THE NORDHEIM TRIO: IAB-an IRONS THAT EXPERIENCED DEVOLATILIZATION AND SILICATE VAPORIZATION

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IAB-complex: There are more than 330 IAB-complex irons divided into a main group, five subgroups with distinct Au and Ni concentrations, two grouplets, and ~30 ungrouped members [1]. The IAB-complex may represent samples derived from different asteroids of similar composition [1] that experienced varied thermal and collisional histories.

Nordheim Trio: Three ungrouped ataxites (the "Nordheim Trio") appear to be extensively devolatilized IAB-an meteorites. ALH 77255 (ALH; 767 g) has a dense plessitic matrix with oriented kamacite spindles; schreibersite was not reported [2]. ALH contains a 5-mm amorphous-silica spherule that is colorless and homogeneous [3]. ALH structurally resembles Nordheim (Nord; 15.15 kg) [2] which has a dense matrix of intergrown kamacite and taenite oriented in a Widmanstätten pattern [4]. Also present are kamacite spindles and small daubréelite and troilite grains. Schreibersite is absent. Babb's Mill (Blake's Iron) (Babbs; 136 kg) has a schreibersite-free polycrystalline kamacite matrix [5].

Oxygen-Isotopic Composition: The ALH silica spherule plots among IAB irons in O-isotopic composition [6].

Bulk Chemical Compositions: We used the large data set of iron-meteorite compositions, compiled by John Wasson, to determine the proper classification of the Nordheim Trio and help illuminate its thermal history.

Common siderophile elements. A diagram of Co vs. Ni shows that the Trio plots within the IAB main group.

Refractory siderophile elements. Plots of refractory siderophile elements show the Nordheim Trio falls within (or near the edges of) the IAB-complex field. The Ir vs. Re diagram shows IAB samples forming a narrow trend; ALH and Nord plot at the upper extreme of the trend and Babbs plots below the center. Relative to average IAB samples, ALH and Nord are enriched in Re, Ir and Pt and have average W; Babbs has average concentrations of Re and Ir and lower than average W and Pt. Mass balance suggests that the moderate enrichment of refractory siderophiles in the Nordheim Trio relative to mean IAB irons is due, at least in part, to the loss of moderate volatiles.

Moderately volatile elements. The Nordheim Trio is highly depleted in moderate volatiles relative to IAB. The absence of schreibersite is consistent with low bulk P compared to IAB irons (which commonly contain schreibersite). Ga vs. Ge shows that the three samples lie along an extrapolation of the narrow IAB trend toward lower concentrations.

Classification: The Nordheim Trio should be classified as IAB-an irons. This is based on the O-isotopic composition of the ALH silica spherule and the concentrations of common and refractory siderophiles in all three meteorites.

IAB Formation Models: The slopes of IABs on element-element diagrams do not conform to formation by fractional crystallization [7]. Many samples contain silicate inclusions with chondritic compositions; a few contain recrystallized chondrules [8]. IAB irons may have been derived from impact-generated melts on chondritic parent bodies.

Depletions of Volatiles by Giant Impacts: IVA irons resemble LL4-6 chondrites in mean $\Delta^{17}O$, $\delta^{18}O$ and $\delta^{17}O$ and appear to have experienced significant loss of volatiles relative to LL: S – 84-97%, Ga – 93%, Ge – >99% [9], probably caused by volatilization during a major impact [9,10]. By analogy, we suggest the large depletions in moderate volatiles in the Nordheim Trio relative to mean IAB irons resulted from a major impact on a separate chondritic asteroid of IAB composition. The collision disrupted the body and caused extensive heating, melting, devolatilization and vaporization of the metal and silicate. Relative to mean IAB irons, the metal that crystallized from metallic melts within the Nordheim Trio's asteroid fragments was depleted in P by 81-90%, Cu (67-95%), Ga (>99%), Ge (>99%), As (92-98%) and Au (75-96%). Nordheim was derived from a fragment that was somewhat less depleted in volatiles than ALH and Babbs and cooled more slowly (based on Nordheim having a Widmanstätten pattern).

Rapid Cooling of ALH and Babbs: After melting and devolatilization, portions of the asteroid quenched. This is shown by the ALH silica glass spherule and the absence of increased Ni in the centers of taenite grains in Babbs [5].

Formation of Free Silica: Impact-vaporization of portions of the chondritic asteroid precursor of the Nordheim Trio would yield a gas of quasi-solar composition highly depleted in H_2 and He, with lesser depletions in moderate volatiles. The gas could acquire a bulk Mg/Si ratio <1 after condensation and isolation of forsterite. Silica could then co-condense with low-Ca pyroxene [11] as found in silicate assemblages in the Steinbach and São João Nepomuceno IVA irons [9]. Isolation of the low-Ca-pyroxene+silica assemblage from the rapidly cooling gas would cause Mg/Si to decrease further, allowing amorphous silica to condense. This may account for the silica glass spherule in ALH. Condensed grains of forsterite and low-Ca pyroxene were not incorporated into the extant ALH sample.

References: [1] Wasson J.T. and Kallemeyn G.W. (2002) *GCA* 66:2445-2473. [2] Clarke R.S. (1982) *Smith. Contrib. Earth Sci.* 24:49-56. [3] Clarke R.S. (1984) unpublished manuscript. [4] Buchwald V.F. (1975) *Handbook of Iron Meteorites*, Univ. Cal. Press. [5] Yang J. et al. (2011) *MAPS* 46:1227-1252. [6] Clayton R.N. and Mayeda T.K. (1996) *GCA* 60:1999-2017. [7] Scott E.R.D. and Wasson J.T. (1975) *Rev. Geophys*. 13:527-546. [8] Schrader D.L. et al. (2017) *GCA* 205:295-312. [9] Wasson J.T. et al. (2006) *GCA* 70:3149-3172. [10] Yang J. et al. (2008) *GCA* 72:3043-3061. [11] Komatsu M. et al. (2018) *PNAS* 115:7497-7502.