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Oxygen isotopic variation of asteroidal materials

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OXYGEN ISOTOPIC VARIATION OF ASTEROIDAL MATERIALS. I. A. Franchi, R. C. Greenwood, L. Baker and A. A. Morris Planetary and Space Sciences Research Institute, Open University, Walton Hall, Milton Keynes, MK7 6AA, United Kingdom. (Email: i.a.franchi@open.ac.uk)

Introduction: The vast meteorite collections now available reveal a fantastically diverse range of different rock types and minerals that originate from asteroids. This suite contains minerals that have existed prior to the formation of the Solar System, grains which formed from the gas and dust of the solar nebula and minerals that are the result of secondary process once these early formed grains, together with ices, had accreted onto planetisimals. As such these rocks and minerals record a large range in oxygen isotopic compositions, reflecting the location, sources and conditions of their formation. This offers an important tool in tracking the origin and evolution of asteroidal and planetary material. Differential incorporation of these components into the planetisimals has led to oxygen isotopic variations persisting at all scales, even measurable isotopic variations between a large number of asteroids and planets. As such, oxygen isotopic measurements are a useful tool in the determining the relationships between randomly collected and diverse meteorites. However, this is only possible as we develop our understanding of the isotopic variation within individual asteroids and the internal processes which modify the oxygen isotopic signatures.

Interstellar Grains: Interstellar oxide grains isolated from acid residues of primitive meteorites have oxygen isotopic enrichments/depletions of up to two orders of magnitude in ^{18}O and ^{17}O [1]. However, with an abundance of ≈ 0.01 ppm [e.g. 1] these can have no measurable effect on the macro isotopic variation observed in meteorites. More recently, in situ studies of matrix material in primitive chondrites has revealed higher abundances of oxides (up to 50 ppm) and interstellar silicates up to 130 ppm [2]. These higher abundances raise the possibility that some measurable differences at the macro scale could be the result of differential accretion of such grains, particularly if the original abundance was even higher – e.g. interplanetary dust grains contain up to 400 ppm pre-solar silicates [3].

Nebula Components: Primitive meteorites contain high temperature condensates from the solar nebula – CAIs, chondrules and mineral fragments. The earliest formed are the CAIs – with oxygen isotopic signatures enriched in ^{16}O by over 40‰ [4]. Chondrules, which formed slightly later than the CAIs, are the dominant component of many primitive chondritic meteorites. The oxygen isotopic signature

of chondrules from ordinary, enstatite and carbonaceous chondrites are all different [5] indicating distinct formation histories, spatially and/or temporally. It is clear that the oxygen isotopic signature of both CAIs and chondrules has been affected by secondary processes [e.g. 6,7]. Resolving the primary and secondary signatures is needed to understand the origin of these primitive components, particularly for chondrules where there is less consensus about the nature of their formation.

Asteroidal Processing: There is clear evidence of asteroidal processes affecting the primitive materials mentioned above. CM, CI and CR chondrites now contain large amounts of phyllosilicates, carbonates, salts, etc which have been produced by water-rock interaction. Such reactions re-distribute oxygen isotopic signatures and generate large isotopic fractionations, which can be used to determine the conditions at which these secondary minerals formed – providing key information about early asteroidal processes. Such work has led to the development of a number of models describing the oxygen isotopic systematics observed [e.g. 8,9] – but uncertainty persists about the fluid conditions during this process.

At higher temperatures, thermal metamorphism and melting lead to homogenization of oxygen isotopic heterogeneity – eventually generating well defined mass fractionation lines – such as those defined by the HED (possibly from Vesta) and angrite meteorites [10], martian, lunar and terrestrial samples. Where such processes are not sufficiently advanced (primitive achondrites) isotopic heterogeneity persists [e.g. 11,12] which can be used to define local areas of homogenisation (i.e. local reservoirs) and to track the onset of melting.

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