The Radiative Heating Model for Chondrule and Chondrite Formation. W. Herbst[1] and J. P. Greenwood[2], [1]Astronomy Dept., Wesleyan University, Middletown, CT 06457, wherbst@wesleyan.edu. [2]Earth & Environmental Sciences Dept, Wesleyan University, Middletown, CT 06457, jgreenwood@wesleyan.edu.

Introduction: Chondrules form at higher densities and with a wider range of oxygen fugacity than is plausible for the solar nebula [1,2]. Their porphyritic textures and other properties, however, do not support direct condensation from hot ejecta that may arise from planetesimal collisions [3]. We have recently proposed that radiative heating of pre-existing dust aggregates could be the primary or only mechanism for chondrule formation [4; hereinafter Paper I]. Here we develop and explore that idea in more detail.

Heating Model: Two potential sources of the required radiant energy that could be present within the asteroid belt at the time of chondrule formation (1-4 Myr) are: 1) giant planets, powered by gravitational collapse, and 2) planetesimals with radii ≥ ~10 km, powered by the decay of ^{26}Al. Models of young planetesimals show that one can expect them to be fully molten at that time [5]. Collisions and/or crustal foundering will lead to the emergence of substantial amounts of lava at their surface from time to time. Aggregated solids of mm- to m-size flying by at the right time will be heated to the temperatures necessary for chondrule formation.

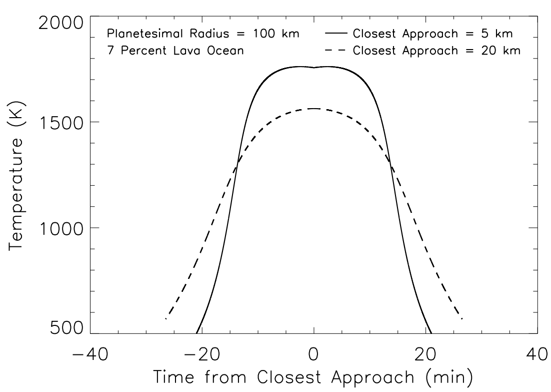

Fig. 1. Representative heating/cooling curves predicted by our chondrule formation model.

In Fig. 1 we show the predicted heating and cooling curve for a model fly-by of a 100 km radius planetesimal with a lava ocean covering 7% of its surface. This serves as an example of what can be expected in such an event. Details will vary with the height at closest approach and the extent and temperature of the lava ocean. Generally speaking, however, one will achieve sub-liquidus temperatures and heating/cooling rates within the constraints known to result in chondrule textures in laboratory settings [6].

Chondrite Lithification: All of the chondrules presently in our possession have arrived embedded in chondritic meteorites. The general problem of chondrite lithification is poorly understood. Pressures and temperatures on plausible parent bodies appear insufficient to account for the observed porosity of carbonaceous or ordinary chondrites [7]. It is possible that chondrites arrived on their parent bodies in already-lithified form. Here we advance the hypothesis that the same heating event that formed the chondrules may also have been involved in lithifying the chondrites, through sintering.

Discussion: We know from the ages of iron meteorites and from modeling [5] that molten planetesimals appeared within the first ~1 Myr and persisted for a few Myr, providing a plausible source for the radiative energy needed for chondrule formation by this mechanism. We also know that virtually all solids in the asteroid belt are swept into large bodies rapidly. Monte Carlo simulations indicate that a 100 km planetesimal in the asteroid belt will suffer ~10^{14} collisions during its lifetime, mostly with 0.1-1 m sized objects [7]. Therefore, a similar number of these dust-laden aggregates must experience close (~40 km or less) fly-bys. On some occasions they will be heated by exposed lava in a manner consistent with chondrule formation and, perhaps, chondrite lithification.

Our proposed mechanism for chondrule formation is consistent with all known constraints on the environment within the asteroid belt at 1-4 Myr. It accounts or potentially accounts for the age and epoch of chondrule formation, the constraint from their textures on heating and cooling rates, the co-mingling of Type I and Type II chondrules, the phenomenon of complementarity, the possibility of re-heating of some chondrules, the bimodal size distribution (chondrules and matrix) of chondrite components, melted rims on some CAI's, and other features. It is a model with firm, testable predictions, that has significant implications for the evolution of solids in the solar nebula.

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