COMPLEX ZONING BEHAVIOR IN PYROXENE IN FEO-RICH CHONDRULES IN THE SEMARKONA ORDINARY CHONDRITE. Rhian H. Jones, Institute of Meteoritics, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, New Mexico 87131, USA.

A detailed understanding of the properties of silicate minerals in chondrules is essential to the interpretation of chondrule formation conditions. This study is further work in a series of petrologic studies of chondrules in the least equilibrated LL chondrite, Semarkona (LL3.0). The objectives of this work are a) to understand chondrule formation conditions and nebular processes and b) to use the data as a basis for understanding the effects of metamorphism in more equilibrated chondrites. FeO-rich pyroxene in the chondrules described shows complex zoning behavior. Low-Ca clinopyroxene, orthopyroxene, pigeonite and augite are all observed, in various associations with one another. Coexisting olivine phenocrysts are also FeO-rich and strongly zoned. Compositional and zoning properties are similar to those observed in boninites and are interpreted as resulting from rapid cooling of individual chondrules.

Textures. A textural description of FeO-rich, porphyritic, pyroxene-rich chondrules in Semarkona has been given previously [1]. The chondrules described here are those classified as types IIAB and IIB: type IIAB chondrules contain both olivine and pyroxene phenocrysts, and type IIB contain no olivine. Large phenocrysts of olivine and pyroxene may be intergrown and are euhedral or hopper-shaped in morphology. Mesostasis in these chondrules is relatively abundant (up to about 30 vol%) and usually glassy, with quench crystals of pyroxene. Some of the chondrules contain coarse (up to 150 μm wide) parallel bars of pyroxene rather than isolated, randomly-oriented phenocrysts. Nine chondrules from Semarkona that fit the textural descriptions above have been studied in detail. Low-Ca pyroxene compositions in this suite of chondrules are in the range Fs_{10-24}.

Pyroxenes. Four distinct categories of pyroxenes are observed in the chondrules studied: low-Ca pyroxene (twinned clinoenstatite), orthopyroxene, pigeonite and augite. The most common association is low-Ca pyroxene with rims of augite, similar to the pyroxene observed in the type I, FeO-poor, series of porphyritic chondrules [2,3]. Augite rims are common but do not rim all low-Ca pyroxene grains. Pigeonite is less common, and when present occurs as a distinct layer between low-Ca pyroxene and augite. Orthopyroxene has been observed in only one chondrule, and in this case occurs as complete, individual, euhedral grains with a small amount of augite overgrowth. These observations are similar to those made by [4].

Low-Ca pyroxene. Complex zoning behavior is observed within low-Ca pyroxenes. In contrast to FeO-poor PP chondrules [3], the more FeO-rich, low-Ca pyroxene grains commonly contain skeletal cores of more Fe-rich compositions that are observed clearly in BSE images. An example is illustrated in Fig. 1. Optically, this grain shows continuous twinning characteristic of clinoenstatite along its length. A microprobe traverse across the zones indicated in the sketch shows the compositional variation typical of these grains. FeO content is 1-2 wt% higher in the skeletal Fe-rich portion than in the core and adjacent overgrowth. There is an overall increase in FeO content from the core to the edge of the grain. The point on the traverse at the outer edge of the grain is a Ca-rich (augite) rim containing 14 wt% CaO (data for CaO > 2 wt% are not indicated on Fig. 1). Cr, Mn, Ca and Al contents also vary with Fe: in the low-Ca pyroxene, zoning behavior of all these minor elements follows that of FeO. In the Ca-rich rim, Al and Cr are also strongly enriched and Mn follows the decrease seen in Fe.

Orthopyroxene. In one chondrule two distinct types of low-Ca pyroxene are recognised: i) low-Ca pyroxene showing characteristic clinoenstatite twinning, and ii) two large, euhedral grains of orthopyroxene that show no optical twinning. Although concentrations of most elements in the two types are not distinguishable, there is a distinct difference in CaO contents. The clinopyroxene has CaO = 0.2 wt% and the orthopyroxene has CaO = 0.6 wt%. Clinopyroxene grains contain Fe-rich skeletal cores similar to those described above (Fig. 1). The two grains of orthopyroxene show concentric oscillatory zoning, with at least 8 zones between core and rim of each grain (Fig. 2). Oscillations correspond to compositional changes in FeO, as illustrated, and there is an overall increase in FeO towards the edge of the grain. These changes are accompanied by changes in Cr, Ca, Mn and Al contents which all vary sympathetically with Fe in similar degrees to the variations observed in clinopyroxene.

Olivine. Olivine phenocrysts in the chondrules studied are Fe-rich and strongly zoned with increasing FeO from core to rim. Mean Fe/(Fe+Mg) ratios of olivine phenocrysts in individual chondrules are similar to mean compositions of coexisting low-Ca pyroxene phenocrysts (Fa_{10-18}). Typical zoning properties of olivine grains show FeO profiles that are flat in the core and increase sharply in the rim regions, similar to profiles observed in olivine in type IIA (olivine-rich) chondrules in the same chondrite [5]. Cr and Mn profiles are similar to Fe and increase in the rim region. Ca profiles are generally flat, or show only very minor increases towards the rims.

Discussion. Cooling rates of porphyritic, pyroxene-rich chondrules lie in the range 5 to >100°C /hr [6]. The presence of twinned low-Ca pyroxene, resulting from inversion from protoenstatite, is also an indication of rapid cooling. Zoning properties of pyroxenes in the chondrules studied are similar to those observed in terrestrial boninites [7] and may be understood in a similar framework of rapid cooling of the parent liquids. The complex zoning observed in the Fe-rich chondrules is likely to result from significant effects of disequilibrium during the rapid cooling interval. The origin of skeletal cores with slightly elevated Fe contents commonly observed in low-Ca clinopyroxene may be attributable to a small degree of undercooling in the initial stages of nucleation. Pyroxene and olivine compositions in each chondrule have similar Fe/(Fe+Mg) indicating that they grew from a common liquid. There is also a correlation between FeO contents of mesostases and mean FeO contents of coexisting pyroxenes and olivines which is additional evidence for closed system crystallization. Oscillatory zoning in orthopyroxene is likely to be the result of disequilibrium boundary layer effects in the adjacent liquid (e.g. [8]). The complexities described need to be fully understood before the effects of metamorphism on pyroxene can be interpreted.

References: [1] Jones RH (1992) LPSC XXIII, 629-630 [2] Jones RH and Scott ERD (1989) Proc 19th Lunar Planet Sci Conf, 523-536 [3] Jones RH (1992) LPSC XXIII, 631-632 [4] Noguchi T (1989) Proc NIPR Symp Antarctic Met 2, 169-199 [5] Jones RH (1990) GCA 54, 1785-1802 [6] Lofgren G and Russell WJ (1986) GCA 50, 1715-1726 [7] Ohnenstetter D and Brown WL (1992) J Petrol 33, 231-271 [8] Downes MJ (1974) Contrib Mineral Petrol 47, 187-196.
Acknowlegdement: Funded by NASA grant NAG9-497, J.J. Papike, P.I.

FIG 1

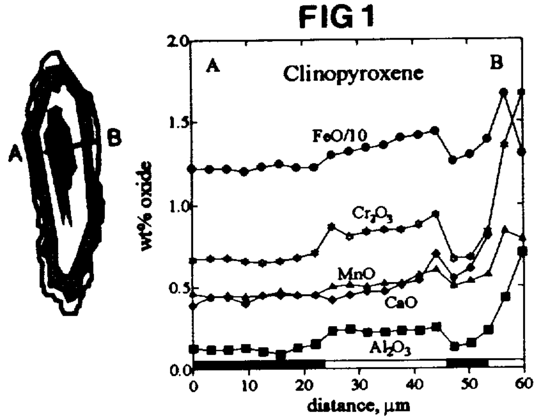
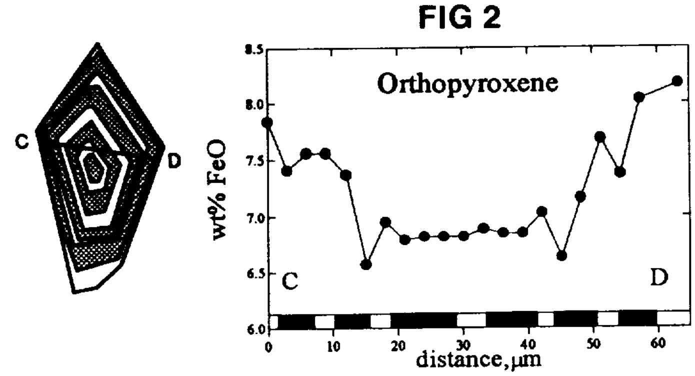


FIG 2



Figures: Zoning in pyroxene. Sketches show general appearance in BSE image. White zones are more Fe-rich than adjacent shaded zones. Fig. 1: Low-Ca clinopyroxene grain with a skeletal Fe-rich zone (white). Fig. 2: Orthopyroxene grain showing multiple oscillatory growth zones.