The Winchcombe Meteorite: A Pristine Sample of the Outer Asteroid Belt

Ashley J. King[1], Luke Daly[2], Katie H. Joy[3], Helena C. Bates[1], James F. J. Bryson[4], Queenie H. S. Chan[5], Patricia L. Clay[3], Hadrien A. R. Devillepoix[6], Richard C. Greenwood[7], Sara S. Russell[1], Martin D. Suttle[7] & the Winchcombe Consortium
[1]*Natural History Museum, London,* [2]*University of Glasgow,* [3]*University of Manchester,* [4]*University of Oxford,*
[5]*Royal Holloway, University of London,* [6]*Curtin University,* [7]*The Open University (a.king@nhm.ac.uk)*

At 21:54 (UT) on the 28th February 2021 a bright fireball was observed travelling approximately W to E over the United Kingdom. The fireball lasted ~7 seconds and was recorded by 16 stations operated by the six meteor camera networks of the UK Fireball Alliance (UKFAll); it was also caught on numerous dashboard and doorbell cameras and there were >1000 eyewitness accounts, including reports of a sonic boom. Following an appeal in the national media, the main mass (~320 g) of the meteorite was discovered by a family in Winchcombe, Gloucestershire. The stone landed on the family's driveway, shattering into a pile of dark mm- to cm-sized fragments and powder, most of which they collected wearing gloves and sealed within plastic bags ~12 hours after the fall. Further meteorites were recovered in the local area over the following week by members of the public and during an organised search by the UK planetary science community, with the largest piece being a 152 g fusion-crusted stone found on the 6th March 2021 on farmland. In total, >500 g of the Winchcombe meteorite was recovered less than seven days after the fall, with no significant rainfall having occurred during that time.

The entry velocity of the Winchcombe meteoroid was ~14 kms^{-1} and the videos clearly show several fragmentation events in the atmosphere. Preliminary analysis of the video footage combined with the measurement of short-lived cosmogenic radionuclides suggest that the original body was small (<100 kg). The calculated pre-atmospheric orbit of the Winchcombe meteoroid suggests an origin in the outer asteroid belt; the orbit is similar to those previously reported for the Sutter's Mill (C) and Maribo (CM2) meteorites, but distinct from Tagish Lake ($C2_{ung}$) and Flensburg ($C1_{ung}$) [1−4].

Inspection of stones and fragments "by-eye" and petrographic observations of 18 polished samples by optical and electron microscopy indicate that Winchcombe is a CM ("Mighei-like") carbonaceous chondrite. It consists of chondrules and calcium-aluminium-rich inclusions (CAIs) set within a matrix (SiO_2 ~28 wt%, FeO ~24 wt%, MgO ~18 wt%, total ~80 wt%) of phyllosilicates, carbonates, magnetite and sulphides. X-ray diffraction (XRD) analysis of several fragments show that the phyllosilicates are a mixture of Fe- and Mg-bearing serpentines present at >80 vol%. Many of the polished samples, plus mm-sized chips characterised using computed tomography (CT), show evidence for brecciation and contain multiple distinct lithologies with sharp boundaries. Most lithologies record a high degree of aqueous alteration (CM2.0 – 2.2 on the Rubin et al. [5] scale); chondrules and CAIs retain well preserved fine-grained rims (FGRs) but have been extensively replaced by secondary minerals including abundant tochilinite-cronstedtite intergrowths (TCIs) and carbonates. A rare lithology containing unaltered chondrules and metal has also been identified. The sulphides are mainly pyrrhotite and pentlandite, and magnetite typically has a framboidal structure. Several large (~50−100 µm) sulphate grains have been found embedded within the matrix, with their textural setting suggesting that they formed from a fluid on the parent body.

The classification of Winchcombe as a CM chondrite is further supported by bulk major and minor element abundances and oxygen ($\delta^{17}O$ = 2.75 & 0.94; $\delta^{18}O$ = 9.48 & 7.29; $\Delta^{17}O$ = -2.18 & -2.85) and titanium isotopic compositions. The bulk water content of Winchcombe is ~12 wt% and analysis of two chips by stepped combustion yielded carbon (~2.0 wt%) and nitrogen abundances and isotopic compositions consistent with other highly altered CM chondrites [e.g. 6]. The release profiles indicated the presence of multiple carbon- and nitrogen-bearing organic components and low voltage SEM characterisation of unprepared chips less than a week after the fall identified several carbon-rich regions with "globule-like" morphologies. However, initial analysis by gas chromatography-mass spectrometry (GC-MS) suggests that the total amino acid abundance in Winchcombe is significantly lower than in most CM chondrites [e.g. 7].

The Winchcombe meteorite is only the fifth carbonaceous chondrite fall with a known pre-atmospheric orbit, and due to its rapid recovery is likely the most pristine member of the CM group. The mineralogical, elemental, and organic properties of Winchcombe provide a snapshot of conditions in the protoplanetary disk and new insights into the chemical and dynamic evolution of volatiles in the early solar system. The nature of the Winchcombe meteorite and timing of the fall makes it complementary to samples of asteroids Ryugu and Bennu collected by the Hayabusa2 and OSIRIS-REx missions, offering an opportunity to develop and rehearse analytical protocols on fresh, carbonaceous materials.

References: [1] Jenniskens et al. (2012) Science 338:1583. [2] Borovička et al. (2019) M&PS 54:1024. [3] Brown et al. (2000) Science 290:320. [4] Borovička et al. (2021) M&PS 56:425. [5] Rubin et al. (2007) GCA 71:2361. [6] Alexander et al. (2013) GCA 123:244. [7] Glavin et al. (2006) M&PS 41:889.