

The chemistry of isotopic anomalies

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Isotopic anomalies can give us direct insight into stellar nucleosynthesis. However, we are presented with a very biased view of nucleosynthetic inputs because of the differing chemical characteristics of the elements. We are in fact presented with isotopic anomalies primarily in the most volatile and most refractory of elements.

Noble gases are widely regarded as anomalous in almost every context of the solar system. Many components are apparent from many sources. Despite their lack of reactivity, the components have remained isolated through the formation of the solar system. While this is not surprising in the case of preservation in presolar grains, large abundance variations on Earth suggest preservation of a variety of components even on a planet that remains geologically active.

Isotopic anomalies in refractory inclusions are ubiquitous. Calcium and titanium anomalies can be especially large. However, their preservation in chemically and petrologically different objects suggests that a variety of different processes are active and care must be taken to isolate the relevant signatures. The most anomalous inclusions have REE abundances that are near chondritic suggesting that at least two refractory inventories are involved, one being a Ca-Ti-Al oxide, the other carrying heavier refractory elements in chondritic abundances. Fractionation of the REE according to volatility is a key parameter in the early solar system, and remains one of the outstanding issues in cosmochemistry. Inclusions carrying this chemical signature appear to show less variation in their isotopic components.

Oxygen is a special case in many ways. It exists in both volatile (e.g. CO) and refractory species (e.g. Al₂O₃) and so covers the entire condensation sequence. While isotopic anomalies are apparent in presolar oxide grains, the isotopic signature in the solar system is dominantly one of chemical fractionation that affected the abundance of the major isotope ¹⁶O. While molecular symmetry plays a role in the oxygen abundances of ozone in the stratosphere, such a scenario probably has a more limited role in the early solar system. Rather, a scenario based on photodissociation of CO is favoured whereby UV photons discriminate the isotopes with optical depth. The key ingredient for determining the processes responsible for oxygen isotope fractionation in the early solar system is the solar composition because it represents the initial state of the nebula.

Evidence for sulfur-rich fluids in the ancient angrite parent body

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Angrite meteorites (now totaling 12 specimens) have non-correlated relative abundances of elements of differing geochemical behavior [1]. Despite relative enrichment in refractory elements (e.g., Ca, Ti) and extreme depletion in moderately volatile elements (e.g., Na, K, Li, Rb, Cs, Mn, Ga), angrites are surprisingly *not* very depleted in highly volatile elements (e.g., S, Se, Br, Zn, Cd, In). Additionally, even though all angrites contain Fe metal, the recent discovery of ferric iron-bearing rhönite in NWA 4590 [2], coupled with lack of evidence for ferric iron-bearing silicates in metal-rich angrite NWA 2999, suggest that the redox state within the APB may be quite variable (perhaps from IW to IW+2). By analogy with the chemical and mineralogical features of terrestrial lithospheric mantle xenoliths (e.g., [3]), the chemical attributes of angrites likewise may imply interaction of primary angrite assemblages with subsequent migratory metasomatic fluids (but, unlike on Earth, anhydrous ones).

Elemental mass balance calculations for the phases within the symplectites and coronas prevalent in NWA 2999 [4, 5] indicate that Ti and Cr were mobile during the non-isochemical, solid-solid reactions responsible for formation of these disequilibrium microstructures. The relative abundance of accessory troilite (with metal) and the chalcophile element enrichment in angrites suggest that such metasomatism may have been facilitated by sulfur-rich fluids (perhaps rich in S-O or sulfide species). The vesicles and vugs prevalent in some angrites also dictate that a free vapor phase existed.

Oxygen isotopic compositions by laser fluorination for acid-washed samples of NWA 4801 are: $\delta^{17}\text{O} = 1.809, 1.823$; $\delta^{18}\text{O} = 3.595, 3.544$; $\Delta^{17}\text{O} = -0.082, -0.041$ per mil. These results extend $\delta^{18}\text{O}$ for analyzed angrites to lower values, giving a data array subparallel to the TFL (as for known planetary meteorites).

[1] Warren P. *et al.* (1995) *Antarctic Met.* **20**, 261-264

[2] Kuehner S. & Irving A. (2007) *Trans. AGU* **88**, P41A-

0219 [3] BVSP (1981) pp. 282-310. Pergamon [4] Irving A.

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