OXYGEN-ISOTOPIC COMPOSITIONS OF INDIVIDUAL FORSTERITIC GRAINS, FAYALITIC RIMS, AND MATRIX OLIVINES FROM THE ALLENDE METEORITE

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Olivine is the most common mineral in type 2 and 3 carbonaceous chondrites. Two varieties of olivine occur in the Allende CV3 chondrite: (a) iron-rich matrix olivine (40-50 mole % Fa), 10 - 30 μm in size, and (b) iron-poor olivine (0-15 mole % Fa), found as individual grains in the matrix and within chondrules and CAIs. The latter are usually surrounded by fayalitic rims and many grains are intersected by fayalitic veins (1-3). Some forsterite grains also contain fayalitic halos around metal and sulfide inclusions (2, 3). The formation of the fayalitic rims, veins and halos is a subject of controversial debates (1-5). Housley & Cirlin (4) and Housley (5) proposed a planetary metamorphic origin, e.g. by the reaction of enstatite and metal. Petrologic evidence against such an origin was presented by several investigators (1-3), who suggested that the formation of rims and veins occurred by nebular condensation. According to thermodynamic calculations by Palme & Fegley (6), this requires high temperatures (~1100K) and higher-than-solar oxygen fugacities. A further problem is the origin of individual forsteritic grains embedded in the Allende matrix. Steele (7) argued that most of these olivine grains, except for a few showing cathodoluminescence, are fragments of broken chondrules.

In order to shed more light on the formation of fayalite-rich rims and the relationship between rim and matrix olivines we have measured the oxygen-isotopic compositions of individual Allende olivine grains by ion microprobe mass spectrometry (Cameca IMS 3F). Experimental details of the analytical technique are described by McKeegan (8). Burma Spinel was used as an isotopic standard. Although isotopic mass fractionation between spinel and olivine has not yet been checked, the influence on the results is believed to be small and would only lead to a shift along a mass-dependent fractionation line. The measured samples include fragments from the forsteritic core and the fayalitic rim (8-10 μm thickness) of a large olivine grain (about 250 μm diameter). The innermost part of the grain shows cathodoluminescence with a sharp texture. Portions of the core and rim were excavated from a polished thin section and gently crushed between quartz disks. The resulting fragments were mounted on a gold foil and checked for FeO-content by SEM-EDX analysis. In addition, single olivine grains from the neighboring matrix (with typical sizes of 8-15 μm) were also mounted for isotopic analysis.

The results of the measurements on forsteritic core and fayalitic rim are shown in Fig. 1. Plotted are individual measurements on olivine fragments with less than 8 wt.% FeO ("Forsteritic Core") and more than 20 wt.% FeO ("Fayalitic Rim"). Measurements on individual Burma Spinel grains (nominal composition: $\delta^{17}O_{SMOW}$ = 11.6 ‰; $\delta^{18}O_{SMOW}$ = 22.3 ‰) are also displayed; the average was used to normalize the olivine data. As do the Burma Spinel data, measurements on olivine fragments scatter considerably. However, the two populations are displaced from each other and the mean compositions lie on the "^{16}O-rich mixing line" with the forsteritic core being distinctly more enriched in ^{16}O. The mean values and errors ($1\sigma_{mean}$) for the forsteritic core are $\delta^{17}O_{SMOW} = -11.15 \pm 0.73$ ‰ and $\delta^{18}O_{SMOW} = -7.77 \pm 1.41$ ‰, and for the fayalitic rim $\delta^{17}O_{SMOW} = -2.32 \pm 1.55$ ‰ and $\delta^{18}O_{SMOW} = 0.87 \pm 1.74$ ‰. Fig. 2 shows measurements on individual matrix olivines. Most of them lie in the vicinity of the fayalitic rim. However, a few grains show much larger ^{16}O-enrichments, exceeding even that of the forsteritic core. Repeat measurements were made on the most ^{16}O-rich grains (data points with error bars in Fig. 2).

These results may be interpreted in the following manner:

(a) The oxygen-isotopic pattern of the forsteritic core and the fayalitic rim is most likely the result of partial equilibration of an originally ^{16}O-rich olivine with an isotopically normal oxygen reservoir. Unfortunately, it cannot be determined whether this event was associated with the rim formation or occurred after the rim was in place.

(b) The variation of the oxygen-isotopic composition of Fe-rich matrix olivine grains is evidence that not all of them have experienced the same history. At least some must have formed in an ^{16}O-rich environment. The isotopically more normal matrix olivine grains could either received their isotopic compositions at their formation, or had originally been ^{16}O-rich and underwent an equilibration process with a isotopically normal reservoir. In the latter case, this equilibration could not have occurred after accretion of the matrix, because this would have led to more uniform isotopic compositions of the matrix olivines.

(c) The measured forsterite grain is more enriched in ^{16}O than bulk chondrules (9). However, this difference cannot serve as an argument against a chondrule origin since it is not known whether individual relict grains found in chondrules are more enriched in ^{16}O than the bulk chondrules. Still, it is likely that the analyzed grain did not originate in a chondrule because of its sharp cathodoluminescence texture (7).

Ref.: (1) Peck J. & Wood J.A. (1987), GCA, **51**, 1503. (2) Hua X. et al. (1988), GCA, **52**, 1389. (3) Weinbruch S. et al. (1988), LPS XIX, 1255. (4) Housley R.M. & Cirlin E.H. (1983), In Chondrules and their origins, 145. (5) Housley R.M. (1986), LPS XVII, 364. (6) Palme H. & Fegley B. (1987), LPS XVIII, 754. (7) Steele I.M. (1988), In Meteorites and the early solar system, 808. (8) McKeegan K.D. (1987), Science, **237**, 1468. (9) Clayton R.N. et al. (1983), In Chondrules and their origins, 37.

Figure 1

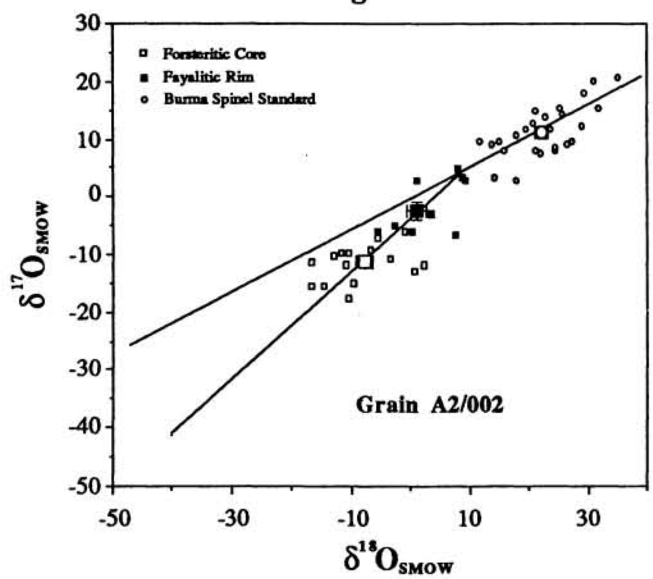

Figure 2