A COORDINATED APPROACH TO INVESTIGATE THE HETEROGENEITY OF AQUEOUS ALTERATION AT THE MICRO-SCALE IN THE WINCHCOMBE METEORITE, A CM FALL

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Introduction: CM carbonaceous chondrites are among the most chemically primitive meteorites, yet are also some of the most aqueously altered [1,2]. This pervasive parent body processing destroys much of the primary mineralogy and texture [2]. Nano-scale investigations indicate that the permeability of aqueously altered carbonaceous chondrites is low, permitting fluid flow only over distances <100 μm [3], and that aqueous alteration is locally heterogeneous [4]. In contrast, recent observations of large veins of carbonate on the B-type asteroid Bennu [5], which has spectroscopic similarities to CMs [6], suggest macro-scale movement of fluids.

On the 28th February 2021 a bright fireball was observed by the UK Fireball Alliance (UKFall) [7]. This resulted in the recovery of the Winchcombe meteorite 12 hours later [7]. It is a CM chondrite breccia with eight distinct lithologies, with variable alteration histories ranging from CM2.0-CM 2.6 plus a cataclastic matrix [8]. The limited terrestrial alteration of Winchcombe, combined with the orbital parameters determined by UKFAll [7], make it an ideal sample to explore macro-nanoscale constraints on aqueous alteration of CM chondrites. Here, we present the key results of the investigations undertaken by the fine-grained sub-team of the Winchcombe consortium study.

Methods: Several rock chips and petrographic sections of the Winchcombe meteorite were analysed using X-ray computed tomography (XCT), electron probe microanalysis (EPMA), scanning electron microscopy (SEM) techniques (including secondary electron (SE) and backscatter electron (BSE) imaging, energy dispersive X-ray spectrometry (EDS), QEMSCAN, electron backscatter diffraction (EBSD)), focused ion beam (FIB) microscopy (including FIB based time of flight secondary ion mass spectrometry (TOF-SIMS) transmission electron microscopy (TEM) techniques (including, HAADF, EELS, STEM, EDS, XANES), atom probe tomography (APT). Permeability at the macroscale were established via numerical simulations.

Key results: *XCT* data indicate that some Winchcombe lithologies have a preferred alignment of relic ellipsoidal chondrules defining a foliation fabric. These foliations are in separate orientations in different lithologies from the same rock chip. Some lithologies also exhibit a 'fracture cleavage' defined by sub-parallel fracture sets. *Numerical simulations* indicate that Winchcombe has an anisotropic permeability with a much lower permeability along one axis. *SEM* imaging reveals a range from complete to incomplete replacement of carbonate and silicate phases in some tochilinite cronstedtite intergrowths (TCIs) with some carbonate-TCI grains separated by only a few 100 μm. *EPMA* data show a moderate spread of compositions within the matrix, fine-grained rims (FGR), and TCIs within each lithology. *TEM* investigations of an FGR around a chondrule within a subtype 2.2 lithology reveal the presence of inclusions that resemble glass with embedded metal and sulphide (GEMS). Coordinated *TOF-SIMS* and *APT* data indicate that Na is concentrated at the boundary between Mg-rich and Fe-rich serpentine intergrowths in TCIs.

Discussion and conclusions: At the macro-scale, XCT results and numerical simulations show that fluids flowed more readily along a 2D plane and less-readily along the pole to that plane. Such an anisotropic permeability network may be generated via compaction or through precipitation of minerals during aqueous alteration, and would serve to limit fluid transfer, resulting in the segregation of fluid compositions which may enhance the preservation of pockets of unaltered material. At the nanoscale, the survival of both GEMS-like phases that are readily altered by minor degrees of aqueous alteration, and the heterogeneity in the extent of carbonate alteration to TCIs over short distances, suggest that regions within otherwise severely aqueously altered regions of the Winchcombe meteorite experienced little fluid interaction. This was likely caused by local variations in permeability on the Winchcombe parent. The cause of this lower permeability that limited fluid migration to reactive surfaces could be a primary texture, a compaction texture, an impact texture, or generated by progressive alteration. Therefore, even in pervasively aqueously altered meteorites it is likely that some nano-macro scale volumes can preserve their primary mineralogy and texture.

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