

EQUILIBRATION REACTIONS BETWEEN SILICATES, SULFIDES AND Fe,Ni-METAL IN EH CHONDRITES. T. J. Fagan^{1*}, S. Kataoka¹, K. Matsui¹, K. Norose¹ and A. Yoshida¹, ¹Department of Earth Sciences, Waseda University, Tokyo, Japan 169-8050. *(fagan@waseda.jp)

Introduction: An understanding of metamorphic reactions is useful because it offers insight into parent body processes and a means of identifying the most primitive chondrites. Recent work has identified some of the reactions that occur during incipient metamorphism in ordinary and carbonaceous chondrites [1]. Extrapolation of this progress to enstatite chondrites is plausible [2], yet different reactions may be significant in light of the distinct mineralogy (and hence formation conditions) of enstatite chondrites.

This project addresses metamorphism of enstatite chondrites by developing a mass-balance model of the main transfers of mass between silicates, sulfides and metallic minerals. We use an algebraic approach (“reaction space”, developed originally for terrestrial metamorphism [3,4]) to limit the number of reactions that need to be considered to model changes in mineral abundances. We combine this model with observations from a small set of EH chondrites to identify parent body vs. parent body effects as well as metamorphic reactions.

Methods: Algebraic manipulation of phases and components follow references [3-6]. Petrologic observations of polished thin sections of ALHA81189 (EH3), ALH 84170 (EH3) and St. Marks (EH5) are based on petrography, and elemental and back-scattered electron (BSE) imaging. X-ray maps, BSE images and quantitative analyses were collected using a JEOL JXA-8900 electron microprobe at Waseda University.

Mass balance model: In the EH chondrite silicate sub-system, main phases include enstatite, olivine, silica, feldspar and diopside. Phase endmembers and solid solutions in Na₂O-CaO-MgO-Al₂O₃-SiO₂ (NCMAS) are shown in Table 1. Fe and K, among other elements, may also occur in the natural minerals, but these can be described in terms of simple exchange components FeMg₋₁ and NaK₁; the phase endmembers as written in NCMAS are sufficient to denote mineral abundances [3,4].

Table 1. EH silicates in NCMAS oxide components.

	Na ₂ O	CaO	MgO	Al ₂ O ₃	SiO ₂
NaAlSi ₃ O ₈	0.5	0	0	0.5	3
CaMgSi ₂ O ₆	0	1	1	0	2
MgSiO ₃	0	0	1	0	1
AlAlMg ₋₁ Si ₁	0	0	-1	1	-1
SiO ₂	0	0	0	0	1
CaAlNa ₋₁ Si ₁	-0.5	1	0	0.5	-1
Mg ₂ SiO ₄	0	0	2	0	1

The use of oxide components in Table 1 is a choice, however, and the phase compositions can be rewritten in terms of a new set of components (Table 2) as long as the new components span the same composition space [3-6].

Table 2. EH silicates in NCMAS new components.

	ab	di	en	tk	qz
NaAlSi ₃ O ₈	1	0	0	0	0
CaMgSi ₂ O ₆	0	1	0	0	0
MgSiO ₃	0	0	1	0	0
AlAlMg ₋₁ Si ₁	0	0	0	1	0
SiO ₂	0	0	0	0	1
CaAlNa ₋₁ Si ₁	-1	1	0	1	1
Mg ₂ SiO ₄	0	0	2	0	-1

Each row in Table 2 is a mass balance. With the new set of components, the bottom two rows can be viewed as reactions:

$$ab = di + tk + qz - CaAlNa_{-1}Si_1 \quad (1a)$$

$$\text{equivalently, } ab = \text{jadeite} + \text{quartz} \quad (1b)$$

$$\text{and } fo + qz = 2 \text{ en} \quad (2)$$

In EH chondrites, reaction (1) appears to be minor, but (2) is a significant monitor of equilibration [7].

Table 3*. Main EH phases in NCMAS+O,S,Fe.

	Na	Ca	Mg	Al	Si	O ₂	S ₂	Fe
ab	1	0	0	1	3	4	0	0
di	0	1	1	0	2	3	0	0
en	0	0	1	0	1	1.5	0	0
tk	0	0	-1	2	-1	0	0	0
qz	0	0	0	0	1	1	0	0
O ₂	0	0	0	0	0	1	0	0
S ₂	0	0	0	0	0	0	1	0
tl	0	0	0	0	0	0	0.5	1
fm	0	0	-1	0	0	0	0	1
ka	0	0	0	0	0	0	0	1
pl	-1	1	0	1	-1	0	0	0
fo	0	0	2	0	1	2	0	0

*ab, di, en, tk, qz as in Table 2; tl = FeS troilite; fm = FeMg₋₁ exchange; ka = Fe,Ni-metal kamacite; pl = CaAlNa₋₁Si₁ plagioclase exchange; fo = Mg₂SiO₄ forsterite.

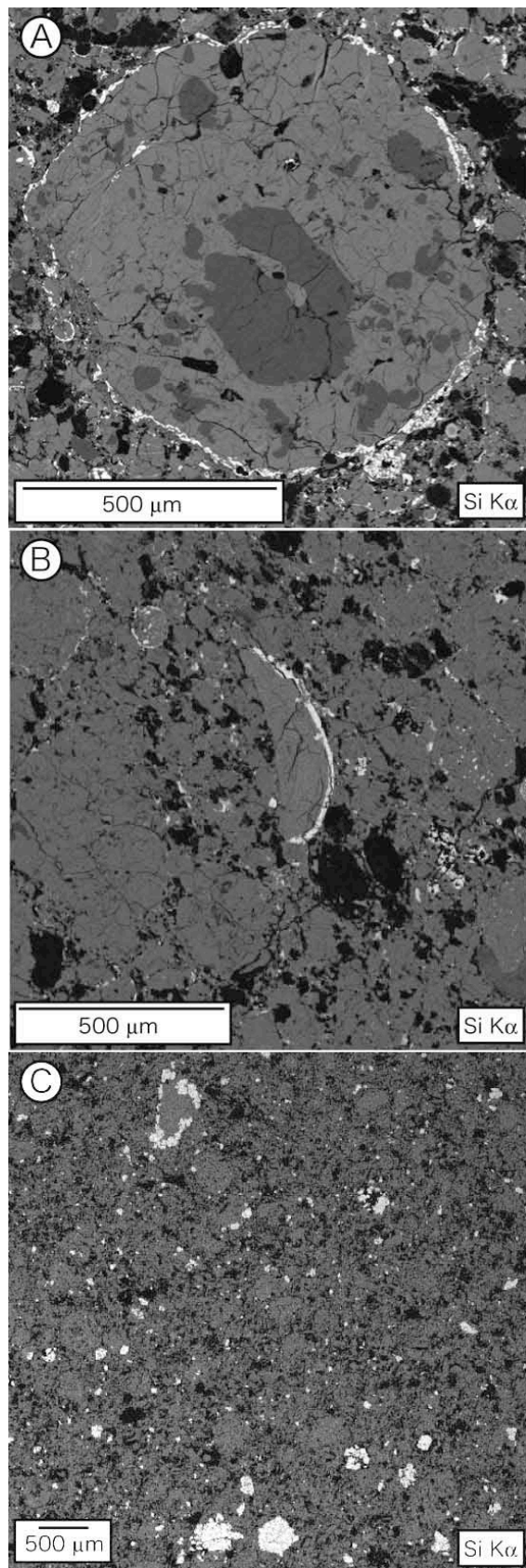
Reduction of a more complete matrix of the EH reacting system (Table 3) shows reactions (1), (2) and:

$$en + fm + 0.5 S_2 = tl + qz + 0.5 O_2 \quad (3)$$

$$\text{and } en + fm = ka + qz + 0.5 O_2 \quad (4)$$

reflecting sulfidation (3) and reduction (4) of silicates.

Application to EH chondrites: The EH3 ALHA81189 has abundant POP chondrules with fine-



← Fig. 1. Si Ka X-ray maps of chondrules and silica textures in (A) ALHA81189, (B) ALH 84170 and (C) St. Marks. In general, gray = enstatite, dark gray = olivine, white = silica.

grained SiO₂-rich rims; in EH3 ALH 84170, silica rims are present, but olivine is less abundant; in St. Marks, olivine is not present and silica occurs as coarse crystals (Fig. 1). This sequence reflects varying progress along reaction (2) toward equilibration in EH silicates.

Chondrules are clearly defined in both ALHA81189 and ALH 84170, yet tend to be whole in the former and fragmented in the latter (Fig. 1A,B). This indicates that ALHA81189 is not equivalent to a metamorphic protolith of ALH 84170. Thus, we infer that the variable progress on reaction (2) relating these two meteorites is due to a pre-parent body process, such as chondrule formation.

Pyroxenes in ALHA81189 and ALH 84170 share similar distributions of Fe-abundance, which contrast with the narrower range and lower Fe-abundance of St. Marks pyroxene (Fig. 2). The pyroxene compositions indicate similar, limited progress on reactions (3) and (4) in the EH3 meteorites. St. Marks experienced greater sulfidation and/or reduction, and equilibration during parent body metamorphism. ALHA81189 is a primitive EH3 chondrite due to limited processing during chondrule formation as well as minor extent of metamorphism.

References: [1] Grossman J.N. and Brearley A.J. (2005) *MaPS*, 40, 87–122. [2] Bendersky C. et al. (2007) *LPS XXXVIII*, #2077. [3] Thompson J.B. et al. (1982) *J. Petrol.*, 23, 1-27. [4] Thompson J.B. (1991) *Canadian Mineral.*, 29, 615-632. [5] Greenwood H.J. (1975) *Amer. Mineral.*, 60, 1-8. [6] Fagan T.J. and Day H.W. (1997) *Geology*, 25, 395-398. [7] Hicks T.L. et al. (2000) *LPS XXXI*, #1491.

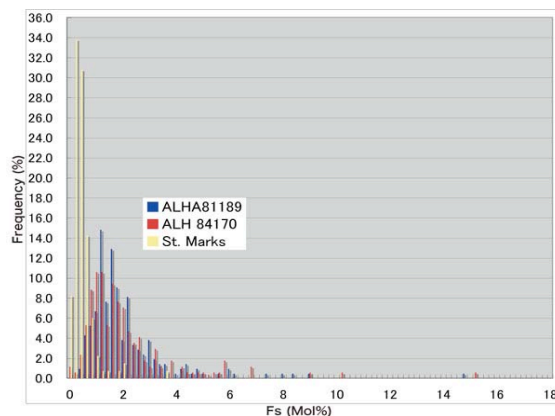


Fig. 2. Histograms of Fs content in pyroxenes from ALHA81189 (n = 209), ALH 84170 (n = 170) and St. Marks (n = 133).