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Differentiation of planetesimals and Hf-W model ages of iron meteorites

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Introduction: Compositions of the magmatic iron meteorites are consistent with crystal-liquid partitioning during crystallization of metal melt. They are, thus, thought to represent the cores of differentiated planetesimals. Based on the concentrations of moderately volatile elements, several groups are distinguished, each representing a separate parent body. Variations in the ^{182}W content of magmatic irons[1] indicate that cores of their parent bodies formed over at least ≈1 Ma possibly due to an early segregation of Fe-FeS and a later segregation of Fe. Inverse correlation of the Hf-W model ages with the S content and, hence, the liquidus T inferred for each core indicate that core formation in S-rich bodies (e.g., IIAB) occurred earlier and at lower T than in S-poor bodies (e.g., IVB). The consistency of the Hf-W data with the melt migration in planetesimals has yet to be evaluated. We calculated the silicate-metal differentiation of the parent bodies of the magmatic iron meteorites comparing them to the metal separation data. Our models are consistent with the separation ages for all five groups considered in [1] and place IVB into the general context suggested by [1].

Model: The numerical model[2,3] used solves energy balance equation in spherical symmetry considering heating by short- and long-lived radionuclides, temperature- and porosity-dependent parameters, compaction of initially porous material by creep, melting and latent heat, metal-rock differentiation by Darcy flow, associated redistribution of radionuclides, and convection in a magma ocean and in the metallic fluid core. We consider an object with a radius of 100 km that accretes very fast within 0.1 Ma relative to the formation of CAIs and has an ordinary H chondritic composition.

Results: For comparison we calculated a purely conductive model that includes porosity and compaction. In such a case, rapid heating causes complete melting of both metal and rock in the interior. This model cannot reproduce the formation conditions of the IVB irons because core formation is too rapid. As another extreme case, we calculated a model that includes differentiation, partitioning of ^{26}Al into the silicate melt, and convection in the mantle and in the core. Here, melting is only partial, the liquidus of pure iron is not nearly reached, and the model fails as well. Finally, we considered an alternative "mixed" model, where the differentiation is considered as a quasi-instantaneous process. Here, plagioclase is extracted from the mantle upon reaching its liquidus temperature of 1570 K. Plagioclase takes 90% of ^{26}Al with it, thereby reducing the heating rate to 10%. The remaining radionuclides provide a slow temperature increase and the depleted mantle has a higher melting T and remains solid. No magma ocean forms and the lower mantle can heat up without being cooled by liquid-state convection. This enables reaching the

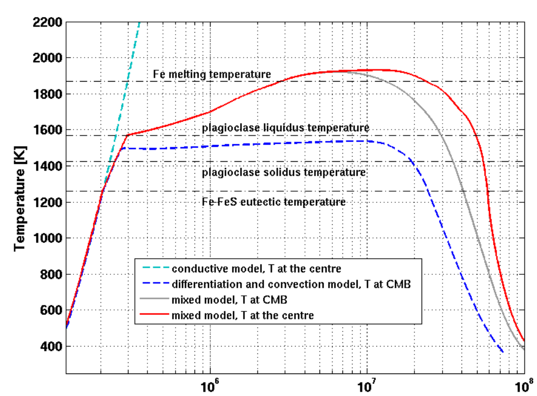

Figure 1: Evolution of the temperature at the center and at the CMB for the conduction, convection, and mixed models.

melting temperature of free iron of 1870 K at $t\approx2.9$ Ma after CAI formation. This is in a very good agreement with the Hf-W core formation age of IVB. The temperature at the center and at the CMB increases to over 1900 K and falls very slowly subsequently. At 23 Ma after CAIs iron crystallizes at the center, while the CMB cools below the metal solidus at ≈20 Ma after CAIs.

Conclusions: Our calculations confirm, in general, that the parent bodies of iron meteorites should have accreted early and that their cores must have formed slowly within several millions of years. The models shown above are consistent with the separation age of IVB and place this group into the general context suggested by [1].

References: [1] Kruijer T. S. et al. (2014) Science 344: 1150-1154. [2] Neumann W. et al. (2012) A&A 545: A141. [3] Neumann W. et al. (2014) EPSL 395: 267-280.