MICRO-TEXTURAL AND -CHEMICAL FEATURES OF ISOLATED FORSTERITES OF C3 METEORITES WITH IMPLICATIONS FOR ORIGIN. Ian M. Steele, Dept. of Geophysical Sciences, The University of Chicago, 5734 S. Ellis Ave., Chicago, IL 60637.

Single crystals of forsterite enriched in refractory minor elements including Al, Ca, Sc, Ti, and V are relatively common within the carbonaceous chondrites but their origin is unclear. Because they are not associated with other phases, coexisting mineralogy can not be used to infer growth conditions although the lack of associated phases suggests individual growth. New observations are described below which suggest unusual growth mechanisms for some olivines and equilibration of most olivines with falling temperature causing redistribution of minor elements. These observations imply some oxygen exchange was possible to modify the original ^{16}O enriched forsterites. These processes occurred prior to incorporation into chondrules and the meteorite matrix. Together these observations suggest growth under dynamic conditions in a chemical and isotopic environment different from that of the bulk meteorite and chondrules.

Oscillatory zoning: In Allende, particularly clear and often subhedral grains are relatively common and these grains are normally zoned to more Fe-rich compositions at the outer margins. The cores have 0.25<FeO<0.5wt% and show brilliant cathodoluminescence (CL)(1). While internal features in the form of sharp boundaries are common when CL is displayed (2), at least one grain shows very fine micron-scale CL banding with clear crystallographic control. The individual zones are several microns across, are continuous into adjacent forms, and crosscut coarse CL features producing a complex textural pattern. The appearance is similar to the common oscillatory zoning in terrestrial plagioclase for which there are many theories but no real explanation.

Compositional scans at 10 μm step intervals were made perpendicular to the bands using scanning CL images as a guide. While the bands are too fine for individual analysis, the compositional variation is shown in Fig. 1 with the three refractory elements Al, Ti and V showing nearly identical profiles. In regions showing uniform CL, concentrations vary smoothly while in regions showing complex zoning, concentrations decrease with superposed oscillations which correspond to CL brightness. In contrast, the Ca (and Fe) profile is smooth across both the uniform and zoned portion of the forsterite. Except for Fe, all concentrations decrease toward the grain edge. Scanning x-ray images for Al Kα clearly match those of the CL images with bright CL corresponding to high Al. The absence of complex zoning for Ca and Fe could indicate either that they originally showed only a smooth variation or that diffusion has occurred giving a smooth profile. For diffusion, the preservation of the complex zoning for Al, Ti, and V and not for Ca and Fe may be due to their more rapid diffusion relative to Al, Ti, and V. The essentially identical profiles for Al, Ti and V would indicate that diffusion coefficients are very low such that essentially no diffusion occurred. The documented substitution of Al in tetrahedral sites of forsterite would by analogy with other silicates give relatively slow Al diffusion compared to the Ca in octahedral sites. By analogy with feldspars the presence of oscillatory zoning for some elements might indicate growth from a liquid, but there are no apparent reports of oscillatory zoning in terrestrial magmatic olivines and there is no *a priori* reason why vapor growth could not produce such zoning; thus its occurrence is not necessarily indicative of growth mechanism. However, its presence suggests growth conditions unlike those on the Earth or Moon.

Inclusions in Forsterite: While isolated forsterites in both Ornans and Allende show few optical defects in thin section, 2-D compositional maps with a 4 micron grid interval show "hot spots" for Al, Ca, and Ti. These were difficult to repeat and initially thought to be surface contamination. However, long integration Al Kα x-ray maps show numerous submicron Al concentrations in nearly all CL emitting central regions of these forsterite grains. No surrounding depletion zone was apparent. With fine repolishing, identical x-ray maps were found indicating that they are inclusions. In BSE images these areas show no contrast indicating an average Z similar to forsterite; this phase is probably spinel but the size precludes analysis. These grains could originate either through nucleation from forsterite or may represent precursor grains incorporated into the growing forsterite. Spinel nucleation on cooling might be expected from the unusual forsterite composition as the amount of spinel in forsterite solid solution decreases with T (3). These forsterites do not show complex zoning which might indicate that diffusion has erased any fine scale variation. Detailed study is required to: (a) identify the phase; (b) determine crystallographic orientation relative to olivine to suggest growth by nucleation or simple incorporation; (c) determine Al partitioning to obtain equilibration T.

Oxygen isotope variation: The isotopic composition of forsterite grains which show CL and hence are refractory-rich is ^{16}O -rich relative to the Fe-enriched rims and bulk Allende (4). While detailed zoning profiles can not be determined until *in-situ* oxygen isotopic measurements are possible, the change in oxygen corresponds broadly to the change in major and minor element chemistry as sketched in Fig. 2. The role of diffusion is difficult to evaluate, but the slow diffusion of Al which is in tetrahedral sites and the preserved sharp Al discontinuities suggest that the chemical change for the refractory elements was sharp and is preserved. The entire grain may have been originally enriched in heavy oxygen with later inward diffusion of normal oxygen; alternatively the change in oxygen may have occurred with the change in chemistry but modified by diffusion. In either case, the heavy oxygen indicates that the forsterite grains did not form in the same oxygen environment as the main portion of Allende.

Summary: These detailed observations for forsterite provide evidence that some forsterite single grains grew with complex zoning of minor elements which is sometimes preserved. Growth of this refractory phase was at high temperature where diffusion could explain both the selective removal of fine compositional variations and precipitation of inclusions. Clearly complete equilibration did not occur and detailed concentration gradients combined with diffusion data may provide estimates of cooling rates. The complication is that some primary zoning is present which is difficult to separate from that of diffusion.

References: (1) Steele I.M. (1989) GCA, 53, 2069-2080; (2) Steele I.M. (1986) GCA, 50, 1379-1395; (3) Schlaudt C.M. and Roy D.M. (1965) J. Amer. Ceram. Soc., 48, 248-251; (4) Weinbruch, S. et al. (1989) Proc. 52nd Met. Soc. Meeting, Vienna, 262.

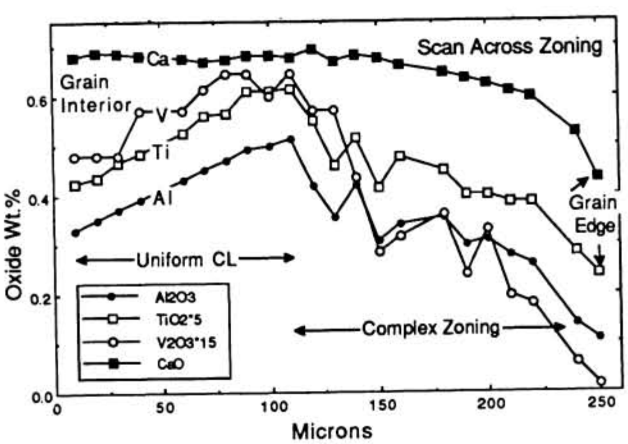

Fig. 1: Variation of Al, Ti, V and Ca across complex zoned forsterite. Ca shows smooth profile; others erratic, but near identical.

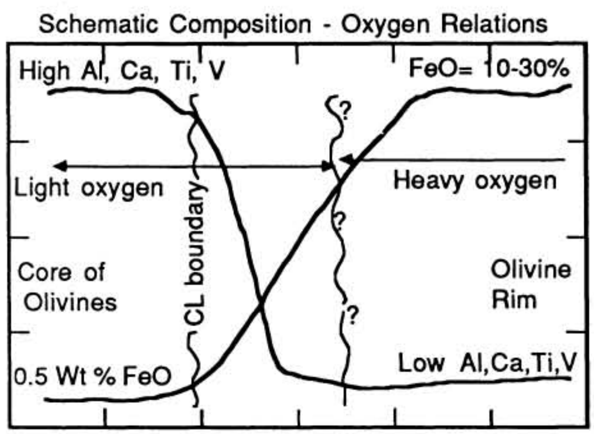

Fig. 2: Schematic oxygen composition relations inferred from data in (4) relative to generalized compositional and CL data.