ON THE ORIGIN AND EVOLUTION OF WINONAITE AND IAB IRON METEORITE PARENT BODIES: APPLICATION OF SILICATE GEOSPEEDOMETRY AND APATITE CHARACTERIZATION

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Introduction: Silicate inclusions in primitive achondrite winonaites and IAB iron meteorites record a complex history of heating, brecciation, fragmentation, and metamorphism. Stony winonaite and IAB irons are thought to come from the same parent asteroid because of their similar silicate mineralogy, mineral chemistry, and oxygen isotopic composition [1]. While both meteorite groups exhibit geochemical trends consistent with differentiation and partial melting, there are questions about whether the compositions of IAB silicate inclusions reflect precursor chondrites or parent body processes. The most common model of parent body evolution is that the winonaite-IAB parent asteroid underwent incomplete differentiation followed by catastrophic impact breakup and reassembly [2]. Application of thermometers sensitive to different temperature intervals and characterization of apatite volatile chemistry that reflects different melt sources and/or melting events place constraints on these processes.

To understand the origin and evolution of winonaite-IAB iron parent bodies, we applied traditional two-pyroxene [3] and Ca-in-olivine thermometry [4] along with recently developed REE-in-two pyroxene [5] and Mg- and REE-in-plagioclase-clinopyroxene [6] thermometers that rely on relatively slow diffusive exchange of REEs between mineral pairs to constrain peak or near-peak temperatures. These methods have helped constrain the thermal histories of ordinary chondrites and other primitive achondrites including acapulcoites and lodranites, suggesting early fragmentation and reassembly in at least four meteorite parent bodies [7,8]. Peak temperatures of IABs are scattered but consistent with thermal metamorphism, and perhaps mechanical phase mixing, before and/or during fragmentation. Winonaites record more self-consistent thermal histories and also record fast cooling rates consistent with fragmentation.

Samples and Methods: We studied six winonaites (Graves Nunataks (GRA) 12510, Queen Alexandra Range (QUE) 94535, Northwest Africa (NWA) 4024, NWA 6448, NWA 725), and three IAB irons with silicate inclusions (Grosvenor Mountains (GRO) 06050, Larkman Nunatak (LAR) 06876, and Maslyanino). Texture and modal mineralogy were explored using X-ray elemental maps using an SX100 electron microprobe at Brown University. Major and minor element compositions of cpx, opx, plg, and ol were measured using an SX100 electron microprobe at University of Tennessee. Silicate trace element compositions including REEs and Y were measured by LA-ICP-MS at University of Texas and Brown University. Apatite major and minor element compositions including F and Cl were measured using the JEOL 8530 field emission electron microprobe at NASA JSC. The apatite X-site hosts F, Cl, and OH as essential structural constituents so OH was calculated as the missing component (MC = 1 - F - Cl) or if F + Cl > 1, then F = 1 – Cl because F can be overestimated by electron microprobe analysis in high F apatite.

Results and Discussion: Cpx REEs(+Y) are typically above detection limit and exhibit a negative Eu anomaly. Opx light-REEs and plg heavy REEs(+Y) are typically below detection limits, but light REEs (in plg) and heavy REEs (in opx) exhibit smooth and systematic chondrite normalized patterns, suggesting the data are good quality. REE patterns are roughly consistent among meteorites except for IABs. This REE variability indicative of disequilibrium partitioning translates into high peak temperature variability suggesting an exogenic origin for some silicate inclusions and thermal metamorphism before and/or during fragmentation and reassembly in IABs. Where cooling rates could be determined, the fast rates at high temperature of ~900-1000 °C (0.5-2 °C/year) are orders of magnitude more rapid than lower temperature metallographic rates [9] and those anticipated for parent bodies with onion shell configurations (3-7 x 10^{-5} °C/year) [7]. This thermal history is consistent with reassembly after early fragmentation.

Apatite in winonaite and IAB iron meteorites exhibit high intersample variability in X-site composition that range from 13-61% Cl and 29-87% F (winonaites: NWA 6448 with $Cl_{61}F_{29}MC_{10}$ and QUE 94535 with $Cl_{37}F_{63}$; IABs: LAR 06876 with $Cl_{61}F_{29}MC_{10}$, Maslyanino with $Cl_{32}F_{53}MC_{15}$, and GRO 06050 with $Cl_{13}F_{87}$). The most Cl-rich apatite in NWA 6448 and LAR 06876 are similar to apatite compositions in some H, L, and LL ordinary chondrites [10], but apatite in the other samples are more F-rich and plot outside the chondritic range. The more F-rich compositions of apatite are consistent with the expected apatite X-site evolution of apatite that remains in the residue after partial melting, as F is much more compatible in apatite than OH and Cl [11]. Future work will explore any corrolations between apatite X-site composition and other indicators of partial melt extraction from primitive achondrites.

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