COMPOSITIONAL HOMOGENEITY AND HETEROGENEITY IN HIGH GRADE ENSTATITE CHONDRITES. R. A. Fogel, P. C. Hess and M. J. Rutherford, Department of Geological Sciences, Brown University, Providence, RI 02912.

The compositional homogeneity of enstatite and kamacite grains has been investigated, on thin section scale, in high grade enstatite chondrites. The minor components FeO, CaO and MnO in enstatite, and Si in kamacite, were carefully monitored both within and between grains to study the effects of prograde/retrgrade metamorphism on the equilibration of these phases with the surrounding environment. A determination of the extent of homogeneous and heterogeneous equilibrium is required in order to successfully apply the enstatite-oldhamite geothermometer (1). This geothermometer makes use of the five phase assemblage kamacite-quartz-enstatite-oldhamite-troilite to determine metamorphic temperatures and can be used on the "mosaic equilibrium" scale if heterogeneous equilibrium cannot be demonstrated.

Polished thin sections of the EL6's Ufana (USNM 6006), Blithfield (USNM 534-1), and the EH5, St. Mark's (USNM 3027-3) were obtained from the Smithsonian Institution and their compositions investigated with the Brown University electron microprobe using the WDS technique. EDS analysis, backscatter and X-ray imaging were also used to obtain qualitative information on the composition of phases and grain-boundaries. Each reported standard deviation (σ) is given on no less than 26 analyses.

Blithfield and Ufana appear to be homogenous with respect to their kamacite Si content and their enstatite CaO content on both the single grain and thin section scale. The silicon content of Blithfield and Ufana kamacite was determined to be 0.99 wt% (σ=0.08) and 1.56 wt% (σ=0.09) respectively. St. Mark's has a higher variability exhibiting a kamacite Si content of 2.58 wt% (σ=0.21, N=13). These Si concentrations are somewhat different from those previously determined (2,3). This variability could be attributed to either different meteorite sections or the Si standard used. The Si standard used for this work was SRM 483, an Fe-Si alloy from NBS which has a Si content of 3.22 wt% ± 0.02 wt%. The CaO contents of Blithfield and Ufana enstatites show low variability and are 0.87 wt% (σ=0.02) and 0.65 wt% (σ=0.03), respectively. St. Mark's displays a higher variability and a much lower CaO content of 0.09 wt% (σ=0.07). These values are in agreement with previous determinations (2,3).

Preliminary investigations found that the FeO content of enstatite was quite variable within each meteorite. For example, 31 random analyses of Blithfield gave an average FeO content of 0.36 wt% and a σ of 0.28. Upon further investigation it was found that nearly all enstatite grains that share a crystal face with a high iron phase—such as kamacite, troilite and schreibersite—show a zonation of high FeO content at the crystal surface to low concentrations at the core. Traverses were made into the enstatite from the grain-boundary with step sizes as small as 1μm. The profiles obtained were hyperbolic, reminiscent of a diffusion profile. An example of such a profile is shown in Fig. 1, which plots enstatite FeO concentration versus distance into the grain in microns. In this case the enstatite grain was surrounded by schreibersite, although the same type of hyperbolic profile is found when the enstatite borders any one of the phases previously mentioned. Furthermore, the profile differs with crystallographic face. Two profiles taken from roughly perpendicular faces showed surface concentrations of 1.23 and 0.64 wt% FeO, respectively, and a core concentration of 0.14 wt% FeO.

Profiles of enstatite bordering alabandite and enstatite bordering dubreelite show Mn and Cr to decrease from measurable levels at the En-Ala and En-Dub grain-boundaries, respectively, to concentrations below probe detectability away from the surface. Similar profiles away from oldhamite grains show a slightly increased CaO level at the En-Old grain-boundaries (roughly 0.1 wt% higher). Profiles were also taken from En-Kam grain boundaries into the kamacite. With the exception of one small reversed Si gradient (1.6 wt% Si at the grain-boundary to 1.8 wt% Si at the core) there is an absence of a parallel Si gradient in kamacite to match the FeO gradients in enstatite.
The possibility that the FeO gradients are an artifact of a large excitation volume and/or secondary fluorescence from the surrounding Fe-rich phase was considered. Enstatite grains were generally selected such that when viewed in both transmitted and reflected light the grain boundary position did not move. When viewed in transmitted light, if the grain boundary moved from its position in reflected light, it indicated that the Fe-rich phase extended under the enstatite grain. In terms of secondary fluorescence, the energy necessary to produce Fe-Kα secondary photons would require the target material (enstatite) to have a component of larger atomic number than Fe. Enstatite does not contain elements of higher Z than Fe. It is concluded that these FeO gradients are real.

A possible interpretation of this phenomenon is that in response to changing metamorphic redox conditions, the enstatite acquires a ferrosilite component in an attempt to maintain equilibrium. This acquisition occurs at the surface of the crystal and diffusion into the crystal takes place. In the case of enstatite–kamacite pairs, both the Fe and the Si can be obtained from the kamacite although the oxygen must be obtained from a vapour phase or through grain-boundary transport. This however, cannot account for Fe enrichment in phase pairs other than En–Kam. Therefore, it is necessary to postulate the existence of a vapour phase. It has been shown that both Si and Fe are volatile under the extreme reducing conditions implied by the enstatite chondrites (5). Calculations using the enstatite–oldhamite geothermometer (1) imply a metamorphic temperature for Ufana of 1030°C and a Log fO₂, Log fS₂ and Log A(Si) of -21.7, -6.2 and -5.5, respectively. These fugacities and Si activity imply Log fugacities of SiS and SiO of -4.3 and -7.8 respectively. These species contain the necessary components that can be transported to the En–Kam, En–Sch and En–Tr interfaces.

The FeO enrichment exhibited by these enstatites, could occur as a result of increased fO₂ at constant temperature, or as a result of fO₂ changes upon metamorphic cooling. For example, the equilibrium between enstatite and kamacite is:

\[
\text{Fe}(\text{kam}) + \text{Si}(\text{kam}) + \frac{3}{2}\text{O}_2 = \text{FeSiO}_3(\text{en})
\]

and the equilibrium constant (K) for this reaction is:

\[
\log K = \log A(\text{FeSiO}_3) - \frac{3}{2}\log fO_2 - \log A(\text{Si}) - \log A(\text{Fe})
\]

At constant T, A(Fe), and A(Si), if fO₂ is increased, the equilibrium is driven to the right requiring a higher FeO content of enstatite. However, reducing T at constant Fe and Si activity, also pushes the equilibrium to the right (higher equilibrium constant at lower T) and produces higher ferrosilite contents. This higher FeSiO₃ activity will be required unless fO₂ decreases such that 3/2Log fO₂ equals the decrease in Log K. Thus, fO₂ can actually decrease and still produce a higher FeSiO₃ potential.

The existence of FeO gradients in E-chondrite enstatite may make it possible to calculate the conditions of retrograde metamorphism, including T, fO₂ and duration. Further work in this area is in progress.

References