COMPOSITIONAL TRENDS AMONG IID RONS; THEIR POSSIBLE FORMATION FROM THE P-RICH LOWER MAGMA IN A TWO-LAYER CORE

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Introduction. It was previously known that S contents were low in the two volatile depleted magmatic iron-meteorite groups IVA and IVB. Group IID, with 21 members, the fourth largest magmatic group, also has a low S content but has high contents of other volatiles. We suggest that this surprising juxtaposition is best understood by two episodes of core formation, with the IID irons forming from the high-temperature, high-P inner magma.

We gathered INAA data for 19 IID irons, 18 of which were not previously studied by this technique. The data confirm previous studies showing that the IID irons formed by fractional crystallization.

Evidence of a low S content in group IID. Two kinds of evidence indicate low S in the initial IID magma. 1) Buchwald [1] called attention to the low S contents observed in sections of IID irons. The observed amount of FeS in irons reflects a combination of the degree of melt trapping and the S content of the melt. If we assume that, on average, the degree of melt trapping is similar in the magmatic groups, then one can conclude that a group that has uniformly low modal FeS contents had a low S in the parental magma.

2) As shown in Fig. 1, we observe low negative slopes on plots of log Ir vs. log Au or log As; slopes are similar to those observed in the low-volatile group IVA [2]. Low slopes imply low D_{Ir}, D_{Au} and D_{As} values, and each of these increases with increasing S content of the magma. The actual S content is not closely constrained. We suggest that it was 7 mg/g, similar to that estimated for group IVA. In most magmatic iron meteorite groups the initial S/P mass ratio was 3 to 4, but in group IID the P content estimated from modal determinations is 14 mg/g, twice the S concentration.

Melt trapping in group IID. In Fig. 1a,b the distance between the solid and liquid tracks is a measure of the degree of melt trapped in each iron. Most of the IID data plot near our best estimate of the solid crystallization track, implying that amounts of trapped melt were low (1 to 14%). According to our modeling the most evolved IID, Wallapai, formed after 73% crystallization of the magma.

Mean composition of group IID. We estimated the composition of the initial melt in group IID by fitting straight lines to the low-Au points on element-Au diagrams and combining this information with the inferred Au distribution coefficient and initial concentration. This exercise shows that, compared to groups IVA and IIAB, IID is enriched in refractory (e.g, Ir, Pt) and volatile (e.g, Ga, Sb , Ge) siderophiles. This suggests that the IID magma is depleted in Fe but that volatiles have not been lost.

Mechanisms to account for the low S content of group IID. Groups IVA and IVB, the magmatic groups known to have low S contents, show major depletions in Ga, Sb and Ge. For this reason it is commonly held that volatilization was responsible for the S loss. This mechanism appears unlikely for IID.

Another mechanism that can reduce the S content of a magma is the loss of an early, FeS-rich melt. Kracher and Wasson [3] pointed out that this could occur in an asteroid that is being internally heated; the first melt would form at ~1300 K and have a composition similar to the FeS-Fe eutectic. The second melt would form at much higher temperatures, perhaps near 1750 K; when this dense, P-rich melt reached the core it would pass through the S-rich magma rapidly enough to avoid appreciable contamination.

It seems probable that ^{26}Al alone could not provide the required heating; however, if the asteroid accreted soon after chondrules formed, a combination of ^{26}Al and ^{60}Fe at the levels reported by Mostefaoui et al. [4] would be adequate to the task. The cartoons in Fig. 2 illustrate our model. We envision three events as the temperature rises in an asteroid that was initially highly porous: 1) at T~1300 K a eutectic melt separates in the asteroid interior and forms a core; at T~1450 K a basaltic melt separates and rises about halfway to the asteroidal surface where cooler temperatures and assimilation cools it and stops its flow; 3) at T~ 1750 K the S-free metal in the deep interior melts, becomes gravitationally unstable, and forms a dense core below the S-rich magma.

The fourth cartoon in Fig. 2 illustrates that the inner core crystallized from the center outwards while convecting to form the IID irons. As discussed by Kracher and Wasson [3], mixing between the two core magmas was inefficient because heat and matter transport through the stagnant boundary layers was entirely by diffusion. The diffusion length calculated for a 1 Ma period is 300 m. Note that diffusion of S downwards and Fe upwards would increase the size of the stagnant zones. The interior of the upper core may or may not have convected.

Chromite would have been a liquidus phase in the inner core. Because the density of the upper core (~4.3

g cm^{-3}) was lower than that of chromite, a chromite layer would have formed within the stagnant zone, further hindering diffusional exchange between the two magmas.

Compositional evidence favoring the two-magma model. The uniform enrichment of the refractory siderophiles in group IID is best understood in terms of removal of Fe from the system. This could indicate that appreciable amounts of Fe were left behind as oxides when the metallic magmas separated. Arguing against this is the fact that carbides have been observed by Buchwald [1] in two IID irons.

The Ge/Ga ratio is lower than found in chondrites. Because Ge is the most volatile of the elements studied by us, it is conceivable that very selective volatilization removed about half the Ge and about 90% of the S. It appears very difficult to devise such selective volatilization models in asteroidal settings, and this model does not account for the enrichment in refractory siderophiles.

We conclude that the two-magma body offers the most plausible explanation of the IID evidence.

References:

[1] Buchwald V. (1975) *Iron Meteorites*, Univ. Calif. Press.
[2] Wasson J. and Richardson J. (2001) *GCA* **65**, 951.
[3] Kracher A. and Wasson J. (1982) *GCA* **46**, 2419.
[4] Mostefaoui S. et al. (2004) Astrophys. J. **625**, 271

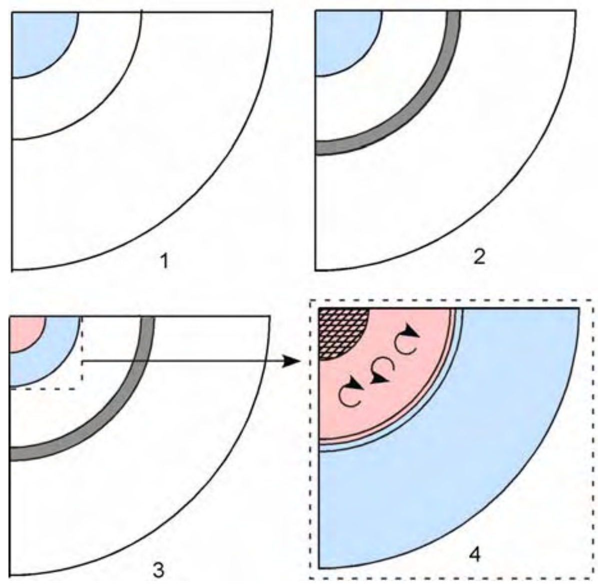

Fig. 2. Suggested stages in the evolution of the IID parent asteroid. 1) At T~1300 K, eutectic-like melt separates and forms a core. 2) At T~1450 K a basaltic melt forms, rises into a cooler zone and cools by assimilating chondritic materials. 3) In the innermost interior at T~1750 K a metallic-melt forms and separates to form an inner core. 4) This blowup of the two-layer core shows the inner core crystallizing with the remaining melt convecting. Transport of heat and matter between the two core magmas is by diffusion through stagnant zones.

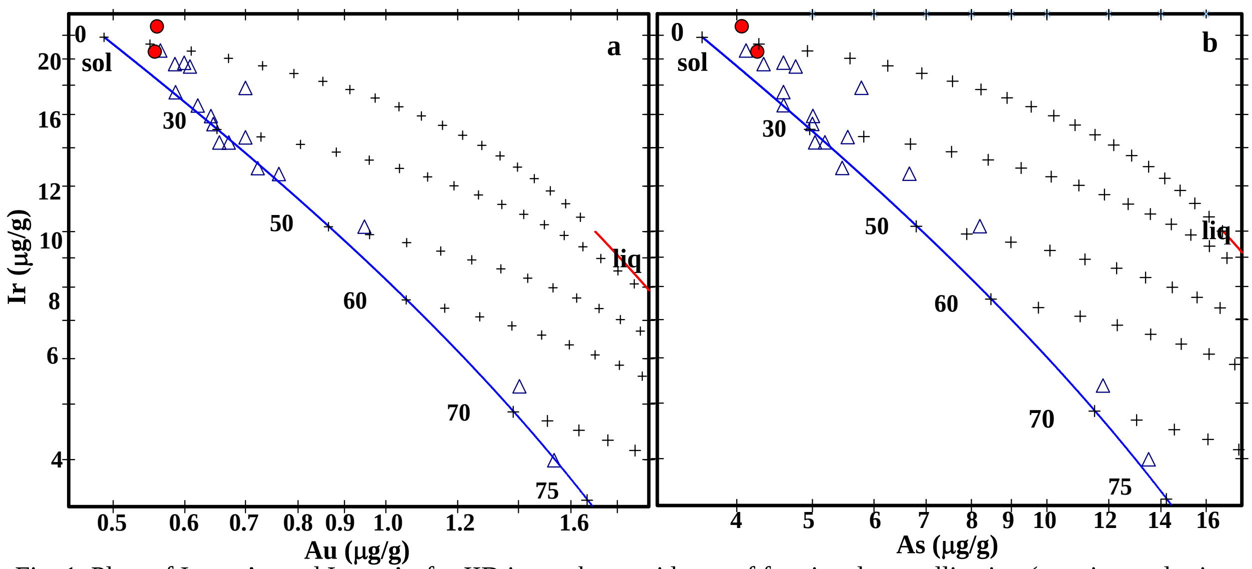

Fig. 1. Plots of Ir vs. Au and Ir vs. As for IID irons show evidence of fractional crystallization (e.g., irons plotting near the solid track on the left) and melt-trapping (irons plotting between the solid and liquid tracks). Numbers at the left of the solid track show the degree of crystallization in percent. The slopes of the data arrays are low (e.g., compared to IIIAB, not shown), an indication of a low non-metal content of the initial IID magma. Inferred amounts of trapped melt are also low, <14%.