OSCILLATORY ZONING IN FORSTERITE FROM CARBONACEOUS AND UNEQUILIBRATED ORDINARY CHONDRITES: IMPLICATIONS FOR ORIGIN OF SOME FORSTERITE. Ian M. Steele, Department of Geophysical Sciences, University of Chicago, 5734 S. Ellis Ave., Chicago IL 60637.

Oscillatory zoning is difficult to recognize in terrestrial olivine but has been described from olivines from phenocrysts in lavas [1]. The compositional contrast is brought out in polished section by acid etching and viewing by Nomarski interference microscopy. More recently oscillatory zoning has been observed in forsterites from the Allende meteorite [2] where cathodoluminescence (CL) contrast reveals compositional differences. Below are reported additional observations of oscillatory zoning in Allende and an unequilibrated ordinary chondrite, details of zoning as revealed by image processing techniques, and compositional correlations among elements measured with high sensitivity. It is concluded that the proposal that all forsterites formed within chondrules is inconsistent with the observed oscillatory zoning which by analogy with terrestrial and lunar occurrences is restricted to slowly growing crystals in contrast to rapidly cooled chondrules.

Occurrence of oscillatory zoning: The recognition of oscillatory zoning using CL is limited to nearly pure forsterite with less than about 2 wt.% FeO because higher Fe content quenches CL. Oscillatory zoning is recognized by linear bands of varying CL intensity. The occurrence is relatively rare possibly due to the small size of most forsterites, most grains are not whole but rather fractured, and luminescing forsterite is only a small fraction of the total sample. While descriptions here apply to forsterite, oscillatory zoning may occur in more Fe-rich grains but could not be recognized by CL. While numerous examples of linear CL features have been seen in Allende forsterites, one grain is particularly interesting because of its large size (1mm), euhedral form, and repeated zoning with a 5μm period (Fig. 1). Another example which shows repeated linear CL features is a forsterite of ALHA 76004 (H3) but does not represent a complete grain and is embedded in a devitrified matrix. Oscillatory zoning has not been recognized in C2 forsterites which is added evidence that C2 forsterites differ from those of C3 and UOC meteorites both with respect to composition [3] and with respect to crystallization dynamics which is thought to cause oscillatory zoning.

Imaging of the CL texture was done by beam scanning and obtaining a digital CL image [4]. This allowed image enhancement using image processing filters to clearly show the bands and recording of the image from a computer screen. Simultaneous BSE images were recorded to allow recognition of gross zoning changes; no indication of the oscillatory zoning is seen on these BSE images.

Correlation of composition and zoning: Electron microprobe traverses were made perpendicular to the CL zoning with 0.5μm steps. Counting times, current, kV and PHA were selected to obtain near 10ppm detection limits for Al, Ca, Sc, Ti, V, Cr, Mn and Fe. These data extend those reported earlier [2] and show an excellent correlation of Al, Ti, Sc and V with each other and with the CL zoning. In contrast, Ca, Fe, and Mn showed no change correlated with the CL pattern but rather a monotonic change consistent with normal zoning in a growing crystal. The variation in Cr showed one compositional step which did not correlate with any other observation.

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The elements measured can be divided into two groups: 1) the high charge ions including Al^{+3}, Sc^{+3}, Ti^{+3}, V^{+3} are incompatible with the olivine structure and all correlate with CL intensity; Al and Ti which are in high enough concentration to give good statistics correlate with the oscillatory zoning shown by CL. 2) the second group of elements Fe, Ca, Cr and Mn are all divalent (it is assumed that conditions are sufficiently reducing for Cr to be predominently divalent), compatible with the olivine structure, and show only monotonic changes (Fig. 2).

Discussion: By analogy with terrestrial and lunar samples of plagioclase, olivine, and pyroxene oscillatory zoning is restricted to slowly cooling samples typified by phenocrysts within lava flows [5]. The conclusion that the forsterites originate from chondrules [6] which have a cooling rate on the order of hundreds of degrees/hour [7] is difficult to rationalize. These textural observations suggest that at least some forsterites, and possibly more Fe-rich olivines, were from a source that cooled slowly on the time scale of terrestrial lava flows. The compositional variation across the oscillatory zoning is similar to that observed for terrestrial samples where Ca, Mn, Fe and Mg did not correlate with the zoning [1]. Measurements have not been made for incompatible minor elements in terrestrial samples. It is proposed that the trivalent ions have a relatively low diffusion rate in the silicate melt and distribution coefficients such that they are not incorporated into the olivine structure. This combination causes a local concentration increase adjacent to the growing olivine which at some point is great enough to force high levels of these elements into the growing olivine. Similar explanations exist for terrestrial examples. If correct, some forsterites must also have grown from a melt in contrast to a vapor. From the many observations made for forsterite, it appears that there is no one process for their formation.

References: [1] Clark et al. (1986) Amer. Mineral. **71**, 734-741; [2] Steele, I.M. (1990) LPS **XXI**, 1196-1197; [3] Steele, I.M. and J.V. Smith. (1986) LPS **XV**, 822-82; [4] Steele, I.M. (1992) Scanning Microscopy **5**, 611-618; [5] Allegre, C.J. et al. (1981) Nature **294**, 223-228; [6] Jones, R.H. (1992) Geochim. Cosmochim. Acta **56**,467-482; [7] Hewins, R.H. (1983) "Chondrules and their origins,122-133.

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Fig. 1. CL intensity as a function of position. The region showing oscillatory zoning is indicated with 6 peaks labeled. The width of scan is 75 microns.

Fig. 2. Variation of Cr, Ca, and Fe across the same region of Fig. 1. While CL, Al, and Ti show distinct maxima and minima, the 3 elements shown show no indiaction of oscillatory zoning.

Fig. 1

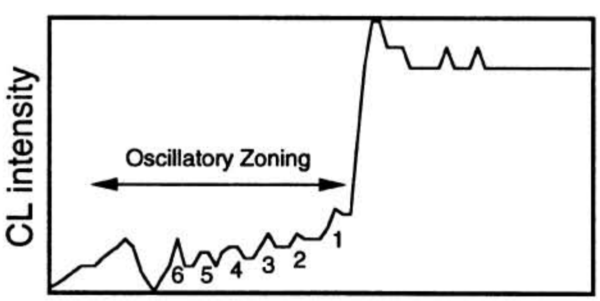

Fig.2