, with (i) the refractory component abundances controlling the refractory element enrichments and the nucleosynthetic anomalies, (ii) the chondrule abundances controlling the moderately volatile element and metal-silicate fractionations, and (iii) matrix controlling the abundances of elements with condensation temperatures below ~800 K. All components contributed to the bulk O isotopes. For the non-CCs, there is very little fractionation amongst the lithophiles, and this is reflected in the average compositions of the chondrules and the nominally refractory component (alkali/Al ratios, for instance, are not very different from CI. In addition, to reproduce the non-CC isotopic compositions, the CI-like material that made up the matrix in the non-CCs and from which their chondrules formed cannot have had CI-like or Earth-like nucleosynthetic isotope anomalies. The same is true for the non-CC refractory component.

Implications for Earth: Estimates of the bulk Earth composition have higher than CI Al/Si and depleted moderately volatile element fractions that correlate with their condensation temperatures. Any volatility trends amongst the siderophile and chalcophile elements have been obscured by core formation. Producing the enhanced Al/Si by enriching the proto-Earth in the non-CC refractory component would result in a composition with abundances of volatile lithophiles that are much too high. On the other hand, a combination of the CC chondrule and refractory components can reproduce the bulk Earth lithophile abundances remarkably well, especially if 2 wt.% of CI material is added to account for the highly volatile element budgets of the Earth.

However, the CC component model cannot explain the Earth's lithophile isotopic composition. Here it is suggested that the fractionations amongst the CCs, rather than the non-CCs, reflect the dominant processes acting in the early Solar System, including in the region where the Earth's building blocks formed. The CC vs. non-CC isotopic dichotomy demonstrates that there was spatial and/or temporal isotopic heterogeneity in or evolution of the nebula. It seems possible that because he Earth's precursors formed at a different time and place from the chondrites their isotopic compositions were also slightly different. Indeed, estimates suggest that there may have been a linear variation between ^{48}Ca, ^{50}Ti, Δ^{17}O and possibly ^{54}Cr in the nebula.