MASS-DEPENDENT OXYGEN ISOTOPIC FRACTIONATION IN NON-FUN FORSTERITE-BEARING TYPE B CAIS.
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Introduction: Forsterite-bearing Type B CAIs (FoBs) are large but uncommon igneous inclusions that are characterized by heterogeneous textures and aluminum-rich outer mantles that in general cannot be related to the interiors by closed system fractional crystallization [e.g. 1-4]. Many have bulk mass-dependent isotopic fractionation in oxygen and magnesium [2], and three FUN FoBs (Allende CG-14, TE and Vigarano CAI 1623-5) [5-7] have been analyzed in detail isotopically using an ion microprobe (SIMS). We report here high precision SIMS oxygen isotopic data for four non-FUN FoBs (Vigarano 3137, Efremovka E64, and the Allende CAIs ALVIN and TS35 F1), all of which exhibit mass-dependent fractionation consistent with melt volatilization that continued during igneous crystallization. Oxygen isotope measurements of two other FoBs, Efremovka E60 and Leoville 3535-3b-F2, are in progress and will be reported at the meeting. The CAIs studied herein have been previously described and reported on by us and others; see [4] for refs.

Methods: All isotopic data were obtained using the University of Hawaii Cameca ims 1280 ion microprobe in multi-collector mode. A focused Cs^+ primary beam of 1.8 nA was used to presputter regions of 25×25 μm^2. The raster size was then reduced and oxygen isotopes were measured from the ~10×10 μm^2 central region. The ^{16}O and ^{18}O ion beams were measured at Mass Resolving Power (MRP) ~2000 using multicollector Faraday cups; ^{17}O was measured in monocollector mode using an electron multiplier (EM) with MRP ~5500. Instrumental mass fractionation (IMF) and mineral matrix effects were corrected by analyzing San Carlos olivine, Burma spinel, Miyakejima anorthite and Cr-augite. Melilite compositions were corrected by assuming their IMF are similar to those of olivine. Uncertainties (2σ errors) of ~1.5‰ in both $\delta^{17}O$ and $\delta^{18}O$ were estimated from overall standard data obtained during all sessions. Standards were analyzed repeatedly before and after each run.

Results: Data are shown in Fig. 1, relative to the terrestrial mass fractionation line (TFL) and the carbonaceous chondrite anhydrous mineral (CCAM) line. In all four inclusions, the oxygen isotopic compositions of all analyzed phases show small degrees of enrichment in ^{18}O relative to (plot to the ^{18}O-rich side of) the CCAM line.

Vigarano 3137. Spinel, pyroxene, and olivine all are ^{16}O-rich and cluster tightly along a slope-½ (mass dependent) line; olivine and spinel are consistently ^{18}O-depleted relative to pyroxene. There is no correlation between position of these phases in the inclusion (mantle *vs.* rim) and isotopic composition. All melilite is ^{16}O-depleted and plots along a slope-½ line just below the TFL. A single anorthite analysis is intermediate in ^{16}O composition between olivine-spinel-pyroxene and the melilite, as is a bulk analysis of 3137 done via conventional gas spectrometry by R. Clayton (unpublished).

Efremovka E64. Spinel, pyroxene, and olivine all are ^{16}O-rich and cluster tightly along a slope-½ (mass dependent) line; spinel and pyroxene are consistently ^{18}O-depleted relative to olivine. One pyroxene analysis plotting at elevated ^{17}O relative to the other pyroxene is believed to be contaminated with epoxy. A single melilite analysis is ^{16}O-depleted and plots on the CCAM line just below the TFL.

Allende "ALVIN". Spinel, pyroxene, and olivine all are ^{16}O-rich and cluster very tightly along a slope-½ line; there is no consistent pattern of relative ^{18}O-enrichment among the three phases. Anorthite and melilite are both ^{16}O-depleted and plot below the TFL.

Allende TS35 F1. Similar to ALVIN, the spinel, pyroxene, and olivine all are ^{16}O-rich and cluster very tightly along a slope-½ line with no consistent pattern of relative ^{18}O-enrichment among the three phases. Anorthite and melilite are both ^{16}O-depleted. Bulk data for this CAI (from [8], labeled in that work as AL6S3) plot intermediate to the spinel-pyroxene-olivine data and the melilite-anorthite data, with the outer rim ("r") fraction being ^{16}O-depleted relative to the inner core ("c") fraction.

Discussion: The consistent enrichment in heavy ^{18}O in these CAIs is consistent with the interpretation [2-4, 6] that FoBs underwent melt volatilization. However, the more refractory (Al-rich) mantles are not enriched in heavy isotopes relative to the core, meaning that although the mantles experienced greater degrees of melt volatilization, the melt remained isotopically equilibrated. The fact that melilite and anorthite are both similarly ^{16}O-poor whereas the other phases are all uniformly ^{16}O-rich indicates that the melilite and anorthite probably experienced isotopic exchange subsequent to the igneous volatilization event, either at low temperatures in the nebula or on the CV parent asteroid.

The degree of mass-dependent fractionation present in these four CAIs is dramatically less than that observed in the 3 FUN FoB inclusions: Vig 1623-5 [9], and Allende TE, and CG-14 [8]. Yet the mineralogy and bulk compositions of the latter CAIs are not different from those of the inclusions studied here. One suggestion [7] is that the fundamental difference between the FUN and non-FUN FoBs is due to the ambient gas pressure in the evaporation environment, with the non-FUN CAIs evaporating more rapidly at higher ambient pressure and experiencing isotopic back-reaction in contrast to the more slowly-evaporated FUN CAIs. Yet, the FUN inclusion Vigarano 1623-5 has a sharply-delineated mantle-core boundary that probably originated during flash-melting [6]. There also remains the problem [6] that FUN FoBs are less refractory than most normal (e.g. Type B) CAIs and yet show much higher degrees of isotopic fractionation. The precursor bulk compositions of the FUN FoBs would necessarily have been nearly dunitic, as indeed would those of the non-FUN FoBs, if only melt volatilization were responsible. An alternative explanation is that the fractionated isotopic compositions of the non-FUN FoBs do reflect the effects of melt volatilization whereas in the FUN FoBs those same small effects are superimposed on a fundamentally-different isotopic composition of the precursors. Both explanations are equally significant: either the FUN and non-FUN FoB contrasts provide a remarkable natural window for understanding melt volatilization under different conditions, or else they point to convergent CAI evolution in very different (and separate) isotopic reservoirs.

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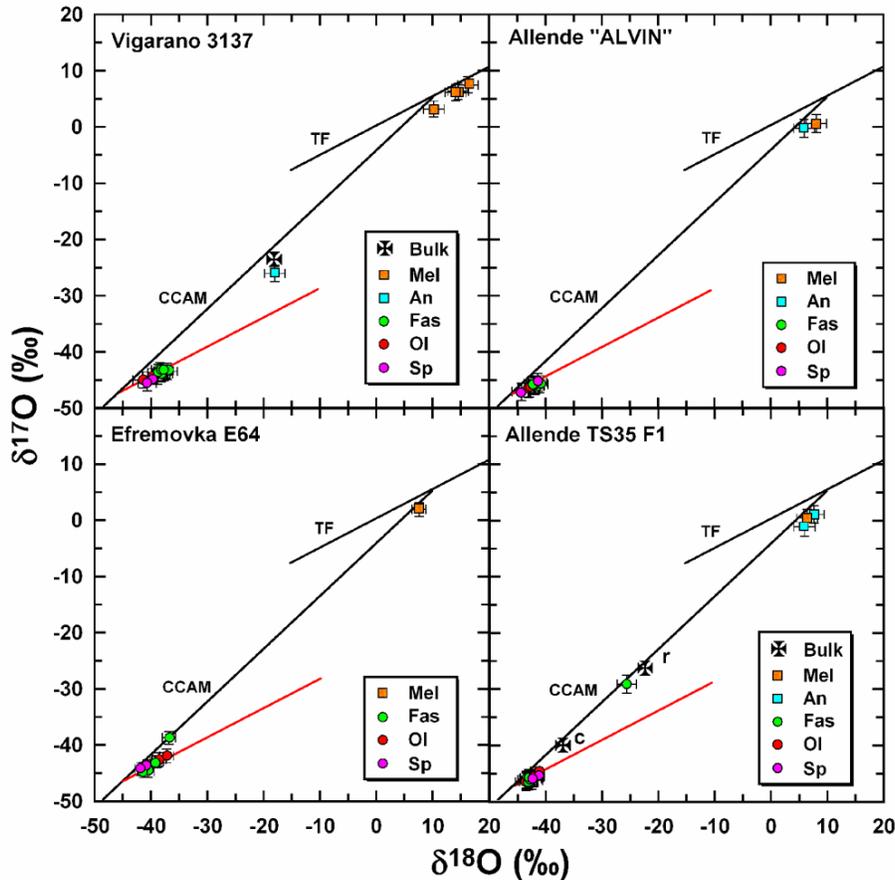

Fig. 1. Oxygen isotope data for four FoB CAIs. All error bars shown are 2σ. The bulk data shown for Vigarano 3137 and Allende TS35 F1 (c = bulk core, r = bulk rim) are from R. N. Clayton.