Magnesium and Silicon Isotopic Compositions of Individual Oxide Grains from a Murchison Acid Residue: A Search for Exotic Material

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Isotopically anomalous materials in carbonaceous chondrites contain a record of nucleosynthetic and chemical processing pre-dating solar system formation. Their preservation, in turn, constrains conditions in the early solar system leading to formation of meteorite hosts. Until recently, isotopic studies of these materials were restricted to multi-grain samples, enriched in anomalous components by selective dissolution techniques (e.g. [1,2]), identification of carrier phases often proving ambiguous.

We have commenced an ion probe study of individual grains from the Murchison meteorite, aiming to; (1) locate particles or inclusions whose constituent atoms are isotopically distinct from the solar composition, and (2) analyse these materials for correlated isotopic effects (in as many elements as grain sizes permit). We hope to be able to recover grain remnants for study by electron microscopy, in order to determine relations between anomalous inclusion phases and hosts crystallised in the solar system (c.f. [3]). Advantages of this approach, the possibility of observing spatial relations and correlated isotopic effects, are balanced by the limited amounts of material available for analysis in single grains.

Initial work has concentrated on Murchison HCl-HF-H_2O_2 residue CFOc [1]. CFOc contains large ^{13}C excesses associated with a Si-rich refractory phase [3], likely SiC [4,5]. Mg-Spinel, Cr-spinel and chromite grains (5-25μm) from the residue, dispersed on a sputter-cleaned Au foil mount, were analysed for Mg and Si isotopes with the PANURGE ion microprobe [6] at a mass resolving power of ≈3200, using a rastered 0.2-2 nA O_2^- primary beam. An 8μm field aperture restricted analyses to secondary ions originating in the grains, excluding contributions from adjacent material or the Au foil. Standards included terrestrial spinel (Mg), synthetic hibonite (Mg, Si) and pyrope (Si).

The Mg isotope composition of most CFOc spinel and chromite shows only limited isotopic fractionation, with F_{Mg} between 0 and 3‰/amu (Fig. 1). One spinel (analysed twice) contains isotopically light Mg with F_{Mg} = -6±2 ‰/amu. No evidence of non-linear effects was found, with $|\delta^{26}Mg| < 3‰$. In contrast to Mg, the Si isotope composition of CFOc grains is highly variable, with an apparent range in $F_{Si} \gtrsim 60‰$. Uncertainty over the host phase of Si requires caution in the interpretation of F_{Si}, given the possibility of systematic variations in $^{29}Si/^{28}Si$ due to instrumental effects. Most Si isotope analyses plot along the mass fractionation line in the 3-isotope diagram (Fig. 2) with $|\delta^{30}Si| < 20‰$, indicating that variation in Si is dominated by mass-dependent effects. (Note that the scale of Fig. 2 is compressed relative to Fig. 1.) Two grains, however, plot off the fractionation line with $|\delta^{30}Si| > 30‰$, suggesting the presence of non-linear effects in Si.

CFOc grains analysed contain Mg as a major element; Si is however, present at minor or trace levels. Analyses were made at $^{28}Si^+$ count rates of 10 - 10^3 s^{-1}, giving equivalent Si concentrations of ≈20 - 2000 ppm. Silicon appears inhomogeneously distributed in individual grains, as evidenced by large variations in $^{28}Si^+$ intensity during single analyses (Mg^+ remaining constant)

and secondary ion images of the sites of Si^+ emission. Si appears to be concentrated in ~0.1 - 1μm Si-rich inclusions within spinel and chromite, consistent with reports of SiC [3,4,5] and of a Si-O(-N) phase in similar residues [4,5]. A careful examination of subsets of data from individual analyses, corresponding to sputtering of Si-rich phases, suggests that the Si isotope composition of this material is highly anomalous. Effects are consistent with variation in either ^{28}Si or ^{29}Si at levels > ±30‰, and conform to the trends shown by Si-rich phases in Murray acid residues [7].

A comparison of Mg and Si isotope data obtained on the same grain show no firm evidence of correlated variations. Magnesium isotopic compositions are approximately normal for grains exhibiting extreme Si isotopic effects. This behaviour is distinct from the correlated isotope effects characteristic of Allende FUN inclusions [8] and may suggest a different origin for anomalous material observed in this study. If the variations in Si isotopes indicate the presence of exotic Si-rich micro-inclusions, Mg data identify host grains as normal solar material.

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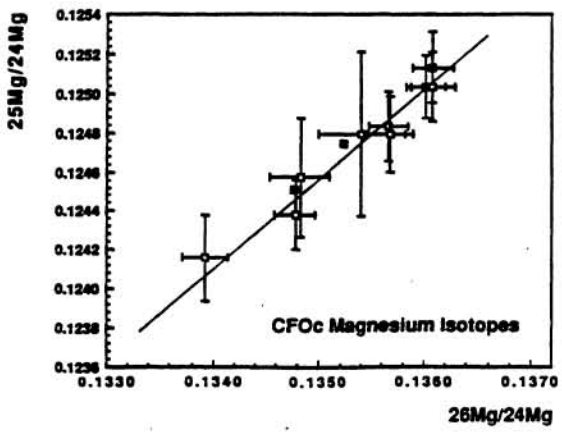

Fig. 1: Magnesium 3-isotope plot of CFOc analyses. Errors are 2σ. Standards plot between dark squares marked.

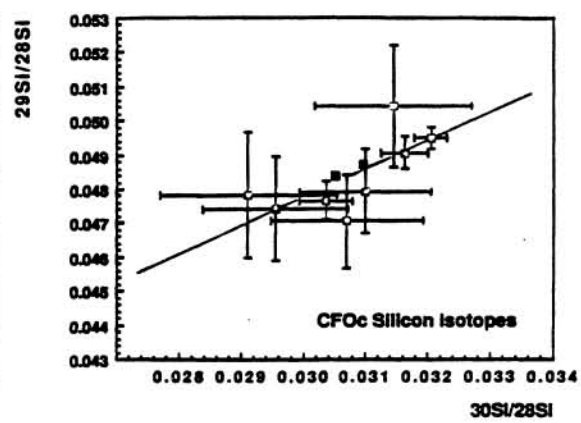

Fig. 2: Silicon 3-isotope plot of CFOc analyses. Errors are 2σ. Standards plot between dark squares marked. Note change of scale from Fig. 1.