

FRACTIONAL CRYSTALLIZATION IN IIAB IRON METEORITES: B. T. Fish¹ and M. Humayun¹,
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Introduction: Magmatic iron meteorites represent solid Fe-Ni crystals grown from the liquid metallic cores of differentiated asteroidal and proto-planetary bodies. IIAB irons have the largest known range in Ir contents suggesting the liquid underwent efficient fractional crystallization [1]. For this reason, IIABs serve as an excellent suite against which to test models of fractional crystallization. Sulfur-dependent solid metal/liquid metal partitioning experiments performed by [2] have shown that elemental partitioning (D) is sensitive to the pressure acting on the system. In the context of natural iron meteorites, the degree of pressure applied to the core is directly related to the size of the parent body. Previous research indicated that pressure in the 5-10 GPa range could account for discrepancies between IIAB Sb vs. Au data and the predictions from a fractional crystallization model with 1 bar coefficients [3]. In this study, we re-examine the need to invoke pressure >1 bar establishing new causes for the discrepancy between prediction and observation [2,4,5].

Samples and Analytical Methodology: Twenty six irons (21 IIAB's, 4 IAB's, 1 IIIAB) were cut with a hand saw and set in epoxy resin mounts. The mounts were polished, and rinsed in a sonicated ethanol bath. Analyses of major and trace element compositions were performed on a single-collector Element XR™ ICP-MS coupled with an ESI New Wave Research™ UP193FX laser ablation system following methods of [6]. Bright signals were obtained by using a 100 μm spot size at 50 Hz for 20 seconds (1000 shots) on the UP139FX. The analysis of Sb in IIABs is challenging due to its low concentrations (~40-100 ppb). Brighter Sb signals were obtained using [3] in a second round of data acquisition. This yielded a more precise correlation with Au, i.e. a precise Sb/Au ratio was measured. Relative sensitivity factors for siderophile elements were obtained from NIST SRM 1263a steel, North Chile (Filomena) and Hoba. Each sample was analyzed at five spots, and the elemental compositions were calculated as the average of the five spots. Where identified from P concentrations, spots that hit phosphide inclusions were not included in calculation of the average compositions. Antimony abundances were calculated from the Sb/Au ratios, using Au abundances determined in the first set of measurements.

Results: To test the accuracy of the analyses in this study, our LA-ICP-MS data was cross referenced with IIAB iron INAA data from [1] for Co, Cu, Ga, Ge, As,

Sb, W, Re, Ir, and Pt due to the large sample set (78 irons) to clearly identify element vs. Au trends. For Ru, Re, Os, Ir, and Pt, our data was found to be in agreement with [7,8].

Out of the 78 irons reported by [1], only 15 have reported Sb abundances, and out of those, none were analyzed in this study, so no interlaboratory sample to sample comparison could be made. To check the accuracy of Sb, five irons were used as secondary standards (Henbury, Campo del Cielo, Toluca, Odessa, Dungannon), and the abundances were compared with existing Sb data [9,10]. The Sb abundances were found to be in agreement, indicating that the NIST SRM 1263a steel standardization used for Sb was accurate. We report a reproducibility of ± 5 -10% for the five spots in each of the IIAB samples. However, our Sb data shows an offset 35% higher than that of [1]. The reason for this discrepancy is not known.

Abundances for Re, Os, and Pt in this study are strongly correlated with isotope dilution data from [8], yet Re and Os are both systematically higher in this study by ~17% and abundances for Pt are ~11% higher. However, since they are correlated on the same fractionation line, this offset can be explained by natural variability between iron meteorite samples. This excludes Negrillos and Coahuila, which showed Pt enrichments in this study, and Sikhote-Alin which showed Re near the detection limit for that sample (6 ppb).

Discussion: Siderophile element partitioning is dependent on S concentration in the melt. Since S is almost perfectly incompatible in the melt fraction ($D=0.01$), its concentration increases in the melt over the course of core crystallization until the Fe-FeS eutectic is reached at 31 wt. % S [5]. Previous work by [11] modeled fractional crystallization in Ge vs. Au plots, and concluded that the IIAB core had an initial S content of 18 wt. %. This study was able to reproduce those results, and used an initial 18 wt. % S content for fractional crystallization models of IIAB irons.

Evidence for low-pressure fractional crystallization in IIAB irons. Elements including Cu, Ga, Pd, W, Re, Os and Ir all plotted trends vs. Au that were successfully predicted by fractional crystallization using 1-bar partition coefficients. No change in partitioning between low and high pressure is seen in W, Re, Os, or Ir since their partition coefficients are not pressure sensitive [2]. Due to the strong dependence on pressure that

D(Pd) exhibits [2], the clear agreement of Pd vs. Au IIAB data with models using 0.1 MPa partition coefficients (Fig. 1) was a significant piece of evidence supporting low-pressure fractional crystallization.

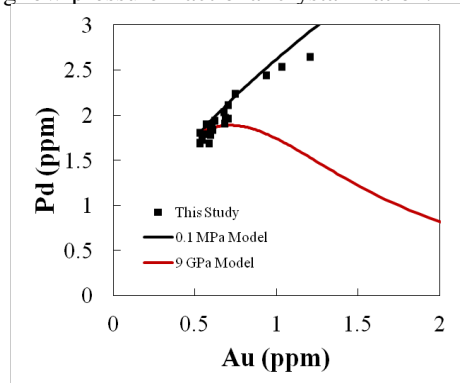


Figure 1: Palladium vs. Au data for IIAB irons fitted to fractional crystallization models.

Improved partition coefficients for As. A particularly important observation was that the As vs. Au data did not follow models using 0.1 MPa partition coefficients (Fig. 2). After close examination of the parameterization used by [2] for 1-bar As partitioning, the S-dependent experimental data that falls between 18-31 wt. % S was found not to fit the parameterized curve of [2]. Since this is the critical S range relevant to modeling IIAB irons, the mismatch results in inaccurate modeling of the As vs. Au data for IIAB irons (Fig. 2).

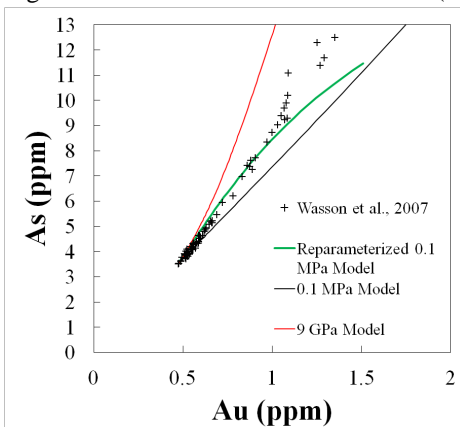


Figure 2: As vs. Au data for IIAB irons [1] superimposed onto fractional crystallization models.

In order to develop a model that better fits the experimental D(As) results, the experimentally obtained D values obtained at 18 wt. % S and higher were selected to accurately represent the S range proposed for the IIAB core. A best fit line to this data yielded an exponential formalism that more accurately captured the experimental partitioning data in this range of S values for 0.1 MPa partition coefficients (Fig. 3).

Using this new parameterization for D(As), a new fractional crystallization model was applied to the As vs. Au data, which was able to better represent the behavior of the IIAB irons as shown by the green line in Fig. 2. Despite the closer fit to the data, it should be noted that this is not a permanent fix that can be ubiquitously applied to every modeled element, nor does this new model successfully capture the behavior of As in the more evolved IIB irons. A more thorough experimental investigation is required into siderophile element partitioning and revised parameterization schemes may be needed to fit the data.

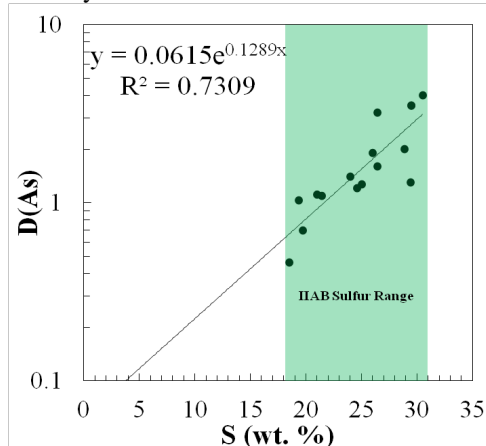


Figure 3: Exponential formula developed in this study used to model experimental D(As) [2] between 18-31 wt. % S.

The failure of As to fit the low pressure model proposed by [5] prompted an investigation into other elements trends that also failed their low pressure models. Similar results to As were observed in Ru and Rh, but acquiring the data necessary to develop new parameterizations for those elements would require new partitioning experiments that are beyond the scope of this study.

References: [1] J.T. Wasson et al. (2007), *GCA*, 71, 760-781. [2] N. L. Chabot et al. (2011), *EPSL*, 305, 425-434. [3] B. Fish and M. Humayun (2017), *Lunar and Planet. Sci. Conf.*, #1714. [4] N. L. Chabot and J. H. Jones (2003), *Meteorit. Planet. Sci.*, 38, 1425-1436. [5] N. L. Chabot et al. (2009), *Meteorit. Planet. Sci.*, 44, 505-519. [6] M. Humayun (2012), *Meteorit. Planet. Sci.*, 47, 1191-1208. [7] E. Pernicka and J. T. Wasson (1987), *GCA*, 51, 1717-1726. [8] D. L. Cook et al. (2004), *GCA*, 68, 1413-1431. [9] J. T. Wasson (1999), *GCA*, 63, 2875-2889. [10] J. T. Wasson and G. W. Kallemeyn (2002), *GCA*, 66, 2445-2473. [11] J. I. Goldstein et al. (2009), *Chemie der Erde*, 69, 293-325.