CRYSTALLIZATION OF THE IIIAB IRON METEORITE GROUP: MULTI-ELEMENT MODELING RESULTS. Kathryn E. Powell[1,2] and Nancy L. Chabot[1], [1]Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA. [2]Rice University, Houston, TX, USA

Introduction: Many iron meteorites are believed to have originated in the molten cores of differentiated asteroids. As the molten core of the parent asteroid cooled and solidified, the metallic core crystallized. Some elemental trends in iron meteorites have been modeled successfully by fractional crystallization [reviewed in 1]. IIIAB is the largest group of iron meteorites. Recent crystallization studies of IIIAB irons have focused on modeling a select subset of elements: Ir, Ga, and Ge vs. Au or As [2, 3]. However, IIIAB meteorite measurements [4] and experimental partitioning data [5, 6] are now available for many elements in addition to these. In this work, we model ten elements simultaneously, including those studied previously as well as Co, Ni, Pt, Sb, and W, some of which are modeled for the first time for the IIIAB group.

Method: We use an overall modeling approach similar to that presented in [3]. In this model, the liquid crystallizes to a solid in discrete increments. The S present in the core is effectively excluded from the solid, resulting in an increasing S concentration in the liquid as crystallization proceeds. The S content of the metallic liquid has been shown to significantly affect the solid metal/liquid metal partitioning behavior of trace elements [e.g. 5, 6]. Thus the trace elements in the liquid have non-constant partition coefficients, and the increasing liquid S concentration alters the partition coefficients of the various elements with time and ultimately affects the partitioning behavior of the trace elements. In the model, crystallization proceeds until the Fe-Ni-S eutectic composition is reached, with a fraction of 0.0001 of the liquid crystallizing at each step. The solid produced is assumed to be removed from the system at each step, and the process is run again with the new liquid concentration as the starting concentration. The equations below detail the calculations in the model at each step:

$$C_L(E) = \frac{[C_i(E)]}{[1 - f + f \times D(E)]} \quad \textbf{Eq. 1}$$

$$C_S(E) = D(E) \times C_L(E) \quad \textbf{Eq. 2}$$

In Eq. 1 and Eq. 2, $C_L(E)$ is the concentration of the element E in the liquid, $C_S(E)$ is the concentration in the solid, and $C_i(E)$ is the defined initial liquid concentration. The partition coefficient D is the weight ratio of the concentration of the element in the solid to the concentratin in the liquid. As discussed, D varies for

each element according to X(S), the molar concentration of S in the liquid, and is recalculated at each step by:

$$D = D_O \left(\frac{1 - 2X(S)}{1 - X(S)} \right)^{-\beta} \quad \textbf{Eq. 3}$$

D_0 and β values were initially taken from previously published sources. D_0 represents the D value that would be found if there was no S present. D values for As, Au, Co, and Sb are from [6]. D values for Ga, Ge, Ir, Ni, Pt, and W are from [5]. A starting liquid concentration of 12 wt % S was used, in accordance with the results of [3]. The solid concentration of each element was plotted at intervals against the solid concentration of Au, with IIIAB meteorite data from [4] overlaid.

Results: The starting liquid compositions for each element are given in Table 1. The starting liquid compositions for previously modeled elements Au, Ga, Ge, and Ir were fairly consistent with [3]. The other elements had not been modeled before using this fractional crystallization model and initial S composition.

Modeling Ni and Sb produced fairly linear fits that are very consistent with the IIIAB meteorite data. The modeling of As is also a fairly linear fit for the IIIAB meteorites. The bell-shaped curves for Ga and Ge were also modeled as in [3]. Ir, Pt, and W all exhibit behavior similar to that observed for Ir in [3]: as S content increases, these elements partition much more strongly into the solid, leaving the liquid highly depleted in these elements. At high concentrations of S, the model does not fit the IIIAB iron meteorite trend as well as for lower concentrations. The misfit is also not explained by a mixture of solid and liquid, as proposed by [2].

Table 1:
IIIAB Iron Meteorite Bulk Liquid Composition

Element	C_i
As	9 ppm
Au	1 ppm
Co	0.37 wt %
Ga	11.5 ppm
Ge	23 ppm
Ir	2.5 ppm
Ni	7.4 wt %
Pt	5.5 ppm
Sb	43 ng/g
W	5 ppm
S	12 wt %

In contrast to other elements, Co did not produce adequate fits when using published parameterizations for D(Co) from [5, 6]. The values for Co found in [6], $D_0 = 1.2$ and $\beta = 1.1$, produced a model that poorly fit the IIIAB meteorite data (Fig. 1). These values were derived from laboratory experiments that produced satisfactory D_0 and β values for almost all the other elements modeled here. Each experiment provides a measurement at a specific S content for a given element's solid metal/liquid metal D value. The parameterized D values, using D_0 and β, should be consistent with the laboratory measurements, but the experimental measurements also contain scatter. We experimented with D_0 and β values for D(Co) in order to find a model consistent with both the IIIAB Co trend and the D(Co) experimental data. We arrived at $D_0 = 0.98$ and $\beta = 1.1$ for parameterizing D(Co). These values are more similar to those given in [5] than in [6].
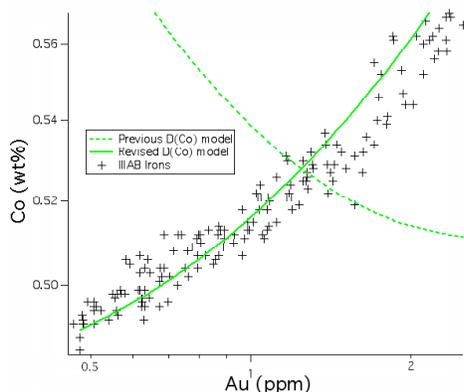

Figure 1: Data from the IIIAB iron meteorite group. Models are shown using both the original and revised values for D_0 and β.
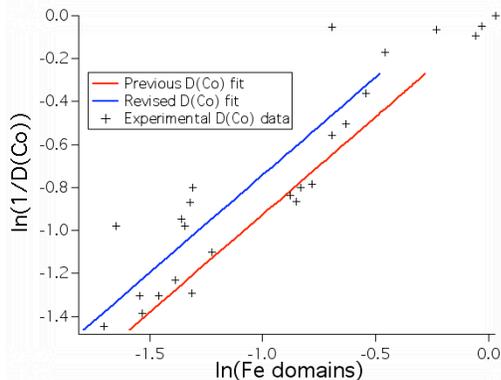

Figure 2: Experimental partition coefficients D for Co, with original published fit and fit from revised values.

Figure 2 plots "Fe domains" [(1-2X(S))/(1-X(S)), 5] against experimental D values determined for Co. We find that our new D_0 and β values are still consistent with results from these laboratory measurements of D(Co) and provide a much improved fit for IIIAB irons, as shown in Fig. 1. We recommend using these

slightly revised D_0 and β values for future work involving D(Co).

Comparison to the IVB Group: Now that we have successfully modeled the fractional crystallization trend of IIIAB irons for 10 elements, we can use the bulk starting liquid compositions of these elements to make comparisons to other iron meteorite groups. Using the starting bulk liquid compositions determined from this study, we plotted the elements used in order of increasing volatility. The starting compositions were normalized first to the CI composition of Ni and then to the CI abundance of each element. The results are shown in Fig. 3 and are compared to the IVB group [7]. Our plot lacks some of the elements reported for the IVB group but adds Sb. The IIIAB group exhibits a flattened profile in low-volatility elements and a less extreme drop in high-volatility elements in comparison to the IVB group that spans several more orders of magnitude overall variations between the elements. Overall, the IIIAB parent core was less depleted in volatile elements than the IVB parent core.
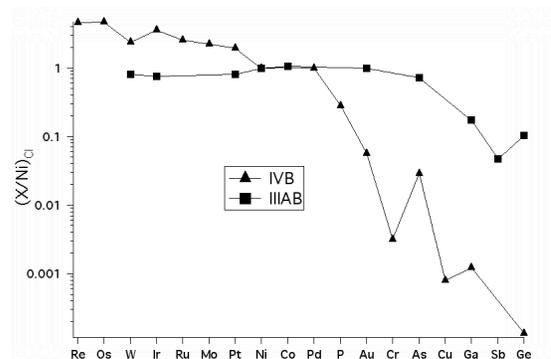

Figure 3: Starting element concentrations normalized to Ni and the cosmic abundance for IIIAB and IVB irons.

References: [1] Chabot, N. L. and Haack H. (2006) In *Meteorites and the Early Solar System II* (Lauretta and McSween eds.), Univ. Arizona Press. [2] Wasson, J. T. and Choi B-G (2003) *GCA* 67, 3079-3096. [3] Chabot N. L. (2004) *GCA* 68, 3607-3618. [4] Wasson, J. T. (1999) *GCA* 63, 2875-2889. [5] Chabot, N. L. and Jones J. H. (2003) MAPS 38, 1425-1436. [6] Chabot, N. L. et al. (2009) *MAPS 44*, 505-519. [7] Campbell, A.J. and Humayun, M. (2005) *GCA*, *69*, 4733-4744.