OXYGEN ISOTOPIC ANALYSIS OF ALLENDE OLIVINE BY ION MICROPROBE AND IMPLICATIONS FOR CHONDRULE ORIGIN.

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Introduction: Oxygen isotope systematics have shown that there are relationships within and among different classes of extraterrestrial samples. Most data have been obtained from bulk samples because of mg sample requirements to achieve a precision of about ±0.2 ‰. These bulk measurements preclude analysis of most individual mineral grains and therefore density separates must be used. In addition, grains within thin section and profiles within petrographic units are not possible. Oxygen isotope measurements using SIMS (1,2) require extraction of 20µm samples and subsequent pressing into a conductive metal to eliminate charging with consequent loss of petrographic relations. Lorin et al. (3,4,5) have analyzed minerals in polished samples of deep sea particles, Greenland micrometeorites and Ornans using low energy electron charge neutralization with 2σ errors of about ±2‰. Hervig et al. (6) have described a technique for oxygen isotope analysis of minerals in thin section which uses a high-energy electron flood gun to neutralize charge build-up on the sample. Interfering molecular ions are removed by collecting secondary ions ejected with >300 eV initial kinetic energy. Analysis of standards allows empirical corrections for instrumental mass fractionation as well as estimates of precision and accuracy. Precision is limited to about ±2 ‰ due both to counting errors for ^{17}O and instability of the secondary ion count rate beyond ~1.5 hour analysis times. This technique and initial results are described below.

Instrumental technique and data analysis: Mass fractionation occurs during SIMS analysis and is a function of element, sample and instrument. A series of olivines of known chemical and isotopic composition was analyzed to obtain an empirical correction factor for the compositional and instrumental mass fractionation effect on the known isotopic ratio. Five samples spanning an Mg/(Mg+Fe) ratio from 1.0 to 0.8 (atomic) were measured and the fractionation effects (per mil per amu): $F_{17} = -18.3 - 0.2(\mathrm{Fo\ mol\%})$ and $F_{18} = -29.2 - 0.4(\mathrm{Fo\ mol\%})$. Over the range of olivine compositions, the compositional effect is small relative to the counting errors.

Analysis of Allende olivines: One objective is to confirm the range of isotopic variation in random grains of forsterite. From a disaggregated Allende sample, 30 olivine grains from 50 to 200 microns in size as well as one standard olivine (San Carlos) were mounted in epoxy, and polished. Each grain was documented using BSE and CL imaging and qualitative EDS to recognize nearly pure forsterite previously shown to have ^{16}O enriched oxygen (2), relative to most Fe-rich olivine, bulk Allende and most chondrules. Because this is a reconnaissance study, we are most interested in obtaining data for a variety of grains as well as multiple analyses on individual grains. Of eight grains analyzed (see Table), six included forsterite and two were relatively Fe-rich (Fo<99 mol%). Each point for which data are entered in the Table was examined using the electron probe and any inhomogeneity is indicated by a 'v' (variable); other points are indicated by 'h' (homogeneous). The table provides the observed data after correction for mass fractionation. The corrected data points for 8 forsterite grains are shown on a standard 3-isotope plot (Figure). Shown schematically are bulk data for chondrules from both ordinary (7) and carbonaceous chondrites (8), a bulk Allende datum, and average data for three forsterite grains given in (2), and average values for the 'homogeneous' forsterite points and Fe-rich points. One sigma errors are approximately ±2‰ for all data as indicated by error bars.

It is clear that some data do fall more than 2 sigma from the mixing line and that some grains with multiple analyses (eg #1) show more scatter than others (eg #6, 8). This may indicate inhomogeneities within grains possibly due to incomplete exchange of oxygen with a surrounding reservoir. Data with variable Fe (open symbols) are not included in the discussion although plotted on the Figure. Significant points are: 1) the average of all data for the homogeneous forsterite (low-Fe) points is on the 1:1 mixing line, is identical to data of (2), and is more ^{16}O rich than the range of chondrules from carbonaceous chondrites; 2) there is an apparent separation of analyses which are Fe-poor (i.e. Fo<1.0 mol%) and show high ^{16}O from other more Fe-rich grains although the latter are poorly represented; 3) the average of the low-Fe data (δ17 = -8.9; δ18 =-6.6) is very similar to that of three grains reported in (2) suggesting that this is a constant value for Allende forsterite. The oxygen composition as well as the trace element content (10) characterize this forsterite as unusual.

Implication for oxygen composition of chondrules: Chondrules have been shown: 1) to be mixtures of several components (9) one of which is olivine-rich, FeO-poor (for chondrules of OC), 2) to contain relic grains of forsterite (e.g. 10), 3) to have a negative correlation between ^{16}O and FeO content (7). For the three forsterite grains (2) and those analyzed here, oxygen is isotopically light with an average $\delta^{18}O$ value of ~ -5.0 which is close to the extreme value observed for CC chondrules (about -3.5). We propose that isotopically light forsterite satisfies chemical and isotopic constraints and represents an observed precursor component the amount of which is a main control of the oxygen isotopic composition of ferromagnesian chondrules. A critical test will be the analysis of relic forsterite and in-situ crystallized olivine in a single chondrule. It is expected that the difference in $\delta^{18}O$ will reflect the Mg (hence forsterite) composition of the chondrule.

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TABLE. Oxygen - Allende Olivine

Point		δ17	δ18	Fo(mol %)	
A1	-1	-2.3	-8.7	0.33	h
	-2	-12.7	-4.9	0.28	h
	-3	-3.8	-5.3	0.31	h
A2	-1	-5.0	-9.1	0.41	h
A3	-1	-10.2	-4.5	0.49	h
	-2	-8.8	-5.4	3.6	v
	-3	-8.4	-8.4	5.2	v
	-6	-6.5	-10.1	1.0	v
	-7	-10.9	-12.0	0.38	h
A4	-1	2.7	5.5	14.0	h
	-2	0.6	-2.1	14.3	h
A5	-1	-2.6	-3.8	4.7	v
	-2	-9.4	-19.9	3.8	v
	-3	-8.9	0.9	0.34	h
	-4	-12.0	0.1	3.5	v
A6	-1	-10.5	-8.5	0.19	h
	-2	-6.0	-0.5	1.8	v
	-3	-12.0	-8.7	0.20	h
	-4	-13.9	-9.8	0.28	h
	-5	-6.2	-5.0	0.24	h
	-6	-9.8	-7.2	0.23	h
	-7	-9.8	-6.1	0.28	h
	-8	-5.0	-4.7	0.26	h
A7	-1	-9.0	-1.2	10.2	h
	-2	-9.2	-1.1	6.7	h
	-6	-5.5	-3.3	3.0	v
A8	-1	-9.8	-5.9	0.45	h
	-2	-13.5	-10.8	0.44	h
	-3	-9.8	-6.1	0.38	h
	-4	-6.2	1.5	0.42	h

Figure: Data of Table plotted relative to that of bulk chondrules from Ordinary (OC) and carbonaceous (CC) chondrites. Stippled symbols represent analyses of low-Fe olivine from homogeneous points, open symbols from variable Fe, solid symbols from Fe-rich points. The averages for low-Fe and hi-Fe homogeneous points are indicated.