OLIVINE ZONING AS FUNCTION OF CRYSTALLOGRAPHIC ORIENTATION; IMPLICATIONS FOR DIFFUSION IN OLIVINE. Ian M. Steele, Department of Geophysical Sciences, 5734 S. Ellis Ave., Chicago, IL 60637.

Nearly pure single crystals of forsterite (0.25 < 100*Mg/(Mg+Fe) < 0.75, atomic) are rather common in primitive meteorites (eq. 1). Within the C3 meteorites, these forsterite grains show chemical zoning at their boundaries with the most Fe-rich outer edge commonly showing Fe = Mg (1-3). The forsterite grains are of particular interest as they are enriched in refractory minor elements indicating an unusual origin. In addition, these grains are 16O rich (δ18O = -6.6) relative to the bulk meteorite and chondrules (4,5) indicating a different environment of formation. The chemical zoning is continuous and must have formed prior to incorporation of the grain within the present meteorite matrix.

The zoning may have formed during growth in response to a changing reservoir, or by subsequent modification of a homogeneous forsterite by diffusion, or by a combination. Both mechanisms have been described for zoning profiles in Allende forsterite (3,5). One possible means of distinguishing between these processes is to examine the anisotropy in the zoning. Diffusion rates for cations in olivine are known to be greatest parallel to the c crystallographic direction and least in the b direction (7). By measuring the profiles with respect to orientation this anisotropy can be verified and if consistent with relative diffusion rates, the two profiles together with measured diffusion coefficients, assumed temperatures and oxidation states can be used to estimate times for profile formation. Only zoning profiles in nearly pure forsterite single crystals are considered in contrast to other studies which have concentrated on chondrules (6), Fe-rich olivine grains(3), or fine-grained olivine.

**Data:** Allende contains common single crystals of forsterite which have Fe<0.5 wt%. Many grains are fractured or have fractures partially filled by secondary olivine or other phases. Chemical zoning profiles for many of these grains have been determined, but no grain has a known crystallographic orientation. From a freeze-thaw sample of Allende, a single, large euhedral grain of forsterite was obtained. This grain was mounted with [100] direction perpendicular to the plane of a section and polished to remove approximately half of the thickness. Optical examination confirmed that the section did expose the b and c directions and BSE examination showed clear zoning. Three zoning profiles were obtained in the [010], [001], and −[011] at 2μm step intervals for Fe, Ca, Ti, V, Cr, Mn, Sc and Ni with detection limits near 50ppm for each. The Sc and Ni concentrations are too low to warrant discussion.

**Results:** Although the scan length was 90 microns, no chemical variation was apparent for Fe, Cr, Mn, and Ca beyond 22 μm from the grain edge and profiles from 32 to 90 μm (near the grain center) were flat. Profiles for Ti and Al showed several correlated discontinuities and spikes probably due to micro inclusions (8). Profiles for all elements showed the greatest changes for profiles along c and all profiles except for Cr were increasing or decreasing monotonically from the edge inward. The profile for Cr showed complex shape which depends on scan direction.

The width of zoning is similar to that observed in many forsterites and from several meteorites including Allende and Ornans. The overall similarities of forsterite composition, texture, and rim thickness are evidence that these grains formed by a common process, were exposed to an environment in which Fe-rich rims formed followed by incorporation into their respective meteorites. The details of the rim profiles should permit estimates of the time span and mechanism of formation.

Each element is discussed below with reference to the five figures.

**A. Iron:** The profile for Fe clearly shows a difference between c and b directions with the c-axis profile extending for 32 μm and the b-axis profile only 12 μm with the 45° profile intermediate. Qualitatively, this difference is expected for a diffusion controlled process. Assuming diffusion as the cause of the zoning, a diffusion time can be calculated using experimentally measured diffusion coefficients (7) for an assumed temperature and pH applied to the Fe profiles. For a D coefficient at 1100°C, pH = 10^-14 and half concentration distances of 7 and 10 μm for b and c axis profiles, respectively, a formation time of about 4 days is obtained for each profile.

**B. Manganese:** Profiles mimic those of Fe but with greater scatter due to the much lower concentration.

**C. Chromium:** Many published profiles, but not all, for Cr show a bump in concentration within the zoned
The three profiles in the Cr figure clearly show that this bump is dependent on the scan direction. The c axis profile shows a pronounced maximum in the Cr concentration while the b axis plot shows a maximum at the grain edge, but a profile shape unlike that due to simple diffusion. The Cr profile, assuming diffusion control, appears to be highly dependent on the Fe concentration. The diffusion rate is high in Fe-rich olivine but is very slow in forsterite resulting in a peak in Cr when the FeO is about 4 wt%.

D. Calcium: The c axis profile clearly shows a loss of Ca within the rim indicating outward migration of Ca; the other two profiles are nearly identical.

E. Aluminum: Profiles are similar to Ca but complicated by the different levels of Al in different sectors apparently inherited from primary growth.

Conclusions: The forsterite rims are consistent with diffusion of minor elements both into (Fe, Mn, Cr) and out of (Ca, Al, Ti) the grains. Crystallographic control of diffusion is apparent and qualitatively matches that predicted from laboratory measurements. The near-equal profile width for all measured elements suggests that diffusion rates are strongly influenced by interelement effects, in particular the Fe concentration. Laboratory measurements (7) have shown the marked enhancement of diffusion rates as Fe increases in olivine. The persistence of internal textures in forsterite corresponding to sharp changes in the concentration of some minor elements suggests that diffusion rates in forsterite are much lower than in Fe-bearing olivine.

References:  

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