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Theoretical and Experimental Updates on A Radiative Model for Chondrule and Chondrite Formation

William Herbst, James P. Greenwood and Kenichi Abe
Wesleyan University, Middletwon, CT USA (wherbst@wesleyan.edu)

Abstract

We update our radiative model for chondrule and chondrite formation, reporting new laboratory results aimed at simulating observed chondrule properties, and considering some implications of the model for the structure of small asteroids. We argue that the majority of primitive chondritic material remaining in the Solar System today is likely to be significantly different – in texture, porosity and density – from most chondrites in our museums; in particular, we argue that chondrules are rare entities.

1. Introduction

We have recently proposed a chondrite lithification model that accounts for many of the observed properties of chondrules and chondrites [7]. As shown schematically in Figure 1, it involves a brief period of intense heating that occurs whenever a small primitive planetesimal (SPP) in the solar disk encounters an exposed magma ocean or lava at the surface of a large differentiated planetesimal (LDP). The model builds on our earlier work proposing the formation of individual chondrules during these "flybys" [6]. Thermal models of LDPs suggest that such heating events will be relatively common between 1 and 4 Ma after the formation of the solar nebula, but rare or absent at other times, consistent with the observed age distribution of chondrules [10].

We propose that chondrite lithification occurs by hot isotatic pressing (HIP) simultaneously with chondrule melting and crystallization. Our radiative transfer model assumes heating on one side of a porous SPP, which is exposed to incandescent lava at a temperature near 2000 K. Orbital motion leads to symmetrical heating and cooling curves with temperatures above 1000 K for times of order 20-40 minutes. The predicted heating curves serve as input to our experimental attempts to reproduce chondrule textures. In addition to melting chondrules, intense heating of the SPP creates excess pressure in Na, Si, and O, over what is expected from any remnant solar nebula that may exist at those times. Chondrules are known to form in just such an environment [1, 5]. The lithification of chondrites in conjunction with the last heating and crystallization of chondrules, as we propose, also leads naturally to the observed phenomenon of complementarity between chondrule and matrix compositions [2, 3].

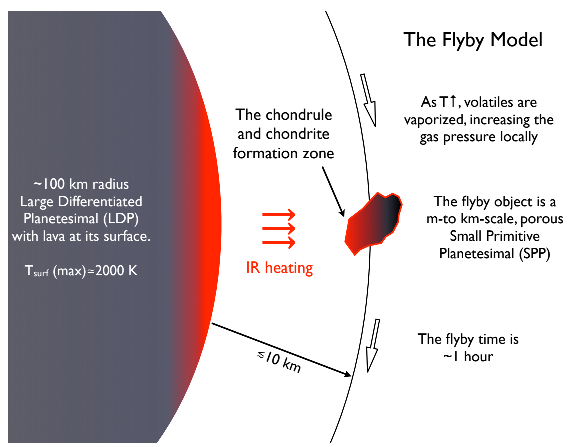

Figure 1: A schematic diagram of the flyby model [7].

2. Experiments

Laboratory experiments demonstrate that FeO-poor porphyritic olivine chondrules can be synthesized with the predicted thermal histories of this model. We have undertaken 1 atm experiments at IW-1 with chondrule analog materials that possess a range of chemistry and mineralogy. Porphyritic olivine chondrules are a dominant textural product, with barred and skeletal olivines much lower abundance, using symmetrical heating and cooling curves from [7]. Experimental olivine Mg# and glass compositions are excellent chemical matches to Semarkona Type I PO chondrules [8]. Experiments using a Type IAB composition show olivine and pyroxene chondrules with textures expected from equilibrium crystallization. These textures are not similar to pyroxene-rimmed Type IAB chondrules, demonstrating that Type IAB chondrule textures support open-system behavior with a Si-enhanced gas [4].

3. Implications

One of the interesting predictions of this model is that the majority of material in the asteroid belt cannot be similar to the chondritic meteorites, as the mass of material heated in this fashion cannot be similar to the mass of the asteroid belt. We would predict, rather, that the material of primitive asteroids would be chondritic in composition, but not in texture, porosity, or density. Our expectation is that asteroids such as Ryugu and Bennu will be composed mostly of much lower density material, material that has been less thermally processed than the chondritic meteorites in our collections. In our view, this asteroidal material is likely more representative of the material hitting the upper atmosphere of Earth, than of what makes it to the ground and the museums. A similar point has been made by [9]. The chondritic meteorites are the objects from those asteroids that are able to survive transport from the asteroid belt to 1 AU and then passage through Earth's atmosphere, rather than the main type of material from these bodies.

4. Summary and Conclusions

It is commonly assumed that chondritic meteorites found on the Earth's surface are representative samples of small asteroids. Here we discuss the evidence that, in fact, the chondrites that make it to the Earth's surface are better-lithified, of higher tensile strength, higher density and lower porosity than most primitive asteroidal material. We suggest that these attributes were acquired during a brief, intense flyby heating episode that was also responsible for the formation of chondrules. Since these heating events are relatively rare, we predict that chondrules are not and never were abundant in the Solar System.

Acknowledgements

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References

[1] Alexander, C. M. O., Grossman, J. N., Ebel, D. S., & Ciesla, F. J. *Science*, **320**, 1617, 2008.

[2] Budde, G., Kleine, T., Kruijer, T. S., Burkhardt, C., & Metzler, K. *Proceedings of the National Academy of Sciences of the United States of America*, 2016.

[3] Ebel, D. S., et al., *Geochimica et Cosmochimica Acta*, **172**, 322, 2016.

[4] Friend P. et al. *Geochim. Cosmochim. Acta* **173**, 198, 2016.

[5] Grossman, L., Beckett, J. R., Fedkin, A. V., Simon, S. B., & Ciesla, F. J. *Reviews in Mineralogy & Geochemistry*, **68**, 93, 2008.

[6] Herbst, W., & Greenwood, J. P., *Icarus*, **267**, 364, 2016.

[7] Herbst, W., & Greenwood, J. P., *Icarus*, **329**, 166-181, 2019.

[8] Jones R. H. & Scott E. R. D. Proc. 19th Lunar Planet. Sci. Conf. 19:523, 1989.

[9] Sears, D. W. G., *The Astrophysical Journal*, **498**, 773, 1998,

[10] Villeneuve, J., Chaussidon, M., & Libourel, G. *Science*, **325**, 985, 2009.