Importance of Material Properties on the Thermal Evolution Models of Parent Bodies

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Introduction: A majority of the chondritic materials in our solar system originated and were partially processed in the first ~10 million years after time 0, defined as the time when calcium-aluminum inclusions (CAIs) condensed [e.g., 1]. The primary heating mechanism for the parent body asteroids was radiogenic heating due to the decay of ^{26}Al [1]. Thermal evolution models alongside experimentally determined physical properties, such as the specific heat capacity, have been used to place constraints on the sizes and times of formation of various chondritic asteroid parent bodies [2–4]. These models allow an understanding of the processes in small bodies that formed early in the solar system history, and are a link to the shapes and geology of the asteroids observed during flyby or sample return missions.

While there are several sources of error in thermal evolution models that vary in their significance, we investigated the effect of uncertainty in some of the material properties, namely aluminum abundance, specific heat capacity, and thermal diffusivity. We adopted the thermal evolution model for the parent body of asteroid Itokawa described by [5], determined uncertainty ranges for the aforementioned material properties, and placed new constraints on the radius and formation time of Itokawa's parent body.

Methods: Our thermal evolution model follows the common approach of approximately solving the radial heat conduction equation using finite difference methods. This calculation also incorporates assumptions about the material properties and the initial and boundary conditions for the system, for which we followed the recipe from [5]. Temperature data from the thermal evolutions calculated by this model were interpolated over the whole range of realistic formation time and radius values, and then compared with known thermal constraints on the parent body of Itokawa [5]. Subsequently, we determined uncertainty ranges for the material properties from the literature: -10% to +10% for specific heat capacity [2, 6], -10% to +200% for thermal diffusivity [6, 7], and -14% to +16% for aluminum abundance [2, 8], and repeated the calculations to ascertain the effects of these uncertainties.

Results: Without accounting for any uncertainties, our model predicts a radius greater than 20.5 km and a formation time range between 1.87 and 2.24 Ma after the formation of CAIs for the parent body of Itokawa. This is in agreement with previous results [5; >20 km, 1.9-2.2 Ma]. Accounting for the uncertainty in all three parameters results in a minimum radius of 18.5 km and a formation time range between 1.6 and 2.5 Ma after CAIs.

Discussion: Although the minimum size for Itokawa's parent body reduced only by about 10%, the formation time range is significantly expanded, after taking the uncertainties into account. We observed that 10% uncertainties in both specific heat capacity and aluminum abundance contributed approximately an additional ±0.1 Ma onto the computed range of valid formation times of the body. Though the exact effects of uncertainty in material parameters on the accuracy of thermal evolution models is likely highly dependent on the specific form of the model, and the values and conditions used therein, aluminum abundance and specific heat capacity are fundamentally important to all thermal evolution models. The efficacy of such models is therefore significantly dependent on the existence of precise measurements of these material properties.

References

[1] Desch S.J. et al. 2018. The Astrophysical Journal Supplement Series 238(1):11. [2] Henke S. et al. 2012. A&A 537:A45. [3] Sugiura N. and Fujiya W. 2014. Meteoritics & Planetary Science 49(5):772–787. [4] Blackburn T. et al. 2017. Geochimica et Cosmochimica Acta 200:201–217. [5] Wakita S. et al. 2014. Meteoritics & Planetary Science 49(2):228–236. [6] Yomogida K. and Matsui T. 1984. Earth and Planetary Science Letters 68(1):34–4. [7] Henke S. et al. 2016. A&A 589:A41.
[8] Jarosewich E. 1990. Meteoritics 25(4):323–337.