MINOR ELEMENTS IN FORSTERITE OF CUMBERLAND FALLS ENSTATITE ACHONDRITE. Ian M. Steele, Dept. of the Geophysical Sciences, University of Chicago, 5734 S. Ellis Ave., Chicago, IL, 60637.

The enstatite achondrites (aubrites) represent a reduced assemblage of mafic minerals dominated by nearly pure enstatite with minor forsterite and diopside. Watters and Prinz (1) compared the mineralogy of most of the recognized members of this group; however, their study did not describe the chemical variations within one meteorite or the chemical features of the chondritic inclusions of Cumberland Falls (2). Because forsterite is the most common high temperature phase in the primitive meteorites, the minor element levels and correlations should provide useful indicators of conditions during olivine growth. To help unravel the factors affecting the minor element chemistry of forsterite, the characteristics of aubrite forsterite are described and compared with those of forsterites of the primitive meteorites.

Thin sections of Cumberland Falls showed two distinct lithologies; light colored areas dominated by enstatite and dark chondritic areas with sharp boundaries against the light portion. The light portion represents a low temperature metamorphic assemblage as indicated by coarse texture, homogeneous compositions and common exsolution in pyroxenes. In contrast, the dark portion shows a fine-grained texture which includes numerous whole or partial chondrules with barred, radiating and porphyritic textures; this portion has not undergone a low temperature event and has been recognized as distinct from other chondritic material (2) as indicated mainly by the reduced mineralogy.

Forsterite was analyzed for Al, P, Ca, Ti, Cr, Mn, Fe, and Ni; Na, Sc, V, and Co were near or below detection levels. Analyses were made as either core-rim pairs or as line scans from edge to edge. Some data are given in the Table. Within the light (aubrite) portion, forsterites have homogeneous cores within any one grain but show variations in minor elements among grains; in addition all forsterites show steep zoning at the rims with increases in Fe and Mn, no or slight decrease in Ca, and no recognized change in Cr or Ti probably due to low levels (Fig. 1). The width of zoning is about 30 microns so grains smaller than about 80 microns show no apparent core. For three grains, the range and correlation of FeO and MnO are illustrated in Fig. 2; the core compositions of the three grains differ and each grain shows a trend of Fe and Mn to some 2-3x higher than in the core. A weak positive linear correlation (also see later) is present with a FeO/MnO of about 1.0 (cf. 65 for Earth mantle, 70-85 for Moon, 97 for bulk C1). Coexisting enstatite in the aubrites shows a FeO/MnO near 0.5; this Mn-Fe distribution between olivine and enstatite is about the same as that observed for terrestrial mantle samples (3) which have undergone similar metamorphic equilibration even though the FeO/MnO is much higher in the latter samples.

For olivines in the chondritic portion, analyses are shown on Fig. 3 with respect to the aubrite forsterites as well as ranges for other well characterized forsterites. Some analyses show a cluster distinct from the linear aubrite trend while others range to relatively high-Fe (and Fe/Mn up to about 10) reflecting the unequilibrated nature. The petrographic site of these two chondritic forsterite types has not been determined although those with high-Fe appear to be associated with chondrules. All chondritic olivine compositions are distinct from those of C2, C3 or UOC forsterites; the closest match is with the aubrite forsterites both with respect to the low MnO/FeO ratio and the Fe-poor composition. The chondritic forsterites are minor element rich relative to aubrite forsterites: TiO_2 130-220; Cr_2O_3 100-1300; NiO 80-240; P_2O_5 200-1000ppmw; Na, Al, Sc below detection, whereas all these elements are close to detection levels in aubrite forsterites. The detectable phosphorus is unusual but has been reported in pallasites and in terrestrial olivines formed under reducing conditions.

The two forsterite types in Cumberland Falls are different and unlike forsterites in other chondritic occurrences. Within the aubrite, each forsterite grain is zoned at the rim with respect to Fe and Mn and only slightly for Ca; this is consistent with diffusion control as diffusion rates for Fe and Mn are some 100 times greater than that for Ca in forsterite (4). The increase of Fe and Mn would indicate inward diffusion and the decrease in Ca outward diffusion. Alternatively, the decrease

in Ca may indicate the onset of diopside growth which would rapidly deplete the remaining trapped(?) liquid in Ca but have little effect on Fe and Mn. The clear indication of low temperature migration of Ca as exsolution and the apparent depletion of Ca at all grain boundaries including enstatite favors diffusion control. The very low Fe content is consistent with the very reduced state with essentially no oxidized Fe; in contrast the chondritic portion formed under more oxidizing conditions, but sufficiently reducing to give the reduced assemblage described in (2). A critical question is whether the high Fe forsterites of Fig. 3 are indeed associated with the reduced minerals? Forsterites in C2 meteorites form a consistent trend near parallel but not overlapping that of the aubrites but with an intercept on the FeO axis at about 0.7 FeO. The luminescing "blue" olivines and their rims as well as other olivines in C3 and UOC meteorites do not overlap compositionally with the aubrites.
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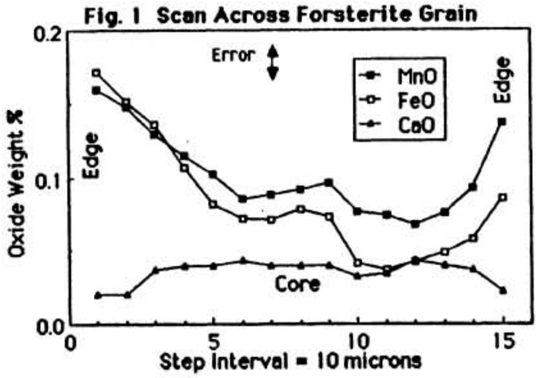
Table: Minor elements in forsterite of Cumberland Falls aubritic and chondritic areas.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
FeO	0.073	0.172	0.453	0.525	0.291	0.418	0.037	0.019	0.017
MnO	0.096	0.160	0.229	0.173	0.241	0.243	0.015	0.006	0.0
TiO_2	0.007	0.0	0.015	0.056	0.015	0.017	0.007	0.0	0.0
Cr_2O_3	0.006	0.0	0.010	0.023	0.009	0.016	0.007	0.0	0.0
CaO	0.039	0.020	0.015	0.021	0.007	0.027	0.055	0.054	0.050
Al_2O_3	0.0	0.0	0.004	0.015	0.0	0.004	0.0	0.0	0.0
P_2O_5	0.0	0.0	0.089	0.031	0.066	0.073	0.0	0.0	0.0
NiO	0.0	0.0	0.006	0.0	0.006	0.009	0.0	0.0	0.0

(1,2) Aubrite, grain center, edge; (3,4,5,6) forsterites, chondritic area; (7,8,9) Aubrite, edge of 1mm grain, 150 microns from edge, interior, respectively.

Fig. 1 Scan Across Forsterite Grain



References: (1) Watters and Prinz (1979), PLSC 10th, 1073-1093; (2) Neal and Lipschutz (1981), GCA, 45, 2091-2107; (3) Delaney et al. (1979), LPS X, 277-279; (4) Morioka (1983), GCA, 47, 2275-2279.

Fig. 2. FeO vs MnO in 3 Forsterite Grains

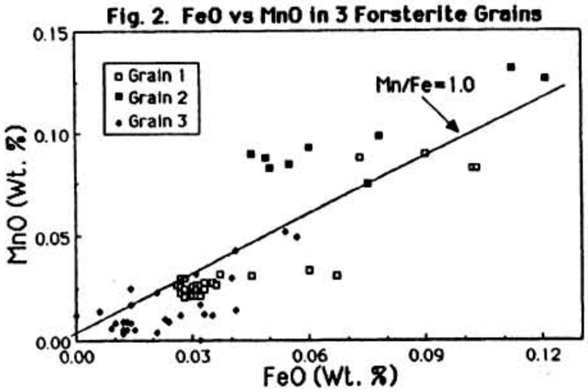


Fig 3. MnO vs FeO in Light and Dark Areas