SURF 2016 Project Description

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Introduction

In recent years, an extensive interest in the magnetic fields of the ancient solar nebula has developed. Magnetic fields are an important factor in models of the origin of the solar system, because they are likely responsible for the transfer of mass and angular momentum that resulted in the formation of Earth and its planetary neighbors. The chondrules of carbonaceous chondritic meteorites arguably represent the oldest material formed in the solar system. They form at high temperatures as dispersed molten droplets, which subsequently solidify and aggregate into chondritic bodies. Therefore they are likely to record the conditions in the early solar system including evidence for ancient solar magnetic fields *[1]*.

Chondrules are round grains, typically millimeter to submillimeter in diameter. They are mainly composed of olivine and pyroxene which contain nanoscale ferromagnetic inclusions (mainly, magnetite and awaruite). Therefore individual chondrules acquire a thermal remanent magnetization (TRM) when magnetic minerals are cooled below their Curie point temperatures during initial solidification. This natural remanent magnetization (NRM) provides quantitative evidence for the presence of a magnetic field in the early solar nebula *[2]*.

When a meteorite enters the Earth's atmosphere, the thermal remagnetization zone from atmospheric passage typically only penetrates less than several mm into the interior of stony meteorites *[3]*. Although some meteorites may endure alteration after their arrival on the Earth's surface, the ferromagnetic inclusions within the chondrules are protected from alteration by the silicate matrices. Therefore, the original NRM is likely to be preserved and can be used to determine the strength of the magnetic field (paleointensity) that the chondrules were formed in.

Traditionally, paleointensity determinations consist of heating rock samples at increasing temperatures and measuring the magnetization after each heating *[4]*. By doing this, the natural remanent magnetization (NRM) in the sample is progressively destroyed while a partial thermal remanent magnetization (pTRM) in a known laboratory field is gained. By comparing the rates of NRM destruction with the rates of pTRM acquisition, paleointensity can be determined.

The previous attempts of paleointensity determinations from carbonaceous chondritic meteorites largely failed because they were done on large bulk samples which matrix experienced heating-induced alteration duing the experiments *[5]*. The unique and novel aspect of the project proposed here is that paleointensity experiments will be conducted on individual chondrules separated from a meteorite (see below). Such experiments have not been conducted before because the chondrule magnetic moments are at the sensitivity limit of conventional rock magnetometers. However, the Earth Magnetism lab has a unique high-sensitivity high-resolution Superconducting Quantum Interference Device (SQUID) Magnetometer specifically designed to measure very weak moments in single silicate crystals and similar objects such as individual chondrules.

Proposed Research

In this project, I intend to investigate whether the magnetic field strength in the early solar system can be determined from individual chondrules extracted from the Allende meteorite. The Allende meteorite is the largest carbonaceous chondrite (CV3 type) ever found on Earth which fell over Mexico in 1969. Because of the timing, the Allende fragments have not experienced any terrestrial weathering. Initial magnetic investigations of the meteorite indicate that the original NRM is preserved *[1]*.

Samples of the Allende meteorite for this project have already been obtained. Before beginning paleointensity experiments on the chondrules, the presence of ferromagnetic inclusions with the appropriate properties will be verified using microscopy, thermomagnetic curves, and magnetic hysteresis measurements. In addition, the fusion crust baked contact test, as described in *[6],* will be done to ensure that the sample has not been remagnetized.

Procedure

My research plan is composed of several "stages" that will be completed between May 16th and August 5th. All magnetic measurements will be done at the Earth Magnetism Lab.

1) Extraction and preparation of chondrules (~1 week): Chondrules will be separated from the parent body through use of a small pneumatic drill. The chondrules will then be repeatedly washed in order to remove the majority of the groundmass. The chondrules will then be ultrasonically cleaned to remove any remaining material before beginning further analyses. Each chondrule will be photographed and measured using a specialized petrological microscope at the Department of GMES. The goal is to acquire at least 40-50 chondrules.

2) Magnetic hysteresis measurements (~2 weeks): Magnetic hysteresis parameters (saturation remanence, M_{rs}, saturation magnetization, M_s, and coercivity, H_c) will be measured from the extracted chondrules using an Alternating Gradient Field Magnetometer (AGFM). From the hysteresis loops I will calculate the squareness ratio (M_{rs}/M_s); ratios between 0.25 and 0.5 indicate nearly single-domain inclusions, which are desired for paleointensity measurements. I will also use the AGFM to check my samples for magnetic anisotropy. For this, I will compare the magnetic hysteresis parameters obtained from measuring each sample at multiple orientations with respect to the applied field.

3) Magnetic susceptibility measurements (~2 weeks): Temperature dependencies of low-field magnetic susceptibility, $\kappa(T)$, will be measured by cycling from room temperature to 700°C (in argon) using an AGICO MFK1-FA magnetic susceptibility meter equipped with a high-temperature furnace and a cryostat. The $\kappa(T)$ curves will also be measured during heating from −192°C to room temperature both before and after the high-temperature thermomagnetic runs. Size, shape, and range of the curves will indicate magnetic carriers, domain type, and degree of alteration of the samples.

4) Determination of NRM unblocking temperatures (~1 week): Several selected chondrules will be thermally demagnetized through a series of step-wise heatings with our CO2 laser system. I will measure the remaining NRM after each step using the SQUID magnetometer. The resulting unblocking temperature spectra will be characteristic of the specific mineralogy of the magnetic inclusions. This information will be used to select the temperature increments for paleointensity experiments.

5) Paleointensity Experiments (~6 weeks): Paleointensity experiments will be conducted on 15-20 chondrules using the method described in *[4]*. The incremental heatings of the samples will be done using the CO2 laser system and the corresponding NRM and pTRM values will be measured using the SQUID Magnetometer. The data will be processed using the ThellierTool-4.22 program *[7]*.

I will present the results of my project as a research report. If my analyses confirm the suitability of chondrules from the Allende meteorite for paleointensity studies, I intend to continue working with them to determine the paleointensity they record. This will lead to the acquisition of valuable data representing the magnetic field in the early solar system, providing important clues in regards to the origin of our planet and the solar system we reside in.

References

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