

**CATION ORDERING IN ORTHOPYROXENE IN ESTHERVILLE METEORITE: IMPLICATIONS FOR COOLING RATE AND ORIGIN OF MESOSIDERITE** : J. Ganguly, Dept. of Geosciences, University of Arizona, Tucson, AZ 85721, H. Yang, and S. Ghose, Dept. of Geological Sciences, University of Washington, Seattle, WA 98195

From Ni zoning profile in metals in several mesosiderite samples, Powell(1) estimated cooling rate around  $0.1^{\circ}\text{C}/\text{Ma}$  at  $500\text{-}350^{\circ}\text{C}$ . Recently Bogard(2) has concluded that although the Ni diffusion data on which this cooling rate was based have been subsequently revised, the metallographic cooling rate still should not exceed  $\sim 1^{\circ}\text{C}/\text{Ma}$ . In contrast to such extremely slow cooling rate, corresponding to burial in the core of a parent body  $\sim 1000$  km in radius (3), the brecciated nature of the silicates and the presence of plagioclase in mesosiderites suggest location at near-surface environment. Several models have been proposed to deal with this enigmatic problem. Some of these models also suggest that the metal and silicate components of mesosiderite did not have a common origin.

Because of the emphasis placed on the very slow metallographic cooling rate in developing models for the origin of mesosiderites, and question about genetic relationship between metal and silicate components, we have undertaken a program to determine the cooling rate of orthopyroxene crystals in mesosiderites from their quenched Fe-Mg ordering states between the two nonequivalent octahedral sites, M1 and M2. The general principles of using such cation ordering as quantitative indicators of cooling rate have been discussed by Ganguly(4).

Two orthopyroxene crystals were selected from Estherville meteorite and ground to approximately spherical shapes. The crystals investigated did not show any exsolution or compositional zoning, and the average of four spot analyses in electron microprobe yields the following concentrations of cations on 6 oxygen basis. **OPx #1**: Fe: 0.321, Mg: 1.619, Ca: 0.026, Mn: 0.011, Na: 0.001, Cr: 0.018, Al: 0.025, Ti: 0.002, Si: 1.978; **OPx #2**: Fe: 0.316, Mg: 1.626, Ca: 0.025, Mn: 0.012, Na: 0.000, Cr: 0.019, Al: 0.027, Ti: 0.001, Si: 1.975. The unit cell dimensions were obtained from 25 reflections between  $25^{\circ}$  and  $40^{\circ} 2\theta$ , and are as follows ( $\text{\AA}$ ): **OPx #1**:  $a = 18.2607(11)$ ,  $b = 8.8498(5)$ ,  $c = 5.1972(3)$ ; **OPx #2**:  $a = 18.3054(15)$ ,  $b = 8.8689(5)$ ,  $c = 5.2087(3)$ ; space group Pbc<sub>a</sub>. Total reflections measured for the crystals #1 and #2 were 3803 and 3856, respectively. Each reflection was measured twice and averaged. The scan speed was  $1.5^{\circ}/\text{min}$  for both crystals. The refinements were carried out by full matrix least square analysis, and the reflection intensities were corrected for Loretz, polarization and absorption factors.

In determining the site occupancies from the x-ray data, it is assumed, as is commonly done, that  $\text{Cr}^{3+}$ , Ti and Al(VI) are restricted completely to the M1 site, Ca is restricted to the M2 site, whereas  $\text{Fe}^{2+}$  and  $\text{Mn}^{2+}$  fractionate similarly between the two octahedral sites. Further, the bulk composition calculated from site occupancy data is constrained to match the microprobe analyses, and the sum of cations in each octahedral site is set equal to one. The results suggest extremely ordered distribution of Fe(+Mn) and Mg between the two octahedral sites in both crystals, as follows.

Site	OPX #1	OPx #2
M1	Mg = 0.9737(19)	0.9756(16)
	Fe+Mn = 0.0033	0.0024
	Cr = 0.018	0.019
	Ti = 0.002	0.001
	Al = 0.003	0.002

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M2	Mg = 0.6453(19)	0.6494(16)
	Fe+Mn = 0.3287	0.3256
	Ca = 0.026	0.025
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	R = 0.038	0.030
	Rw = 0.024	0.020

The inferred site distribution of Fe+Mn and Mg, which is quite similar in both crystals, is more ordered than that reported so far from any terrestrial or meteoritic orthopyroxene crystal. Available calibrations (5,6) of Fe-Mg ordering in orthopyroxene as a function of temperature suggest that the quenching temperature ( $T_c$ ) of Fe-Mg ordering in the Estherville meteorite is about 200°C lower than that corresponding to the site occupancy data of Reid et al. (7) for an orthopyroxene crystal from the Steinbach meteorite. The latter crystal reflects a cooling rate  $\sim 10^\circ\text{C}/\text{Ma}$  around 500°C (7), which is in agreement with metallographic results (8).

Thus, if the common assumptions about the site distribution of cations other than Fe and Mg are essentially correct, then the orthopyroxene from Estherville meteorite must have cooled at a much slower rate than that from Steinbach meteorite. This conclusion is consistent with the metallographic results and implies that the silicates and metal grains were both subjected to deep burial at least when the rocks have cooled to 500°C. Further work is currently in progress to determine the site distribution of Cr in synthetic (Mg,Cr)-Opx, the results of which will be utilized to further refine the Fe-Mg ordering to yield quantitative result on the cooling rate of Estherville orthopyroxene.

References: (1) Powell, B.N. (1969) *GCA* **33**, 789-810; (2) Bogard et al. (1990) *GCA*, **54**; (3) Wood, J.A. in *Asteroids* (ed. T. Gehrels) ; (4) Ganguly, J. (1982) *Adv. Phys. Geochem.* **2**, 57-99; (5) Anovitz et al. (1988) *Amer. Min.* **73**, 1060-1073; (6) Molin et al. (1991) *EPSL* (in press); (7) Reid et al. (1974) *EPSL*, **22**, 67-74; (7) Ganguly et al. (1989) *LPSC XX*, 331-332