RECONCILING Hf-W MODEL AGES OF IVB PARENT BODY WITH NUMERICAL MODELS

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Introduction: Magmatic iron meteorites are thought to represent the cores of differentiated planetesimals. Based on the chemical composition and on the concentrations of moderately volatile elements in these meteorites, several groups are distinguished, each representing a separate parent body. Furthermore, variations in the 182W content[1] indicate that cores of their parent bodies formed over a time interval of 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., at ≈2.9 Ma after CAIs for 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 iron meteorites’ parent bodies comparing their evolution 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 a typical H chondritic composition.

Results: We calculated several types of models with different degrees of complexity. The most simple model is a purely conductive one that includes dust 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 circumstances of the IVB irons because core formation is too rapid. As another extreme case, we calculated a model that includes differentiation, partitioning of 26Al into the silicate melt, and convection in the mantle and in the core. Here, only partial melting is given, the liquidus of pure iron is not nearly reached, and the model fails as well. As an alternative, we considered a "mixed" model, where the differentiation is quasi-instantaneous. Here, early partial melt is extracted instantaneously via dikes[3] from the interior to the surface upon reaching the temperature of 1570 K (corresponding to a melt fraction of 10% containing ≈90% of 26Al), and no further differentiation is considered. This melt takes 26Al with it, thereby reducing the heating rate to 10%. The remaining nuclides 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 melting temperature of free iron of 1870 K at t ≈2.9 Ma after CAI formation. While this is in a very good agreement with the Hf-W core formation age of IVB, 182Hf is extracted to the surface along with the early partial melt. Thus, this partial melt needs to be mixed with iron at 2.9 Ma in order for iron to equilibrate and drag 182W into the core. This is possible assuming ineffective diking which results in the formation of a shallow magma ocean from the partial melt[3]. The partial melt and 26Al are removed from the interior but not to the surface. Distribution of the melt in a shallow layer and mixing with the remaining silicates and iron (which are present at these depths from the primordial composition) leads to a convecting shallow magma ocean. The magma ocean heats the mantle from above inducing the formation of a proto-core by Stokes settling of iron particles contained in the largely molten mantle. The shallow magma ocean crystallizes around 2.9 Ma. Iron particles contained there equilibrate and sink into the mantle. They separate from the mantle within the second stage of the core formation and melt afterwards in the core.

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 shallow magma ocean model shown above is consistent with the separation age of IVB and places this group into the general context suggested by [1]. While the radius of the parent body of IVB can differ from R ≈100 km used here, calculations for bodies with different sizes lead to similar results.