THE IMPACT OF NEBULAR EVOLUTION ON VOLATILE DEPLETION TRENDS OBSERVED IN DIFFERENTIATED OBJECTS. P. A. Bland[1] and F. J. Ciesla[2], [1]Impacts & Astromaterials Research Centre (IARC), Department of Earth Science & Engineering, Imperial College London, South Kensington Campus, London SW7 2AZ, UK (p.a.bland@imperial.ac.uk); [2]Department of Geophysical Sciences, The University of Chicago, 5734 South Ellis Avenue, Chicago, IL 60637, USA (fciesla@uchicago.edu).

Introduction: Recent Hf-W ages indicate that core formation in the parent bodies of magmatic irons occurred within 1Myr of CAI formation [1-3] - well before accretion of chondritic parent bodies. Dynamically, it is likely that iron meteorite accretion occurred in the terrestrial planet region [4]. Differentiated planetesimals then evolved collisionally, with fragments scattered into the main belt [4]. In addition to older ages, magmatic irons also show significant depletions in volatile elements (plausibly inherited from precursor materials [5]), at levels not seen in chondrites.

Although models that propose incomplete condensation from a 'hot' disk [6,7] as the mechanism for volatile depletion have encountered problems [8], these problems principally arise from constraints on chondrite formation (ie. achieving a hot disk, 'late', at asteroidal distances). In the search for a mechanism for volatile depletion there has been a tendency to take chondrite depletion as the starting point, before extending those models to differentiated objects and the terrestrial planets. But if core formation in differentiated objects occurred 1-2Myr before chondrite accretion, and differentiated planetesimals formed at smaller heliocentric distances than chondrites, how does this affect a 'hot' disk model? Can we achieve depletions consistent with magmatic iron compositions? And if so, how relevant is a chondrite model to the broader question of volatile depletion in the early solar system?

The model: In this study we use a "Cassen-like" model [7], with minor modifications [8]: a simple one-dimensional alpha-viscosity disk model, that begins with a very compact structure, high surface density near the Sun, dropping off rapidly moving outward. The disk evolves due to mass accretion and angular momentum transport, allowing the disk to cool over time as viscous dissipation decreases and the radiation escapes more easily due to the decrease in disk mass over time. The planetesimals then grow as defined by some "timescale" where dust is continuously taken from the disk and incorporated into these larger objects.

Our focus here is not on chondrite parent bodies, but rather generic planetesimals in the inner solar nebula. The compositions of the planetesimals that form is very sensitive to the initial structure and rate of evolution of the disk [7]. These factors determine the locations at which depletions would develop in planetesimals and also the level of depletion. We are investigating how the detailed evolution of a viscous disk may produce planetesimals of different compositions (Fig. 1AB), and extrapolate how this may have impacted the chemistry of bulk planets.

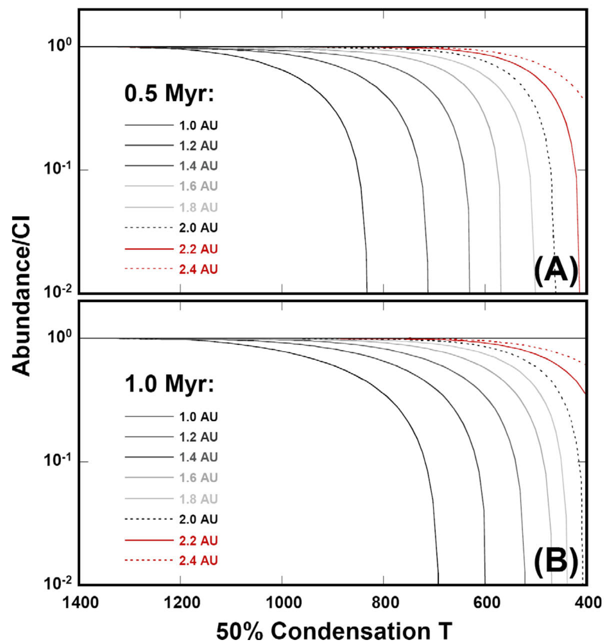

Fig. 1: Examples of model depletion scenarios at a variety of heliocentric distances occurring at 0.5 Myr. after CAI formation (A), and 1.0 Myr. after CAI (B).

Results and Discussion: It is apparent that incomplete condensation from a 'hot' disk is a viable mechanism for producing significant levels of volatile depletion, with the proviso that bodies accrete early, and in the terrestrial planet region (Fig. 1AB). Using parameters for a 'canonical' nebula we find depletion levels and trajectories that are a close fit to magmatic iron compositions. For IIAB and IIIAB irons, scenarios in the 0.5-1.0Myr/1.0±0.1AU range (in line with Hf-W ages [1-3] and dynamical models [4]) appear most consistent with observed compositions (Fig 2A). But even highly depleted IVA and IVB irons have compositions that are achievable (Fig. 2B), in this case requiring accretion slightly earlier, at 0.3Myr. Given the large range in depletion levels that we observe in our model scenarios we can potentially account for the variety of depletions observed in (for instance) HEDs and angrites, and the large number of ungrouped irons.

We also note an interesting feature of magmatic iron chemistry that is consistent with a formation scenario as outlined here. If we consider IIAB and IIIAB irons: in the moderately volatile region they show relatively similar depletion levels to the bulk Earth, and even CV chondrites. But unlike Earth and chondrites,

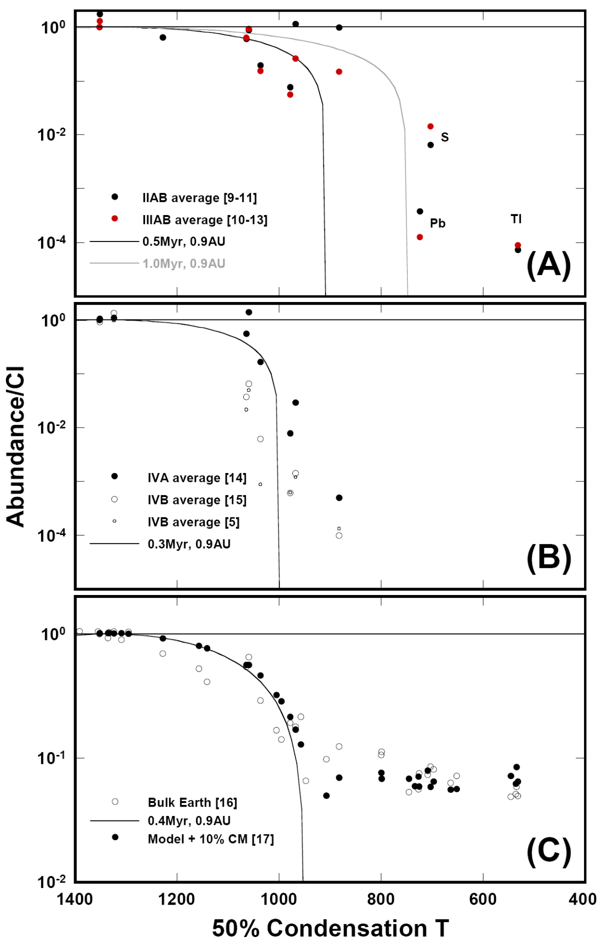

Fig. 2: Depletions in IIAB/IIIAB irons (A): compositions consistent with formation in the 0.5-1.0Myr/ 1.0±0.1AU range. Model scenario at 0.3Myr/0.9AU compared with IVA/IVB compositions (B). Component modelling (C): model scenario at 0.4Myr/0.9AU combined with 10% CM compared to bulk Earth.

where the expected depletion does not continue into the highly volatile elements [16,17], in the case of the IIABs and IIIABs it does. We see significant depletions in IIAB and IIIAB highly volatile elements (S [9,12,13], Pb and Tl [10,11]). These depletions are at much greater levels than observed in Earth and chondrites, but consistent with depletion trajectories from our modelling. A first order interpretation: both chondrites and the Earth had volatile-rich material added late, but for magmatic irons accreting early from a 'hot' disk, there was no possibility for that to occur. Clearly, these results also have significance for volatile depletion of the terrestrial planets. If a sizable fraction of the planetary embryos that contributed to the proto-Earth accreted ~0.5Myr after CAI formation then we can explain the level of depletion observed in terrestrial moderately volatile elements. The departure for highly volatile elements in the bulk Earth could be accounted for by late accretion of material from beyond 2.5AU (Fig. 2C). In this example we illustrate the effect of addition of 10% CM-type material (simulations indicate that the fraction of material from beyond 2.5AU added to the final terrestrial planets has a median value of 15% [18]).

Conclusions: Hf-W data has shown that magmatic irons differentiated early. A popular dynamical model identifies the terrestrial planet region (0.5-1.5AU) as a plausible location for the accretion of these objects. Our work has shown that the level of volatile depletion observed in magmatic irons may be explained by incomplete condensation from a ‘hot’ disk at 0.5-1.5AU, on a timescale entirely consistent with Hf-W ages. It also appears consistent with models of planetesimal accretion and oligarchic growth in the early solar system [19]. Finally, if our principal goal is to explain volatile depletion in the terrestrial planets, then it may be appropriate to re-examine the relevance of models based on chondrite chemistry (models which have - until now - formed the basis for attempts to understand volatile depletion), given that chondrites do not appear to have been the first objects to accrete.

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