

VISIBLE AND INFRARED SPECTRAL ANALYSIS OF THE WINCHCOMBE METEORITE FOR COMPARISON WITH PLANETARY SURFACES.

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Introduction: The Winchcombe fall was observed on the 28th of February 2021 and ~600 g of meteoritic material was recovered over the following month [1]. Winchcombe is classified as a CM2 chondrite, though several lithologies are represented in the recovered material showing variations in petrologic type and degree of aqueous alteration. Analyses have been performed to gain a comprehensive understanding of its bulk material properties as part of a nationwide collaboration [e.g. 1, 2]. Here we discuss spectral analyses conducted at the Planetary Spectroscopy Facility at the University of Oxford. These measurements include visible to near-infrared (VNIR; 0.7-5 μm) and mid-infrared (MIR; 5-25 μm) reflectance measurements of two Winchcombe samples, as well as multi-angle VNIR Bidirectional Reflectance Distribution Function (BRDF) measurements made using the Visible Oxford Space Environment Goniometer [3]. The BRDF was measured for a powdered sample characterized in terms of porosity and surface roughness, and this dataset was used to determine the broadband albedo (0.35-1.25 μm) of Winchcombe in [1].

IR Spectroscopy: Reflectance spectra of two samples (BM.2022,M1-91; BM.2022,M2-41) were measured with a Bruker VERTEX 70v Fourier Transform Infrared spectrometer, using a diffuse reflectance accessory under vacuum (~2 hPa) at 4 cm^{-1} resolution and an average of 150 scans calibrated to a diffuse gold target. The shortest wavelength range (0.8-2 μm) was acquired using an InGaAs detector coupled with a VIS/Quartz beamsplitter, while a RT-DLaTGS detector and wide range beamsplitter were used for the near- and mid-infrared (2-25 μm). We correlate the spectra with modal mineralogy as determined using position-sensitive-detector X-ray diffraction (PSD-XRD) [1] and water abundance using thermogravimetric analysis (TGA) [2] for the same samples.

A strong feature near 2.7 μm is attributed to OH⁻ stretching, which indicates the aqueously altered mineralogy of the meteorite. It can also be affected by terrestrial alteration products and adsorbed water. Several studies [4,5,6] have used reflectance near this feature to estimate water content of asteroids and meteorites. We compared water abundances as measured through TGA to calculated water abundance using reflectance parameters and found reflectance measurements generally underestimated measured water abundance.

The Christiansen feature (reflectance minimum) is located near 9 μm and indicates poor silicate polymerization. The shift in position between the two Winchcombe spectra (~0.1 μm) correlates to slightly different olivine contents. The positions in the Winchcombe spectra are consistent with spectra of other CM chondrites [e.g. 7]. The transparency feature (reflectance maximum) near 11.5 μm is another compositional indicator and has been shown to correlate to aqueous alteration in CM chondrites [7]. Shifts in this feature indicate BM.2022,M2-41 is more aqueously altered than BM.2022,M1-91. This is consistent with the determined mineralogy [1].

Bidirectional Reflectance Distribution Function (BRDF): The BRDF was measured for a powdered sample of the Winchcombe meteorite (BM.2022,M1-22) across 0 – 70° reflectance angles, in steps of 5°; at 15°, 30°, 45° and 60° incidence angles; and at 0°, 90° and 180° azimuthal angles. The dataset was then fitted using the Hapke BRDF model to enable constraints to be placed on the bulk scattering properties of the meteorite sample [8]. Importantly, the surface profile of the sample was characterized using an Alicona 3D[®] instrument. Therefore, two of the free parameters within the model – the filling factor, ϕ ; and the RMS slope angle, θ – could be set, as $\phi = 0.65 \pm 0.02$ and $\theta = 16.11^\circ$ (at 500 μm size-scale). This enabled w , b and h_s to be set as the three open parameters within the Hapke BRDF model Least-Squares Levenberg-Marquardt fitting function. The best fit Hapke parameters were determined to be $w = 0.152 \pm 0.030$, $b = 0.633 \pm 0.064$ and $h_s = 0.016 \pm 0.008$. From the BRDF dataset, the broadband albedo value was calculated to be $A = 4.09 \pm 0.18\%$, which can be converted to hemispheric albedo by multiplying by π [8]. As with the reflectance samples (previous section), modal mineralogy and water abundance were obtained for BM.2022,M1-22 [2].

Summary: VNIR and MIR spectroscopy are highly effective tools used in planetary remote sensing to determine the composition and physical properties of rocks and minerals. Here we are able to catalog several important spectral features and derived properties of the Winchcombe material for comparison to other meteorites and asteroids. The laboratory measured Winchcombe BRDF provides a reference photometric dataset for use in remote sensing studies of similar airless bodies, and by combining the IR spectra of the pristine Winchcombe material with other measurements on Earth, we can better understand and interpret data from Solar System objects and, in turn, learn more about their origins and evolution.

References: [1] King A. J. et al. 2022. *Science Advances*. In review. [2] Bates H.C. et al. 2022. *MAPS*. In prep. [3] Curtis R. et al. 2021. *RSI* 92.3:034504 [4] Rivkin A. S. et al. 2003. *MAPS*. 38:1383-1398. [5] Sato K. et al. 1997. *MAPS*. 32:503-507. [6] Beck P. et al. 2021. *Icarus*. 357: 114125 [7] Bates H. C. et al. 2020. *MAPS*. 55:77-101. [8] Hapke B. 2012. *Icarus*. 221:1079-1083.