RECORDS OF MAGNETIC FIELDS IN THE CHONDRULE FORMATION ENVIRONMENT.

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Introduction: Chondrules contain minor amounts of ferromagnetic minerals, which typically consist of the FeNi alloys kamacite and taenite. If the cooling of chondrules to ambient conditions took place in the presence of a magnetic field, the chondrules would have acquired a thermoremanent magnetization that can be measured in the laboratory and used to estimate the strength of the primordial ambient magnetic field.

In the absence of post-formation remagnetization processes, a pristine record of nebular magnetic fields can place several important constraints on the mechanisms and setting of chondrule formation. Hypothesized formation processes predict different magnetic field intensities. The x-wind model predicts strong solar fields of ~1000 μT (i.e., ~20 times Earth strength; [2]). In contrast, nebular shocks and planetesimal collisions are likely to result in magnetic fields substantially lower than 100 μT [3], assuming background magnetic fields of order 10 μT [4].

Paleomagnetic records of primordial field intensity may also constrain the location of chondrule formation. Assuming a constant accretion mechanism and rate [5], magnetic field strength is expected to decline rapidly within increasing orbital radius, falling by a factor of ~20 between 1 and 10 AU [6]. As such, systematic paleointensity variations among chondrite groups may reflect their formation radii. In particular, lower paleointensities recovered from chondrules of carbonaceous chondrites would support the Grand Tack hypothesis of planetary migration and the in-situ formation of chondrules at large orbital radii [7].

Chondrule paleomagnetism: Despite these motivations for the recovery of paleofield intensities from chondrules, the acquisition of robust measurements has proven challenging. Aqueous alteration, metamorphism, and shock on parent bodies are effective mechanisms for removing primordial remanent magnetization, implying that only a very small subset of chondrites are suitable for paleomagnetic analyses. Another challenge is that most FeNi metal in chondrules occurs in >>1 μm blebs, which are too large to retain a high fidelity record of ancient fields [8].

We will review recent results from the Semarkona LL3 ordinary chondrite [9], which meets the above criteria for the lack of parent body remagnetization processes. To avoid the poor magnetic field recording properties inherent to most chondrule metals, we extracted and measured only dusty olivine-bearing chondrules. Mean paleointensities computed from five dusty olivine-bearing chondrules suggest a magnetic field during chondrule formation of 54±21 μT, most consistent with a low magnetic field mechanism such as nebular shocks or planetesimal impacts.

To test the uniformity of chondrule formation mechanisms and setting across different chondrite classes, we then obtained paleomagnetic data from seven sub-samples of three chondrules from the CR carbonaceous chondrite LAP02342, which has experienced a lower degree of metamorphism than Semarkona and mild aqueous alteration compared to other CR chondrites [10]. Unlike Semarkona chondrules, the measured chondrules from LAP 02342 carry no internally coherent components of magnetization. By imparting the chondrules laboratory magnetizations in the presence of ever weaker magnetic fields, we determined that the magnetic field strength in the CR chondrule formation environment was likely <15 μT to produce the observed lack of coherent magnetization.

If this result is confirmed, chondrules from CR chondrites formed in a weaker magnetic field than those from LL chondrites, implying that the former were produced at greater orbital radii, at a later time in nebular evolution, or in a distinct formation mechanism. However, because our chondrules from LAP 02342 contain >1 μm grains of FeNi metal, the accuracy of the inferred paleointensity is lower than that for Semarkona chondrules, while the location of these FeNi blebs in silicate grain boundaries raises the possibility that they were affected by aqueous alteration. To address these uncertainties, we will present ongoing paleomagnetic measurements on three dusty olivine-bearing chondrules in the CR chondrite GRA95229. The <1 μm grain size typical of the dusty olivine metals and their location within enclosed olivine grains are expected to permit the accurate recovery of remanent magnetization unaffected by aqueous alteration.

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