THE FUSION CRUST OF THE WINCHCOMBE METEORITE: VIGOROUS DEGASSING DURING ATMOSPHERIC ENTRY.

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Introduction: Fusion crusts form during the atmospheric entry heating of meteorites and preserve a record of the conditions that occurred in the last few seconds of their deceleration in the atmosphere [1]**.** Although fusion crusts are ubiquitous they are rarely characterised and studied because they obscure the primary features of meteorites.

Here we report the results of a study of the fusion crust of the Winchcombe CM2 chondrite. The Winchcombe meteorite fell at 21:54 hours on 28 February 2021 in Gloucestershire in the UK and was recovered over the next week. The fall was observed on UKFAll network cameras and recorded by CCTV. The meteoroid had a low entry velocity compared to other observed falls of 13.5 km/s. Study of the fusion crust reveals unique textural features that testify to previously unknown processes related to vigorous degassing of this intensely altered CM2 chondrite.

Methods: Six polished blocks of Winchcombe were studied using backscattered electron imaging, elemental mapping, energy dispersive spectroscopy (EDS), electron backscatter diffraction (EBSD) and micro-X-ray fluorescence (XRF). Apparent size distributions and abundances were obtained by threshold analysis using ImageJ.

Results: The fusion crust consists of an inner thermally altered substrate and outer melted crust. The altered substrate exhibits unusually abundant dehydration cracks extending up to 5 mm into the meteorite. The crack network encompasses fragments up to 70 µm in diameter (dense rock equivalent) with increasing abundance with decreasing size. Loss of sheet-like habits for phyllosilicates and tochilinite testifies to progressive dehydration towards the exterior. The outer melted crust has a vesicular porphyritic texture with olivine phenocrysts and magnetite in a glassy mesostasis. Grain-size and magnetite abundance increase outwards similar to other CI/CM2 fusion crusts [2]. High Ni (<80 wt%) sulphide-metal droplets occur – often as menisci on vesicles. A magnetite rim occurs on the exterior surface and some vesicles, and include some tabular, rim-parallel magnetite crystals.

Unique features in the fusion crust are oscillatory zoned olivine crystals, monolayers of magnetite and silicate warts. Monolayers form chains of magnetite crystals within the mesostasis that have tabular crystals similar to magnetite rims. EBSD data reveals [111] is parallel to the length of tabular crystals and is layer parallel in rims and monolayers. Oscillatory zoned crystals are equant with up to 4 Mg-rich zones. Silicate warts form lenticular features on the surface of the fusion crust and contain dendritic olivine – their compositions are, however, similar to the rest of the crust. Magnetite monolayers lie between warts and the underlying crust.

Discussion: The unusualy high abundance of dehydration cracks suggests the tochlinite-rich matrix of the Winchcombe meteorite is particularly sensitive to dehydration, owing to the low decomposition temperature of this mineral (250ºC [3]). Mechanical failure of the substrate, in part driven by gas pressure, is likely to inject large abundances of particulates into the meteoroid gas stream. Observations of episodic pulsed plasma in the trail of the fireball may be a phenomena associated with calving of the dehydrated substrate and generate thermal pulses explaining the presence of oscillatory zoning. Other features also are consistent with vigorous degassing. Magnetite monolayers appear to have formed as surface magnetite rims – owing to their similar alignment of tabular crystals. Trapping of surface magneite rims through collapse of melt protrusions is likely to explain how these layers become buried within the crust and is probably driven by perturbation of surface melt by rapid vesicle loss. Finally, silicate warts are likely to be droplets attached to the crust surface. Their dendritic textures suggest higher peak temperatures and strongly suggest they represent droplets removed from other stones in the shower. Warts represent the first discovery of inter-shower transport of ablation materials, possibly owing to enhanced ablation as a result of vigorous degassing.

Implications: The fusion crust of the Winchcombe meteorite illustrates the complexity of processes affecting meteorites during atmospheric flight. Features such as magnetite monolayers and silicate warts have not previously been described, and may be unique to tochlinite-rich CM2 chondrites, which experience vigorous degassing. They may also allow ablation debris to be related to particular types of meteorite, thus providing a distributed record of the meteorite flux. Winchcombe underlines the utility of fusion crust, which should be routinely characterised in addition to meteorite interiors.

References: [1] Ramsdohr P. (1967) EPSL 2, 593-598, [2] Genge M. J. & Grady M. M. (1999) MAPS 34 (3). 341-356. [3] Fuchs, L. H et al. (1973) Smithsonian Contrib. Earth Sci. 1–39