EXPERIMENTAL FORMATION OF CHONDRULES BY NEBULAR LIGHTNING. S. Keenan[1], J. A. Cartwright[1], K. D. Genareau[1], and C. Park[2], [1]Department of Geological Sciences, University of Alabama, Tuscaloosa, AL 35487. [2]Department of Electrical and Computer Engineering, Mississippi State University, Starkville, MS 39762. Email: smkeenan@crimson.ua.edu

Introduction:

Chondrules are a major component of chondrite meteorites, which formed from molten dust in the Solar Nebula [1]. Due to their formation ~4.6 billion years ago (Ga) in the Solar Nebula [1], they are important markers for early Solar System processes, including the formation of the Solar System. Chondrules are generally spherical and uniform in shape, but have variable petrographic, chemical, and isotopic signatures (e.g. [2, 3]). Their mineralogy is typically dominated by a proportion of olivine and low calcium (Ca) pyroxene [3]. They also display a variety of textures, which are hypothesized to reflect the thermal history of the chondrules, and are broadly divided into two types: porphyritic and non-porphyritic, where non-porphyritic is further subdivided into cryptocrystalline, radial pyroxene, and barred olivine [3]. Porphyritic chondrules likely formed through incomplete melting of dust in the Solar Nebula and retain nuclei, while non-porphyritic chondrules formed by complete melting and thus do not retain nuclei [3].

The precise mechanism behind chondrule formation is still unknown and somewhat controversial, with specific parameters required to achieve the variety of textures observed and their compositions, including flash-heating and a rapid cooling rate [3,4]. The formation of chondrules by the flash-heating of dust within the Solar Nebula is supported by the retention of moderately volatile elements, such as sodium (Na) or potassium (K), and by the presence of relict grains [3,4]. The mechanism(s) that causes flash-heating of the dust would have to be a repeatable process, capable of occurring at a range of intensities across the relevant region in space [4]. Along with flash-heating, the cooling rate is another important parameter that is necessary to take into account when determining the chondrule formation mechanism. The cooling rate of chondrules is not currently well-constrained due to many unknown factors associated with the formation event, such as unknown grain size of precursor dust and an unknown ratio of dust to gas in the environment [4]. Based on previous studies [4], a cooling rate of 10-1000 K/hr is currently constrained and is consistent with a flash-heating mechanism.

Four main models have been suggested for chondrule formation: shockwaves, lightning, planetesimals collisions, and bipolar outflows (e.g. [3]). Nebular lightning was initially proposed by Whipple in 1966 [5] and refers to the occurrence of lightning within the Solar Nebula as the mechanism that melted the precursor material into chondrules. Through triboelectric grain charging and the aerodynamic sorting of grains via turbulence in the Solar Nebula, Desch and Cuzzi [6] were able to develop a theoretical model where there was sufficient grain charging and separation for lightning to occur. Similar processes have been noted to be at work within volcanic ash clouds leading to the formation of lightning [7].

Despite the constraints based on their thermal history, there has been limited focus on the size distribution of chondrules and/or how certain size chondrules could have been selectively formed or preserved [1]. Overall, a narrow size distribution of chondrules has been observed in the carbonaceous chondrite groups, with mean diameters ranging from 0.2 to 1 mm, with similar trends in ordinary and enstatite chondrites [8].

In this study, we are going to investigate how the size distribution of analog chondrules formed from high-current impulse experiments compares to that of natural chondrules, in order to determine the validity of the nebular lightning model for chondrule formation. This formation mechanism must be able to replicate the observed size distribution trend of natural chondrules in the analogs.

Methods:

Powdered analog chondrite material (commercially available, Exolith Labs) is placed on copper tape affixed to a copper plate and subjected to high-current impulse (≥100 kA) experiments conducted at Paul B. Jacobs High Voltage Laboratory at Mississippi State University. The samples will then be analyzed using general microscopy and a JEOL JSM 6010 Plus/LA scanning electron microscope (SEM) at the University of Alabama. Following the imaging of the samples, a size distribution for the formed spherules will be obtained by measuring the size of each spherule using imaging software to create a statistical data-set.

Future work will involve further lightning experiments of analog materials and further testing of the nebular lightning model by examining the internal textures of the spherules produced, and characterizing collisional features such as compound spherules, for comparison with natural chondrules.

Results and Discussion:

We have preliminary results for chondrite analog materials subjected to lightning experiments performed at ≥100 kA. We observe that the chondritic analog material that was located in closest proximity to the location of the electric discharge was likely mostly vaporized or dissociated as a result of the high-current impulse experiment, and as seen for volcanic ash materials [7]. Some of the remaining material was unaltered by the discharge and so will not be considered further. However, a significant proportion of material is noticeably altered by the lightning experiment. Within the altered material, there are an abundant number of grains that show evidence of melting and subsequent cooling. These grains, or spherules, are spherical in shape and have a rather uniformly smooth surface (Figure 1). Therefore, this flash-heating lightning experiment was capable of forming grains of a similar shape as natural chondrules. Future analysis will focus on the overall size distribution of the sample and which, if any, internal textures are able to be recreated using this experimental set-up.

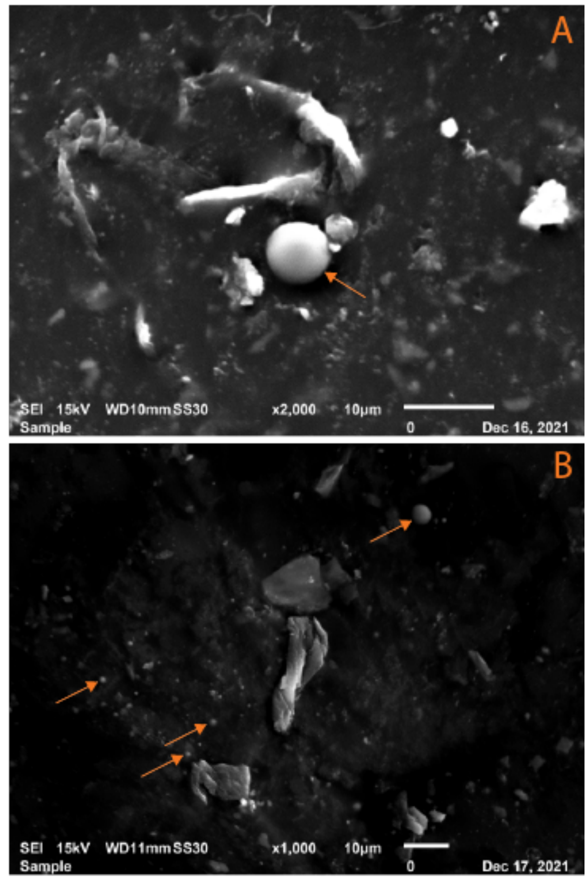

Figure 1: Images of spherules (indicated by arrows) formed from high-current impulse experiments with chondrite analog, imaged using JEOL JSM 6010 Plus/LA SEM in secondary electron mode from two regions of interest on recovered copper tape. A) One large spherule (and crater) is observed – this area had an overall lower abundance of spherules. B) One moderate-sized spherule with several smaller spherules is observed in the tape, along with craters.

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