FAYALITIC OLIVINE IN ALLENDE MATRIX: EVIDENCE FOR A SECONDARY ORIGIN. L. E. Watt[1,2], P. A. Bland[1], D. J. Prior[3] and S. S. Russell[2], [1]IARC, Department of Earth Science and Engineering, Royal School of Mines, Exhibition Road, Imperial College, South Kensington Campus, London, SW7 2AZ, UK (lauren.watt@imperial.ac.uk), [2]Department of Mineralogy, Natural History Museum, London, SW7 5BD, UK, [3]Department of Earth & Ocean Sciences, University of Liverpool, Brownlow Street, Liverpool, L69 3GP, UK.

Introduction: Fayalitic olivine is the major matrix component in type 3 carbonaceous chondrites and other unequilibrated chondrites [1]. However, the origins of fayalitic olivine are a matter of continuing debate, with a variety of models being proposed from nebular [2-6] to secondary asteroidal origins [7-11].

Previous work by Bland et al. [12], using electron backscatter diffraction (EBSD) to look at fabrics in the matrix of chondrites, noted a short a-axis crystal morphology for fayalitic olivine in Allende matrix. Further investigation has revealed that this is atypical for both terrestrial [13-15] and chondrule olivines [16], which exhibit a short b-axis. This raises the possibility that crystal morphology may be a probe of formation mechanism. In order to help constrain the origin of fayalite, we have used EBSD to determine and compare crystal morphological data for olivine formed in a range of different environments.

Experimental Methodology: EBSD is a scanning electron microscopy technique, in backscatter electron (BSE) mode, which permits the measurement of the full crystallographic structure and orientation at any point [17]. BSEs that escape from the specimen will form a diffraction pattern that can be imaged on a phosphor screen. Crystallographic orientations are obtained by automatically indexing these diffraction patterns, which are unique for any given phase. Samples were analyzed in a CamScan X500 crystal probe fitted with a thermionic field emission gun [18]. They were mapped by beam movement on a grid with a fixed step of 0.2 µm, to ensure that each (sub) grain contains several measurement points [18]. The stored EBSD patterns were indexed using the program CHANNEL 5.1 from HKL technology.

Results: We obtained EBSD data for fayalitic olivine in the matrix of the Allende CV3 chondrite; olivines from experimentally dehydrated serpentinite; a fayalitic margin surrounding a porphyritic, forsteritic olivine bearing chondrule; and matrix olivines from the unique carbonaceous chondrite, Acfer094, which is considered to have a primitive matrix component, containing refractory olivine formed by condensation [19].

1. Fayalitic olivine in Allende matrix. Allende matrix is dominated by fayalitic (Fa_{38-56}) olivine plates, mostly 1-5 µm in size, with some up to 20 µm [6]. Several thousand (~35,000) of these fayalitic olivine grains have been indexed and mapped using EBSD to visualize fabrics in this meteorite [16]. These data consistently show short a-axis crystal morphology.

2. Olivine from experimentally dehydrated serpentinite. Experimentally dehydrated serpentinite samples, which have undergone heating to 700°C, were donated by Tenthorey & Cox [20]. Their experiment resulted in the complete antigorite breakdown to forsteritic olivine and talc [20]. We conducted EBSD analysis on several hundred of these experimentally generated olivine grains and these data also consistently show short a-axis crystal morphology.

3. Olivine from fayalitic margin surrounding a porphyritic, forsteritic chondrule. Imaging of this fayalitic margin, using SEM & EBSD, revealed that the large (<50 µm to 0.3 cm), sub-rounded, forsteritic olivine grains in the centre of the chondrule become lath-shaped and much finer grained (2-10 µm width; 5-20 µm length) as you move into the fayalitic margin. This area also shows a substantial increase in porosity. EBSD analysis revealed short b-axis crystal morphology for the forsteritic chondrule olivines, and short a-axis morphology for the fayalitic olivines at the margin.

4. Olivine from the matrix of Acfer094. The matrix component of Acfer094 is unlike that of Allende. It is dominated by amorphous material (20-80%), which encloses tiny anhedral forsteritic (Fa_{0-2}) olivines (200-300 nm; ~30 vol%), pyroxenes (300-400 nm; ~20 vol%), and Fe, Ni-sulphides (100-300 nm; ~5 vol%). Larger subhedral-euhedral forsteritic olivine (Fa_{0-2}) and pyroxene grains, up to 2 µm in size, are also present, but rare [19]. It is these larger olivine grains that are resolvable and have been indexed using EBSD. Because such grains are rare, fewer have been analyzed than for Allende and the dehydrated serpentinite sample - approximately 50 grains in total. These data reveal a variety of crystal morphologies, with examples of a, b and c short-axis being observed. In many cases the crystal morphology is poorly defined and difficult to depict.

Discussion & Conclusions: Short a-axis crystal morphology for olivines in the matrix of Allende contrasts with terrestrial and chondrule olivine morphologies, which both have a short b-axis.

Allende matrix olivines have a typical composition of ~Fa_{38-56} [6], however, terrestrial olivines (for which we have found crystal morphological data for) and Allende chondrule olivines are somewhat more magnesian rich (Fa0-Fa22 [13, 15] and Fa3.6-Fa7.6 [21-23], respectively). Therefore, one possible explanation for the contrasting olivine morphologies may be the relationship between olivine composition and crystal morphology. However, the presence of short a-axis crystal morphologies for the olivines in the dehydrated serpentinite samples, which are almost pure forsterite, would suggest this is not the case. Additionally, we can test this by analyzing more ferrous chondrule olivines from other primitive meteorites.

Both terrestrial and chondrule olivines are formed by crystallization from a melt and have a short b-axis crystal morphology. It has been suggested [2-6] that Allende matrix olivines are nebular condensates, and thus, it is possible that their short a-axis crystal morphology may be a characteristic of such materials. However, analysis of primitive olivines in Acfer094 reveals an inconsistent crystal morphology for these olivines, suggesting that the crystals are poorly developed. A well developed short a-axis does not appear to be a characteristic of primitive, condensed silicates.

Alternatively, it has been proposed [7-11] that fayalitic olivine in CV matrix is the product of aqueous alteration and dehydration on the parent asteroid. The occurrence of short a-axis crystal morphology in both Allende matrix and experimentally dehydrated serpentinite olivines would support this interpretation. The presence of a change in crystal morphology, from short b-axis in the forsteritic chondrule core, to short a-axis in the fayalitic chondrule margin, would therefore suggest that the fayalitic margin may have been generated during an aqueous alteration and dehydration process, causing short b-axis olivine to be replaced with short a-axis, secondary olivines.

It is unclear what causes the development of a short a-axis in olivine when it is produced through dehydration of serpentinite. However, Brindley & Zussman [24] discuss an oriented breakdown of serpentinite to olivine, during dehydration. In their experiments, during the serpentinite-olivine transformation process, olivine always grows along the basal plane of serpentinite, with the a-axis remaining perpendicular to the basal plane and the b- and c-axes remaining parallel to it. Thus, it is likely that the olivine crystals are restricted in growth along the a-axis. This may be due to rapid growth along the b & c-axes causing limited growth along the a-axis, or because a-axis growth is inhibited by the serpentinite crystal structure.

While we believe these data provide an argument for a secondary origin for fayalitic olivine in the matrix of Allende and other CV3s, they have no implications on the location of aqueous alteration and dehydration. This may be a parent body process [11, 25], nebular process [1, 26-29], or a combination of both.

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