

**MID-IR MAPPING OF MARTIAN METEORITES; SPATIALLY RESOLVED MINERAL SPECTRA FROM A SYNCHROTRON SOURCE.** N. R. Stephen<sup>1,2</sup>, P. F. Schofield<sup>1</sup>, A. J. Berry<sup>2,3</sup> & P. Donaldson<sup>4</sup> (Email: [n.stephen@nhm.ac.uk](mailto:n.stephen@nhm.ac.uk)) <sup>1</sup>Dept. of Earth Sciences, The Natural History Museum, London, SW7 5BD, UK, <sup>2</sup>Dept. of Earth Science & Engineering, Imperial College London, London, SW7 2AZ, UK; <sup>3</sup>Research School of Earth Sciences, Australian National University, Acton ACT, 0200, Australia; <sup>4</sup>Diamond Light Source Ltd., Harwell Science & Innovation Campus, Didcot, OX11 0QX, UK.

**Introduction:** A wealth of spectral data from the Martian surface exists within databases and libraries due to many years of spectroscopic investigation by both orbiting satellites and rovers on the surface of Mars. The Martian meteorites, however, provide the only example of true Martian material available to study in the laboratory [1] and therefore act as a ground truth for this spacecraft data.

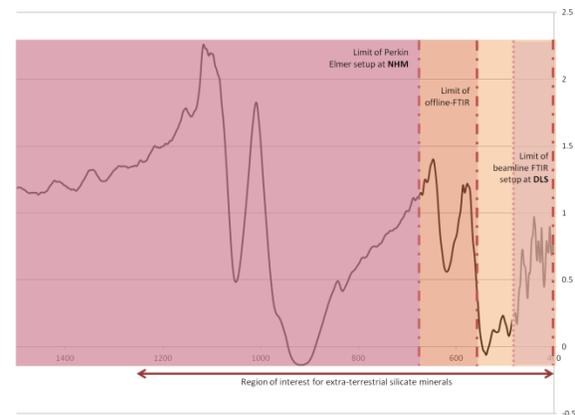
Previous studies have illustrated that individual phase spectra can be extracted from these meteorites [2-6] and compared to those available within the spectral libraries that are currently used for analysis of the remotely collected data [7]. Micro-FTIR has also been used to study alteration products within these meteorites [8]. In order to achieve this, high spatial resolution is required to account for the complex mineral textures and small crystal sizes observed in these meteorites. To date, however, this has not been achieved. Furthermore, a large spectral range is desired to minimize the ambiguity in the identification of the specific silicate minerals common on Mars, which in meteorites display chemical zoning and highly variable crystallographic orientations.

The necessary spatial resolution and extended spectral ranges are not available on standard laboratory instrumentation but are provided on microscopy beamlines at synchrotron sources, see figure 1.

**Samples & Analytical Techniques:** 13 polished sections of Martian meteorites were available; DaG 476 (BM2000, M7), EET 79001, Los Angeles (BM2000, M12), SaU 005 (BM2000, M40), Tissint (BM2012, M3), Zagami (BM1966, 54) and new anomalous meteorite NWA 7034. Two in-house pyroxene mineral standards were also analysed for completeness; augite and “pigeonite”, with a standard quartz crystal (BM1921,120) used for calibration.

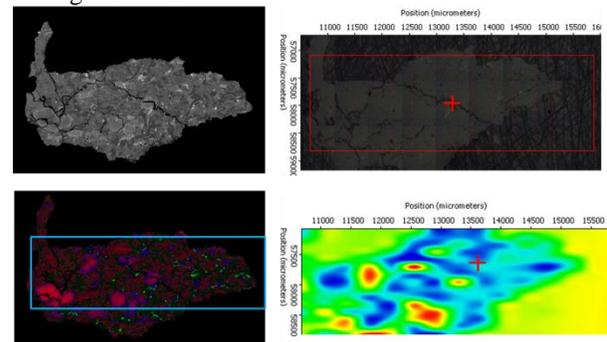
The samples were analysed on beamline B22 at Diamond Light Source (DLS) the UK synchrotron facility. A Bruker Hyperion 3000™ spectrometer with microscope attachment and motorized stage was used with the standard KBr beam-splitter and 36x objective. The spectral range of this spectrometer is within the mid-IR wavelength range, 4000 – 450 cm<sup>-1</sup> and used the synchrotron source as an input. An aperture of 15 x 15 μm was used with 256 scans and a 4 cm<sup>-1</sup> resolution. A 5 μm overstep was used for mapping runs to

improve data quality. The data were processed using the Bruker OPUS® software.



**Figure 1:** The addition of the synchrotron source to otherwise similar benchtop micro-FTIR setups increases the spectral range down to the lower wavenumbers within the mid-IR region. The pink region indicates the limits of the in-house micro-FTIR system at the NHM; the orange region indicates the extended data range when using the offline and beamline micro-FTIR setups at DLS.

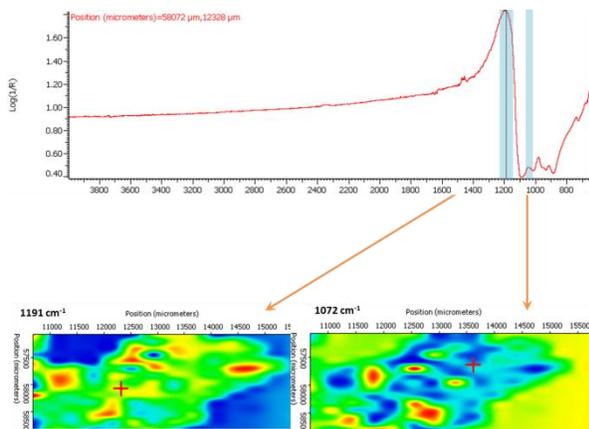
**Results & Discussion:** The polished meteorite sections were each mapped to present spectral variation as a contoured image, which can then be compared to chemical maps to extract particular phases of interest, see figure 2.



**Figure 2:** BSE image (top left) and visible image survey of IR analysis (top right) modal mineralogy map (bottom left) using combined element maps in the RGB channels; red=Mg, green=Ca and blue=Fe; spectral variation map for the ~1072 cm<sup>-1</sup> band (bottom

right) highlighting areas of  $\text{Ca}^{2+}$  depletion, corresponding to macrocrystic olivine location within Tissint.

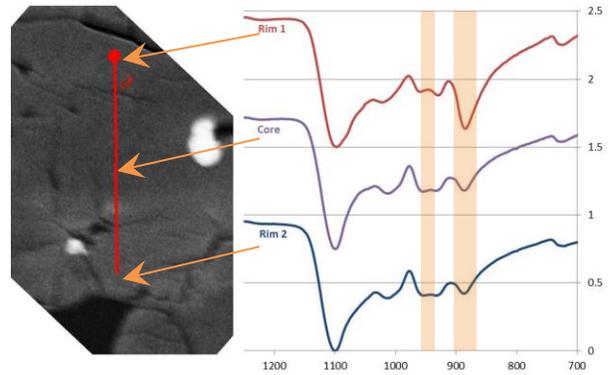
Contoured maps are produced by selecting a particular band of interest within the section and therefore can be used to map specifically for each phase (figure 3). For the 12 polished shergottite sections studied, olivine macrocrysts, zoned clinopyroxene (augite and pigeonite), accessory phases and the amorphous feldspathic-glass or maskelynite were each identified. For polymict breccia NWA 7034, the fine-grained nature of the matrix was in some areas beyond spatial resolution of this experiment, although with the application of an  $8 \times 8 \mu\text{m}$  aperture allowed larger clasts and crystals to be resolved from the matrix. Further work is required to isolate the fine-grained phases within the breccia.



**Figure 3:** Spectral maps extracted from Tissint section P17952; (left) areas of pigeonite concentration are highlighted using the  $\sim 1191 \text{ cm}^{-1}$  band and (right) areas of olivine concentration using the  $\sim 1072 \text{ cm}^{-1}$  band.

Due to the small  $15 \times 15 \mu\text{m}$  aperture used in this study, spectra were isolated from within cores and rims of individual chemically zoned crystals; a well-documented characteristic of Martian-specific silicate minerals. Previous studies of this nature have not been able to isolate such small-scale features owing to the spot size of standard microscopes ( $50 - 100 \mu\text{m}$ ) averaging the composition over a larger region [8]. Preliminary data analysis suggests that the chemical zonation throughout silicate minerals within the Martian meteorites affects both band depth and the sharpness of associated features within the spectrum, see figure 4.

Crystallographic orientation can also be quantified within this study. Targeted analysis of the pyroxene standards before rotating the subject crystal  $90^\circ$  revealed a change in peak intensity and a shift in band position by  $\sim 20 \text{ cm}^{-1}$  in some cases.



**Figure 4:** Zonation profile through a single pyroxene crystal within the SaU 005 meteorite. The BSE image (left) was generated during microprobe analysis to determine the pyroxene composition. This aided targeted analysis of the same thin section during FTIR analysis (right); the three spectra, which are offset for clarity, can be placed according to mineral composition on the rims or within the core of the single pyroxene crystal.

Vibrational spectra were extracted from various phases and orientations within all 13 polished sections and the three standards; full results will be presented at the meeting.

**References:** [1] McSween, H.Y. (2003) in *Meteorites, Comets and Planets* (ed. A.M. Davis), Vol 1 *Treatise on Geochemistry* (eds H.D. Holland and K.K. Turekian). [2] Palomba et al. (2006) *Icarus* 182:68-79; [3] Klima R. & Pieters C. (2006) *JGR* 111:E01005; [4] Morlok A. et al. (2006) *MAPS* 41:773-784; [5] Benedix G. & Hamilton V. (2007) Abstract #1805, *38th Lunar & Planetary Science Conference*; [6] Stephen, N. R. et al. (2012) Abstract #2199, *42nd Lunar & Planetary Science Conference*; [7] Hamilton, V. E. et al. (2003) *MAPS* 38:871-885; [8] Muttik, C. B. et al. (2013) Abstract #5216, *76th Meeting of the Meteoritical Society*

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