Fall and Initial Examination of the Sept. 25, 2009 Grimsby H5 Ordinary Chondrite

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Fall event

On the early evening of Sept 25, 2009 (01:03 UT Sept. 26, 2009), a brilliant fireball showing three major bursts was observed over southwestern Ontario and adjacent regions, with reports of sonic booms or simultaneous sound. The event was recorded by a network of automated cameras, radar and infrasound sensors operated by the University of Western Ontario.

The fireball trajectory and peak brightness greater than that of the full moon indicates that a multi-hundred kg object on a 27° inclined Apollo-type orbit collided with the upper atmosphere at 20.9 km/s. Camera records as well as visual reports suggest that a number of ~kg mass fragments survived to reach the ground to the west and south of Grimsby, Ontario.

During the autumn of 2009, a field search was undertaken in the projected strewnfield, along with an effort to raise public awareness of the event. The first recovered meteorite hit the windshield of a parked vehicle and was collected as five fragments on the morning after the fall by A. (Tony) Garchinski, but remained unrecognized until October 11, 2009. As of January 2010 a total of 13 meteorites have been found by search parties and individuals. Fragments of the meteorite are located within a 4 by 8 km strewnfield west of Grimsby; more are expected to lie to the southeast on the escarpment and to the east, in Grimsby itself.

Recovered Grimsby meteorites

Of the thirteen recovered meteorites, eleven are complete or nearly complete individuals. Two individuals show evidence of preferred orientation. Individual masses range from 1g to 69g, giving a total known weight of 215g. Fracture surfaces that are free of fusion crust reveal a sub-mm chondrule rich matrix with abundant sub-mm flecks of metal and sulphide and occasional large chondrules exceeding 3 mm in diameter. All meteorites except the initially recovered Garchinski individual show some terrestrial weathering of metal (Fig. 1).

Figure 1. Grimsby 21.9g fragment "HP-1" upon field recovery with quarter for scale (left); 1.11g complete individual "pjam-2" (top centre); 1.2g complete oriented individual "wing" (top right); and, 22.4g Grimsby "Five" (bottom right)

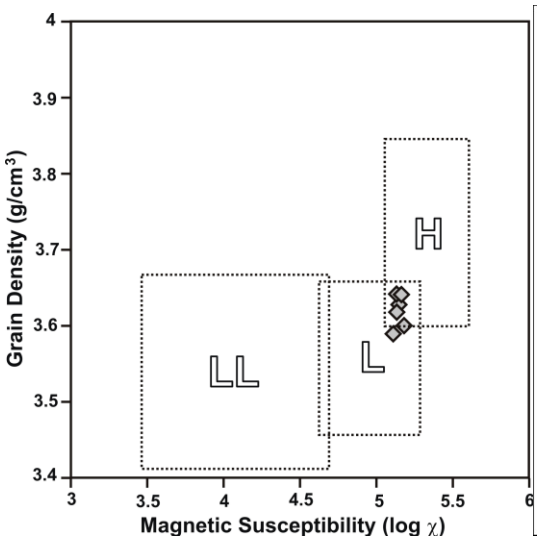
Preliminary Non-destructive Analysis

Most recovered fragments of the Grimsby meteorite have undergone non-destructive analysis to determine the meteorite's bulk physical properties and mineralogy as an aid to its classification.

Bulk density was determined by the Archimedean method (Consolmagno and Britt, 1998; Macke et al., 2009) using 100 µm glass beads as a fluid. Determinations of volumes for six Grimsby meteorites ranging in mass from 21g to 69g provide a bulk density of 3.37±0.03 g/cm^3. Grain density for eight fragments was determined by He pycnometry (Consolmagno and Britt, 1998; McCausland and Flemming, 2006) using a Quantachrome Multipycnometer, giving a mean of 3.62±0.02 g/cm^3. The six fragments with measured bulk and grain densities provide calculated porosities of 6.7±0.8%, with no apparent distinction between the two "fresh" Garchinski fragments and the other, slightly weathered Grimsby individuals.

Magnetic susceptibility (e.g, Rochette et al., 2003) was measured using a Sapphire Instruments SI2b susceptibility meter for 16 fragments of the Grimsby meteorite, including all five "fresh" Garchinski fragments. Again no distinction was found between the fresh and weathered fragments, giving a mass-based magnetic susceptibility of log χ = 5.14±0.04 (log of E-9 SI units). These bulk properties imply that there is little discernable lithological variation within the Grimsby meteorite thus far (Fig. 2). In this case, the bulk values alone unfortunately do not clearly discriminate between an L or H chondrite identity (Consolmagno et al., 2008).

In situ micro-XRD (Flemming, 2007) was performed on ten locations on a fresh broken surface of Grimsby Five (Fig. 1) using a Bruker D8 Discover diffractometer, operating with Cu K-alpha radiation (lamda = 1.54056 Å) at 40 kV and 40 mA and an incident beam diameter of 300 µm. Diffracted X-ray spot patterns and their integrated analyses indicate the ubiquitous presence of low shock state ~Fo90 olivine and enstatite, kamacite and troilite as well as polycrystalline magnesioferrite spinel in the fusion crust. A large white 3.5 mm chondrule consists almost entirely of ferroan forsterite (Fig. 3). The best-fit Fo patterns imply an olivine composition consistent with classification of Grimsby as an H chondrite.



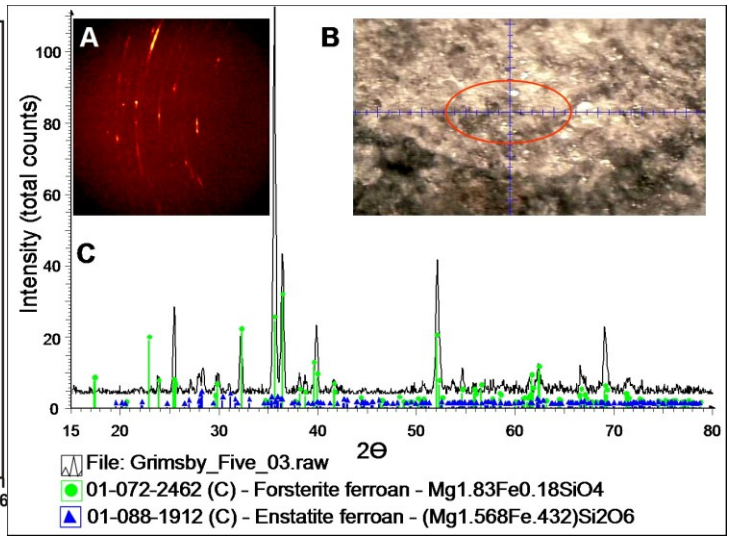


Figure 2 (left). Grain density versus bulk mass magnetic susceptibility for six fragments of the Grimsby meteorite (modified H, L, LL chondrite fields from Consolmagno et al., 2008).

Figure 3 (right). Paired two-dimensional detector image of diffracted rays (A) and inline microscope context image (B; 2 mm field of view) of a location within the large white chondrule seen in Grimsby Five (Fig. 1). Integrated X-ray response is plotted as intensity versus 2 Theta (C), with best fit matches from the International Centre for Diffraction Data (ICDD) database. The dominant mineral present is ferroan forsterite, giving bright spots in the 2D image.

X-Ray Micro-Computed Tomography (Micro-CT) was performed for most Grimsby fragments as a first pass non-destructive reconnaissance of the meteorites' interiors (McCausland et al., 2010) to define fragment interior density distribution, bulk volume and surface area. X-ray scans were performed using a GE eXplore speCZT CT scanner at 110 kV peak energy, applied for five-minute scans each consisting of 900 separate images over one full 360° rotation. Volume resolutions were 50 or 100 µm depending on the sample size. Micro-CT relies on the response of X-rays to the electron densities of material within the scanned meteorite; FeNi metal will attenuate the incident X-rays far more effectively than silicates and will thus appear as "bright" in the tomographic images (Fig. 4). Grimsby fragments exhibit little lithological variation; metal and sulphides occur as disseminated blebs and as rims to some larger >1 mm chondrules. Interior cracks can be identified. Bulk densities of four fragments with masses ranging from 1.1g to 69g have a mean of 3.33±0.05 g/cm^3, similar within error to that found by Archimedean methods.

Petrography

Examination of two polished thin sections from the Grimsby HP-1 fragment (Fig. 4) reveals abundant chondrules and chondrule fragments ranging in size from 0.03 to 0.70 mm in apparent diameter. Chondrule types include porphyritic olivine, barred olivine, radial pyroxene, finely crystalline orthopyroxene and cryptocrystalline textures. The matrix is variably recrystallized and chondrule rims typically are poorly defined, but feldspar is not well developed. Coarse olivines and pyroxenes show sharp optical extinction, implying a low shock state. In the examined sections, minor Fe-oxide has developed adjacent to the metal and troilite.

In SEM backscatter, olivines do not show evidence of zoning, indicating a petrologic grade of 4 or higher (Brearley and Jones, 1998). Mesostasis feldspar is present within chondrules, interstitial to olivine and pyroxene. Strings of chromite inclusions within some matrix olivine grains imply a more complex brecciation and shock history involving annealing of preexisting shock damage (Rubin, 2003).

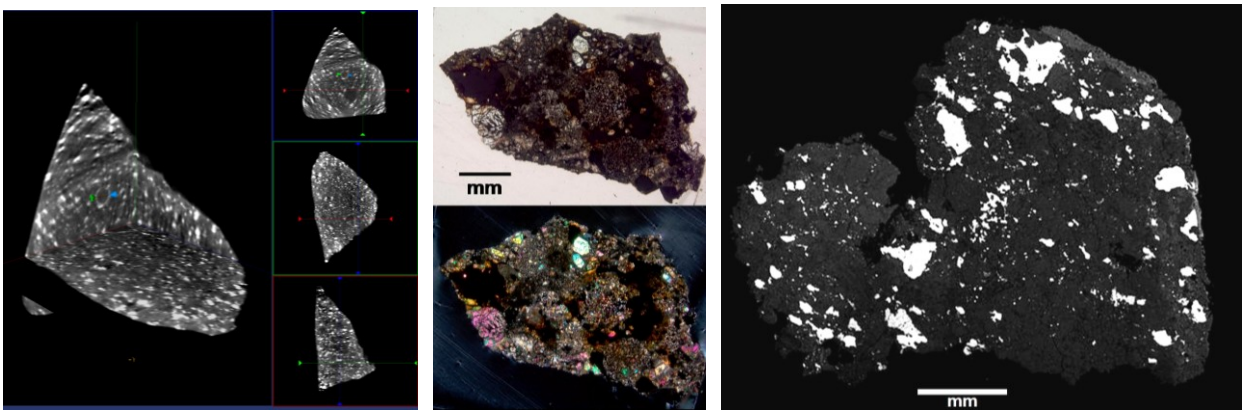


Figure 4. X-ray Micro-CT reconstruction of the Grimsby "HP-1" fragment (left), shown with virtual cut surfaces orthogonal to arbitrary X,Y,Z axes for the fragment. A 1.7mm chondrule rimmed by metal and sulphides is highlighted. Three inset panels show cut surfaces orthogonal to X,Y,Z. In the centre view, a polished thin section from "HP-1" is shown in PPL (centre top) and XPL (centre bottom), exhibiting porphyritic olivine and polycrystalline chondrules, isolated olivine grains and opaque metal and sulphides with adjacent Fe-staining. In SEM backscatter (right) the second "HP-1" polished thin section contains vesicular fusion crust along the top and right sides of the view.

Classification

Initial electron probe microanalysis (EPMA) data for olivine in chondrules and matrix are $Fa_{17.8\pm0.4}$, (n=8 grains) and for low Ca pyroxene, $Fs_{15.8\pm1.0}$, (n=5), indicating Grimsby to be an H chondrite (Van Schmus and Wood, 1967; Brearley and Jones, 1998).

In summary, from this preliminary examination via non-destructive techniques, petrographic examination of thin sections, SEM and EPMA, Grimsby is deemed to be an H5 (S2, W0-1) chondrite, with a possibly more complex shock history.

Acknowledgements

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