TEXTURAL AND MINERALOGICAL VARIATIONS IN WINONAITES: CLUES TO THE HISTORY OF THE IAB IRON-WINONAITES PARENT BODY

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Introduction Stony iron meteorites and primitive achondrites provide our best record of processes of partial melting and incomplete differentiation. Primitive achondrites include the acapulcoites, lodranites, winonaites, and silicate inclusions in IAB and IIICD irons [1]. This work is the first comprehensive study of the winonaites (Winona, Pontlyfni, Mt. Morris (Wis.), Tierra Blanca, Yamato 74025, Yamato 75300, and Yamato 75305 [2]). Other meteorites previously called winonaites are now known to be acapulcoites (e.g., Acapulco and ALH A77081 [5]). The winonaites and IAB’s are distinguished from other primitive achondrite groups by oxygen isotopes [3] and their reduced mineral chemistry. The distinction between IABs and winonaites is somewhat arbitrary, but winonaites are those members that are stony and do not have a metallic matrix. Previous work on winonaites included chemical and mineralogical analyses [2, 4-9], evidence for high temperature metamorphism [2] and relationship to silicates in IAB irons [4, 5, 10, 11]. The origin of these meteorites involved metamorphism, partial melting, and brecciation on the parent body.

Results We have examined eleven PTS of the winonaites, including all members except Y-75305. The winonaites are characterized by roughly chondritic mineralogy of orthopyroxene (45-55 vol.%), olivine, plagioclase, Fe,Ni metal, troilite, clinopyroxene, and minor daubreelite and schreibersite [2, 5-7]. Silicates are magnesium-rich, with olivine composition ranging from Fa0.8 (Pontlyfni) to Fa5.1 (Winona) and low-Ca pyroxene ranging from Fs0.5 (Pontlyfni) to Fs8.5 (Winona) [2, 5-7]. The minerals do not appear to exhibit zoning. Estimates of two-pyroxene equilibration temperatures vary from 850 to 1200°C. The overall textures range from fine- to medium-grained with abundant triple junctions. Chondrules have not been previously reported, but we have found one in Mt. Morris. Slight undulatory to sharp extinction in olivine indicate that shock effects are minor to non-existent (S1-S2). Mt. Morris, Winona, and Tierra Blanca are all heavily weathered, while in the Antarctic winonaites and Pontlyfni, a fall, weathering is minor.

Several of the winonaites are heterogeneous in grain size or mineralogy on a scale of hundreds of microns. Pontlyfni has a very fine-grained texture. Mt. Morris and Winona exhibit a mixture of coarse-grained (avg. 300-500 µm) and fine-grained areas (80-100µm). These coarse-grained areas occur mainly as clumps, occasionally as veins, and are sometimes located near pockets or veins of weathered Fe,Ni and FeS. Coarse-grained areas in Winona and Mt. Morris are dominated by olivine, in sharp contrast to the host which is dominated by opx. Y-75300 shows two layers of distinct grain sizes and troilite content [2]. Y-74025 has slightly larger grains with pyroxene poikilitically enclosing olivines. Tierra Blanca exhibits an overall coarse-grain size (avg. 197 µm) with large (~3 mm) pyroxenes which poikilitically enclose olivines.

Formation of Winonaites It seems likely that both metamorphism and partial melting of a chondritic precursor (suggested by a relict chondrule and chondritic mineralogy) played parts in the formation of the winonaites. The best evidence for partial melting comes mainly from Winona and Tierra Blanca. Winona has coarse-grained areas that are olivine-rich and depleted in plagioclase and pyroxene, indicating that these areas are residues of partial melting. These areas are near and, sometimes in contact with, Fe,Ni-FeS grains that may be the signature of Fe,Ni-FeS partial melt. Tierra Blanca has large, mm-sized pyroxenes, indicative of trapped partial melt.

The winonaites group exhibits a range of degrees of partial melting. Silicates in Pontlyfni probably never melted and, thus, the temperature never exceeded ~1050°C. This is also true of the fine-grained areas in Winona and Mt. Morris. However, the coarse-grained areas in these meteorites experienced a high percentage of partial melting; they appear to be residues produced by ~40% partial melting [12]. The overall coarse texture and large poikilitically pyroxene grains of Tierra Blanca indicate that it experienced an intermediate level of silicate partial melting consistent with its two pyroxene temperature (1200°C); to a lesser extent, Y-74025 may have a similar history.

A remarkable feature of this group is the apparent heterogeneity within a single section (e.g., Winona) on a mm scale. The fine-grained "chondritic" lithology in association with coarse-grained residues, implies a range of heating and temperatures from ~950°C (metamorphosed, but unmelted) to ~1350°C (40% partial melting [12]). The question is whether the partial melting occurred in situ or took place elsewhere and the lithologies were subsequently mixed by brecciation.
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Two possible in situ sources are shock melting and a non-collisional heat source. Shock melting is not likely to explain the heterogeneous heating. The absence of significant shock effects in winonaites (shock stage S1-2) and the composition of the coarse-grained areas argue against this hypothesis. Impact-melt pockets are typically of whole rock composition or slightly enriched in plagioclase and have glassy to cryptocrystalline textures [13], in contrast to the olivine dominated composition of the coarse-grained areas in winonaites.

The second possibility involves injection into the fine-grained matrix material of hot metal-sulfide veins from a hotter region of the parent body. This might cause either solid state coarsening of the material or partial melting. Neither seems likely. The veins of molten Fe,Ni-FeS would cool too fast (~mins) to cause coarsening of the olivines to the sizes observed. Further, the coarsening should be uniform around the veins, which is not observed. In addition, this process would not cause the loss of pyroxene and plagioclase. These phases could be lost by partial melting, but the temperatures of a sulfide melt would not be high enough to cause the required amount of partial melting. Even if a silicate partial melt could form, it would accumulate nearby which is not observed. Finally, a sulfide rich vein in Winona cuts across fine grained material with no evidence for partial melting or coarsening.

We believe that the coarse and fine grained areas were heated and melted elsewhere on the parent body and were then mixed by brecciation. One might suppose shock features should accompany brecciation, but this is not necessarily the case. If the colliding bodies were of equal size, disruption of the target body would take place at very low velocities (<1 km/s) and shock effects would be minimal or absent. Furthermore, even in a hypervelocity impact, at least 75% of the target material, though brecciated, is shocked to < 0.1 GPa [14]. The peak metamorphic temperature was achieved after brecciation.

Relationship to IAB Irons: Based on oxygen isotopes [3], mineral chemistries [4], and silicate textures [4], it appears that winonaites and IAB irons are from a common parent body. However, the exact relationship between the two groups is unclear. It has been suggested that silicate-bearing IABs are the core-mantle boundary, while winonaites may sample the overlying mantle [1]. Arguments have also been made that winonaites are "removed" silicate inclusions from IAB's, with the removal occurring either upon ejection from the parent asteroid or, at least in the case of the Mt. Morris (Wis.) winonaites and Pine River IAB iron, during or after fall to Earth [8].

Our studies of winonaites, in conjunction with a brief examination of IAB's, reveals several important similarities and differences. Some silicates in IAB's (e.g., Pine River, Landes) resemble very closely some Winona-Mt. Morris-type winonaites in both texture and mineralogy, Campo del Cielo even shows an increase in grain size relative to a Fe,Ni metallic boundary, reminiscent of Y-75300. However, there are no inclusions among the IAB silicates that resemble the textures of Pontflyni and Tierra Blanca, nor is there an analog among the winonaites for Pontflyni and Tierra Blanca-type winonaites. Campo del Cielo even shows an increase in grain size relative to a Fe,Ni metallic boundary, reminiscent of Y-75300. However, there are no inclusions among the IAB silicates that resemble the textures of Pontflyni and Tierra Blanca, nor is there an analog among the winonaites for Pontflyni and Tierra Blanca-type winonaites.

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Do these differences reflect sampling biases or real differences between these groups? The answers to these questions will probably become clear when a thorough study of the IABs is conducted. Our future goal is a complete study of the relationship between the winonaites and silicate inclusions in IAB irons.