COOLING RATE ESTIMATES FOR IAB AND IIICD IRON METEORITES.
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Introduction: Measurement of the size of the high-Ni phase in the cloudy zone microstructure can be used to determine the relative cooling rates of meteorites [1]. The scanning electron microscope was used to measure the size of the high-Ni island phase in 10 members of groups IAB and IIICD iron meteorites (Table 1). These size measurements were used to determine the relative cooling rates of these meteorites. We use these data in order to distinguish whether the subgroups of the IAB and IIICD irons formed in the same or different pools of metal distributed throughout the parent asteroid. These irons have very different origins from most groups as they are not derived from asteroidal cores [2]. In addition, their cooling rates have not been studied recently. The most recent cooling rate estimates are 15 years old [3,4].

Table 1 – Meteorite samples studied

Name	Chemical Group [2]	Ni Content (wt%) [2]
Canyon Diablo	IAB-MG	6.93
Gladstone (iron)	IAB-MG	6.56
Mount Ayliff	IAB-MG	7.35
Toluca	IAB-sLL	8.02
Goose Lake	IAB-sLL	8.24
Balfour Downs	IAB-sLL	8.38
Edmonton (KY)	IAB-sLM (IIIC)	12.9
Carlton	IAB-sLM (IIIC)	13.2
Dayton	IAB-sLH (IIID)	17.1
Woodbine	IAB-Pitts Gr	10.05

Wasson and Kallemeyn [2] grouped together into a "IAB complex" what had been previously called groups IAB and IIICD and many chemically similar irons. They then divided this into a main group (IAB-MG) and numerous sub groups including IAB-sLL which contains what were high-Ni IA irons, IAB-sLM (previously IIIC) and IAB-sLH (previously IIID). (sLH is a subgroup *l*ow in Au and *h*igh in Ni.)

Cooling Rate Method: The cloudy zone region in the taenite of meteoritic metal consists of a microstructure of a low-Ni honeycomb phase and a high-Ni particle or island phase, which most likely was formed by a spinodal reaction. The size of the high-Ni island particles is a function of the cooling rate of the parent body of the meteorite. The slower the cooling rate, the larger are the high-Ni phase particles. High resolution scanning electron microscopy is usually necessary to measure the size of the high-Ni particles since the particles are submicron in size.

Experimental Method: All the meteorite samples were mounted in epoxy and were polished with 3 μm and 1μm diamond paste, followed by 0.05 μm silica. After polishing, the samples were etched using a 1% nital solution which preferentially removed the low-Ni honeycomb phase and provided for the necessary contrast between the high-Ni island phase and the honeycomb phase for measurement with the scanning electron microscope. Photomicrographs of cloudy zone regions were taken using a FEI Magellan field emission SEM 400 which has a resolution of 1 to 2 nm. All images were taken at the outer edge of the cloudy zone region, along the interface with the tetrataenite phase where the local Ni content is constant [1]. A minimum of 90 measurements of the high-Ni phase were made in 3 separate taenite bands in each meteorite.

Results: Measurements of the high-Ni particle size varied from 85 to 120 nm. The $\pm 2\sigma$ errors of the mean values are shown in Fig. 2. The errors of the particle sizes are very small compared to the total range of particle sizes suggesting that a significant variance in the particle sizes exists. The range of particle sizes is plotted in Fig. 1 together with particle sizes and metallographic cooling rates for groups IIIAB, IVA, IVB and pallasitic metal. A least-squares line for the latter implies that the cooling rates in the 10 IAB and IIICD irons varied from 8 K/Myr for Toluca to 24 K/Myr for Dayton. These results suggest a significant range of cooling rates for the IAB/IIICD irons. All of the estimated cooling rates fall in the range of the pallasites and are significantly slower than the magmatic iron groups IIIAB, IVA, and IVB.

Discussion: Group IAB and IIICD iron meteorites were reclassified by Wasson and Kallemeyn [2]: Table 1 and Figs. 2 and 3 show these classifications. The three main group (MG) IAB irons do not show a significant range of cooling rates, consistent with an origin from a single molten metallic pool [2]. However, Toluca (IAB-sLL), which has essentially identical mineralogy to the IAB-MGs [5], has a significantly slower cooling rate suggesting that data for more IAB-MGs may show a significant spread of cooling rates. Any significant spread for IAB-MG irons would argue against their formation in a single large impact that extensively melted the target body [2]. Such a spread in cooling rates for IAB-MG irons, if it exists, would favor a non-collisional heat source [6] such as ^{26}Al. This heat source could more plausibly create several metallic pools in a single body, assuming that the concentration of ^{26}Al was not sufficient to cause extensive silicate melting.

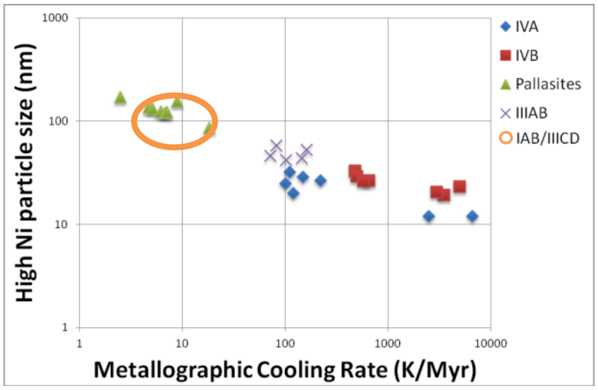

Figure 1 – High Ni particle size in the cloudy taenite zone vs. metallographic cooling rate for iron and stony-iron meteorites [7], [8], [9], [10]. The oval for IAB and IIICD irons shows their range of particle sizes.

The MG's and sLL's (formerly all classed as IAB's) show a range in high-Ni particle sizes of approximately a factor of 1.5 (Fig. 2), while the cooling rates of these groups have a range that varies by a factor of over 2 (Fig. 3). The variances in high-Ni phase particle sizes and cooling rates suggest that the MG's and sLL's formed in different pools of molten metal in the parent asteroid. Similary the sLM's (formerly IIIC's) and sLH (formerly IIID) samples show a range of particle sizes (Fig. 2) and cooling rates (Fig. 3). Likewise, these variations between the data of these groups suggest that they also formed in different pools of metal in one or more parent asteroids.

Figure 1 and a similar figure in Yang et al. [10] show that iron meteorite groups that are thought to be derived from asteroidal cores (IIIAB, IVA, and IVB) cooled more rapidly than the metallic meteorites containing angular silicate rock fragments, viz., IAB irons, pallasites and mesosiderites. If they had formed and cooled in similar sized bodies, one would have expected precisely the opposite trend, with core samples having slower cooling rates than impact mixtures of molten metal and silicate. These cooling rates and the presence of angular rock fragments in the stony-irons suggest that differentiated asteroids were involved in early impacts that drastically rearranged their interiors and that iron meteorites from cores cooled with little or no silicate mantles [9, 10]. Vesta may be the only example of an asteroidal core that cooled inside a thick silicate mantle.

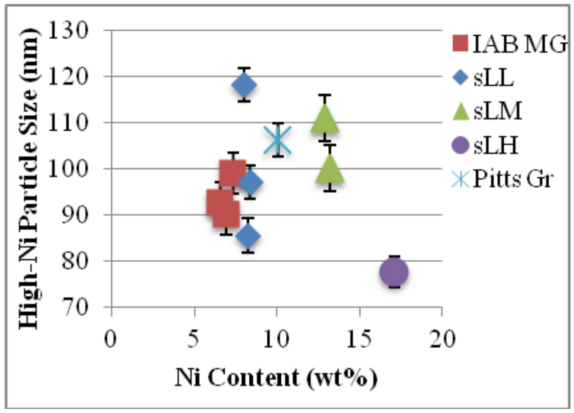

Figure 2 – High-Ni Particle Size vs. Ni content

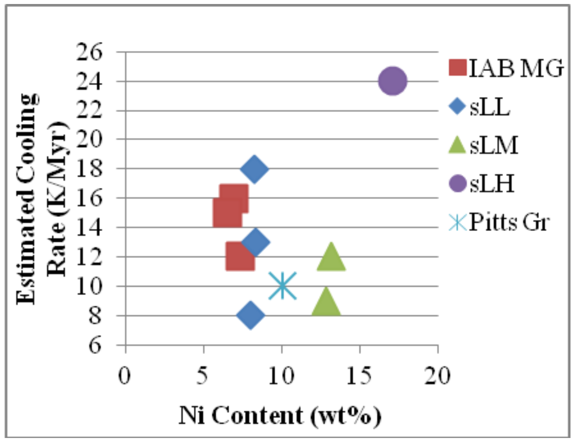

Figure 3 – Cooling Rate vs. Bulk Ni content

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