THERMAL HISTORIES OF GROUP IAB AND RELATED IRON METEORITES AND COMPARISON WITH OTHER GROUPS OF IRONS AND STONY IRON METEORITES. J. I. Goldstein[1], E. R. D. Scott[2], T. Winfield[1], and J. Yang[3], Department of Mechanical and Industrial Engineering, University of Massachusetts, Amherst, MA 01003, USA. [2] Hawai‘i Institute of Geophysics and Planetology, University of Hawai‘i at Mānoa, Honolulu, HI, 96822, USA. [3] Carl Zeiss Microscopy, LLC, One Zeiss Dr., Thornwood, NY 10594, USA. E-mail: jig0@ecs.umass.edu

Introduction: Within most iron meteorite groups, chemical trends are broadly consistent with fractional crystallization, implying that each group formed from a single molten metallic pool or core. Hf-W isotopic systematics suggest these groups are derived originally from bodies that accreted <1 Myr after CAI formation and melted to form cores. However, diverse cooling rates for each group suggest they cooled in metallic bodies with little or no silicate mantle. The silicate-bearing iron meteorite groups, IAB and IIE, are rich in silicates and have very different elemental trends showing that they were not fractionally crystallized. Each group was probably not derived from a single metallic pool. Impacts probably mixed molten metal and silicates creating numerous metallic pools [1].

Group IAB irons and irons with similar chemical characteristics were lumped by Wasson and Kallemeyn [1] into a IAB complex composed of main group IAB and many subgroups including sLL (high-Ni group IABs [2]), sLM (group IIIC), sLH (group IIID), and sHL and various meteorites like Pitts and San Cristobal (called anomalous IAB [2]). Although group IAB is the second largest group and is closely related to the winonaites, there are few measured metallographic cooling rates [3] and even these measurements do not incorporate modern ternary phase diagrams and diffusion coefficients. Cooling rates will help us understand the structure of the IAB parent asteroidal body or bodies, how silicates were incorporated in the parental melt, the solidification process, and will provide constraints on burial depths and body sizes.

Cooling rate measurements: Metallographic cooling rates are difficult to obtain for many IAB meteorites as Widmanstatten growth is impeded by silicate and phosphide inclusions. In coarse octahedrites significant kamacite plate impingement takes place. Little taenite phase remains and it is difficult to determine the orientation of the kamacite-taenite interface with the sample surface.

Metallographic cooling rates at ~500-600^0 C were measured for four IAB group irons with medium or fine octahedral Widmanstatten patterns by applying the Wood [4] or Goldstein and Ogilvie [5] methodology based on Ni gradients in taenite and bulk Ni and P contents. The Ni gradients or the taenite central Ni content were compared with calculated Ni gradients calculated for various cooling rates. The cooling rate is determined at the point at which calculated and measured Ni data converge.

To obtain cooling rates for other IAB irons, we measured the sizes of the high-Ni particles in the cloudy zone microstructure, which formed at ~350°C. We compared these sizes with particle sizes in the four irons with measured cooling rates and well developed Widmanstatten patterns. A minimum of 90 measurements were made on 3 separate taenite bands to obtain the average cloudy taenite particle size in each meteorite. We then used a calibration curve of metallographic cooling rate vs high-Ni taenite particle size for the four irons to derive cooling rates for all the IAB irons.

Results: Metallographic cooling rates and high-Ni taenite particle sizes were measured for 4 IAB complex irons: Toluca (sLL), Pitts (Pitts group), Carlton (sLM, IIIC) and Tazewell (sLH, IIID). The cooling rates vary between 10 and 20 K/Myr and the high-Ni particle sizes between 120 and 85 nm. Figure 1 shows the variation of high-Ni particle size vs metallographic cooling rate for the 4 IAB complex irons as well as their relation to irons in groups IIIAB, IVA, and IVB and metal particles in pallasites, H chondrites, and mesosiderites [1, 6-8]. The high-Ni particle size in the CZ of meteorites in all these groups increases with decreasing cooling rate. Figure 2 shows the variation of high-Ni particle size vs metallographic cooling rate for the 4 IAB complex irons and a comparison of these values to the high-Ni particle size vs metallographic cooling rate relationship obtained for 7 groups of meteorites.

Measurements of high-Ni taenite particle size were obtained for 4 IAB MG, 4 IIID, 2 IIIC, 2 Pitts group, 3 sLL, 1 related to IAB (San Cristobal), and 1 sHL iron (Algoma) using the IAB calibration curve for the 4 IAB irons in Fig. 2. Figure 3 shows the variation of calculated cooling rate with bulk Ni content for the 17 Group IAB irons. The ranges observed within IAB and its subgroups are relatively small:-IAB MG 16-20 K/Myr, sLL 12-22 K/Myr, sLH IIID 20-26 K/Myr, sLM IIIC 13-16 K/Myr, and Pitts Group 14-16 K/Myr. For sLH IIID, cooling rate decreases with increasing Ni content (Fig. 3). In addition, cooling rates for sub groups IIIC and IIID appear to be distinctly different. Cooling rates of the IAB irons overlap the cooling rates of H chondrites and are faster than those of pallasites and mesosiderites (Fig. 1). Cooling rates of the IAB irons are much slower than those of the fractionally crystallized groups: IIIAB by a factor of 2 to 10, IVA by a factor of 4 to 200+, and IVB by 15 to 200.

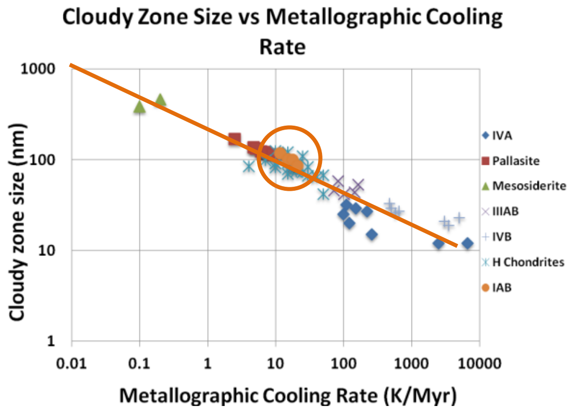

Figure 1. Cloudy zone particle size vs metallographic cooling rate for 7 groups of meteorites (72 meteorites). The 4 IAB complex irons are outlined by a circle.

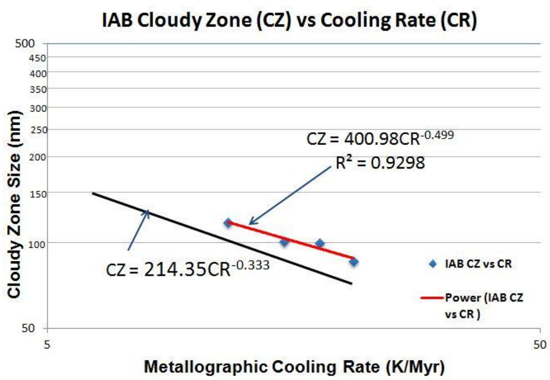

Figure 2. Variation of cloudy zone particle size vs. metallographic cooling rate for 4 IAB complex irons (red line) compared to the variation for 7 groups of meteorites (black line). The IAB iron offset is relatively small (Note Fig. 1).

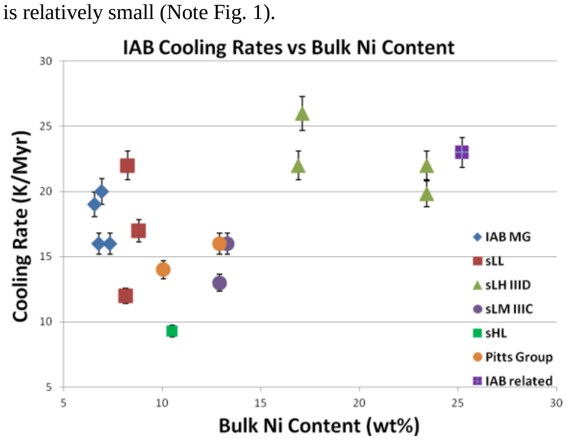

Figure 3. Cooling rates for 17 members of the IAB complex vs. bulk Ni. Cooling rates were derived from cloudy zone particle sizes using the red calibration line in Fig. 2.

Discussion: The cooling rate ranges in the sLL subgroup and the IAB complex are too large for an origin in a single well insulated metal pool. Cooling rate measurements and the link with winonaites suggest that the IAB complex irons cooled at depth at different locations in one or more silicate-rich bodies. The crystallization history of IAB irons is substantially different from that of the fractionally crystallized groups and from simple fractional crystallization of an undisturbed metallic melt. The cooling rate data are consistent with an origin in metallic pools formed by either impact melting of cold chondritic material or catastrophic impact fragmentation and reassembly of a body that was already hot and partly molten.

The differences between the cooling rates of IAB irons and other metal-rich meteorites (Figs. 1 and 3) can be understood in terms of their proposed early impact histories when differentiated asteroids were partly molten. The fastest cooled meteorites are the fractionally crystallized groups IIIAB, IVA, and IVB. If they had cooled in well-insulated cores we might expect they would have the slowest cooling rates. However, the significant cooling rate ranges within each group suggest they cooled in metallic bodies with little or no silicate insulation following impacts that separated core and mantle material [9]. The slowest cooled metal-rich meteorites--pallasites and mesosiderites, and IAB complex irons --are all thought to have formed by impacts that mixed metal and silicate and created bodies predominantly composed of silicate in which metal-rich meteorites cooled slowly within fragmental silicate material. Thus cooling rate data are key constraints on meteorite origins.

The lack of shock features in IAB silicates and winonaites [10, 11] as in pallasites and mesosiderites favors low-velocity impacts during accretion [12] for metal-silicate mixing rather than subsequent high velocity impacts after asteroidal orbits were excited. Low velocity grazing impacts during accretion were also invoked to explain how metallic bodies might be produced with little or no silicate insulation [6, 9].

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