THE HETEROGENEOUS RESPONSE OF MARTIAN METEORITE ALLAN HILLS 84001 TO PLANAR SHOCK

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Introduction: Allan Hills 84001 (ALH 84001) is an orthopyroxenite Martian meteorite containing coarse-grained inclusions of chromites, carbonates and plagioclase feldspar, in addition to fine-grained iron oxides and sulfides that host a heterogeneously oriented natural remanent magnetization (NRM) [1]–[4]. The meteorite contains several shock-induced textures and mineral thermometers indicative of one or more impact events.

The NRM hosted in the iron oxides and chromite-sulfide assemblages within the meteorite is understood to be a thermoremanent magnetization (TRM) and has two strongly magnetized components that do not share common alignment, in addition to several incoherent, weakly magnetized grains, indicative of an underlying mechanism capable of localized (~200 nm) heating [5].

We have developed a methodology, using thermal constraints from paleomagnetism and petrologic observation, where we are able to place new constraints on the shock pressures associated with multiple impacts suffered by the meteorite up to and including its ejection from Mars. To reconcile the reported thermal histories of the meteorite, we have simulated planar shock wave propagation through computational analogs of two samples of ALH 84001.

Modeling: Using the iSALE-2D shock physics code [6]–[8], we have performed a suite of 'mesoscale' simulations to quantify the effects of impact-induced shockwaves likely to have been experienced by the meteorite. The materials used in our simulations are each described by an equation of state and strength model. As the availability of accurate equations of state for meteoritic materials is limited, we have used the closest analog materials possible.

Results: We found strong and complex material shear responsible for steep thermal gradients throughout the sample. Shearing occurs principally in the rock matrix, using the (weaker) inclusions as nucleation points (Fig. 1). We see both intra- and inter-material variations in temperature on length scales of tens of microns.

Subsequent modeling of post-impact thermal equilibration reveals that the constituent materials reach equilibrium ~3 seconds after the release wave has passed through the meteorite (Fig. 1). This has implications for paleomagnetism: small fractions of the meteorite may be remagnetized in low-pressure impacts, meaning the meteorite is capable of hosting NRMs recorded at different times.

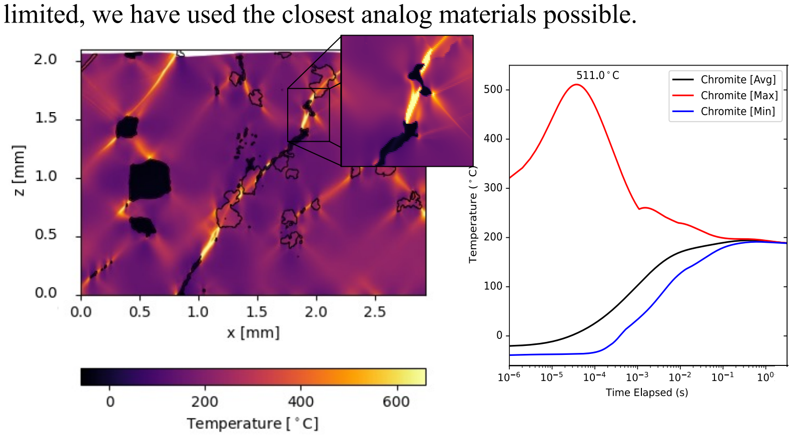

Figure 1: Thermal experience of a sub-volume of the cross-sections we examined of the cross-section close to a shear zone in a 33 GPa impact. Time zero is immediately after the release wave passes through the sample. We see the chromite experiences a maximum temperature after the impact due to heating from a nearby shear zone before settling to thermal equilibrium approximately 3 seconds after the impact.

Implications for Paleomagnetism: Palaeomagnetic studies of this meteorite have found a heterogeneously oriented pattern of remanent magnetization, indicative of remagnetization in the meteorite on the sub-millimeter scale, but the mechanism for such heterogeneous heating was unclear. We observe that portions of chromite grains close to shear zones will experience temperatures significantly higher than those elsewhere in the meteorite which only warm up to the equilibrium temperature. Since the meteorite was magnetized in an initial extensive thermal event where the whole meteorite was heated above the curie point of the chromite-sulfide assemblages, our simulations suggest that a subsequent impact with a bulk shock pressure between 25-45 GPa would achieve partial remagnetization.

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