

INFRARED ANALYSES OF MINERALS AND ORGANICS IN THE SUTTER'S MILL METEORITE.

G. J. Flynn¹, S. Wirick², S. A. Sandford³, and M. Nuevo^{3,4}, ¹Dept. of Physics, SUNY-Plattsburgh, 101 Broad St., Plattsburgh, NY 12901 (george.flynn@plattsburgh.edu), ²CARS, The University of Chicago, Chicago IL 60637, ³NASA-Ames Research Center, Moffett Field, CA 94035, ⁴SETI Institute, Mountain View, CA 94043.

Introduction: A daytime fireball and sonic boom were observed over California and Nevada on April 22, 2012 [1]. Following an air burst, weather radar detected meteorites falling over an area near Sutter's Mill, CA. Three fragments of the Sutter's Mill carbonaceous chondrite were recovered on April 24, 2012. Search efforts were interrupted by a 2-day rainstorm, after which ~70 additional fragments were collected [1].

Sample Preparation: We obtained milligram mass samples from the SM20 and SM30 fragments of the Sutter's Mill meteorite. Both meteoritic fragments were collected after the rain. SM20, weighing 1.1 g, was collected on April 27, 2012 (at GPS coordinates: 38.8054°N, 120.8955°W) by R. Garcia, while SM 30, weighing 3.5 g, was collected on May 1, 2012 (at: 38.7989°N, 120.8810°W) by J. Matin and M. Dayton.

Each sample was prepared by crushing a small piece, <1 mm in size, between two clean glass slides. Tapping the slides removed large particles. The meteoritic material that remained on the glass slide was suspended in a 600 mL sterilized water droplet (Sigma no. W3500). A copper TEM grid, backed with silicon monoxide was used to collect material from the surface and near surface of the droplet. The water was allowed to dry, and any water-soluble material formed a thin film on the grid substrate. The rest of the particles were randomly distributed over the whole TEM grid. This technique biases against large crystals, which our prior analyses show to contain little or no detectable organic matter, and disperses small particles, generally less than ~1 μm in size, on the TEM substrate.

Analysis: We used synchrotron-based Fourier Transform Infrared (FTIR) spectroscopy to examine the mid-infrared spectral region, from 650 cm⁻¹ to 4000 cm⁻¹, referred to as the molecular fingerprint region because many functional groups exhibit characteristic absorption features in that range. These measurements were made with a Nicolet Continuum FTIR microscope coupled to a synchrotron-generated infrared beam on beamline U2b of the National Synchrotron Light Source (Brookhaven National Laboratory, Upton, NY). This beamline produces a highly polarized infrared beam that has ~1000 times the infrared intensity of a conventional global source. This provides about 400 times better signal/noise than conventional global FTIR instruments. The high infrared intensity allows us to either: 1) detect much weaker features than are accessible with conventional global FTIR instruments,

or, 2) operate with analysis beamspots much smaller than are employed with global sources. By operating close to the diffraction limit, with beamspots ranging from 7×7 to 10×10 μm, we were able to examine the dispersed Sutter's Mills samples at a spatial resolution that frequently provided spectra of isolated areas dominated by a single mineral, olivine, pyroxene, clay, or carbonate, and to investigate the types and abundances of organic matter associated with each mineral phase.

Organic Matter. Although most of the organic matter was associated with the mineral grains, we identified rare areas dominated by organic matter, ranging up to several micrometers in size, in both SM20 and SM30. Figure 1 shows that the organic-rich spots in both samples have essentially identical infrared spectra.

The broad feature centered at 3065 cm⁻¹, consistent with an aromatic C-H stretching absorption, accompanied by the sharper feature centered at 1652 cm⁻¹, consistent with aromatic C=C, indicate the presence of a significant amount of aromatic hydrocarbon. The broad feature centered near 3265 cm⁻¹ is consistent with O-H stretching, suggesting a significant amount of water, possibly from exposure to the rain after the fall. The pair of bands at 2960 and 2875 cm⁻¹ are consistent with the asymmetric and symmetric C-H stretching modes of aliphatic -C-H₃, while the pair of bands at 2924 and 2854 cm⁻¹ are consistent with the asymmetric and symmetric C-H stretching modes of aliphatic -C-H₂-. The pair of aliphatic C-H bending features at 1395 and 1453 cm⁻¹, further identify aliphatic hydrocarbon as a major component in this organic matter.

Proteins exhibit two characteristic absorption features, the Amide I band in the 1600-1700 cm⁻¹ range, resulting from the stretching vibration of the C=O bond, and the strong Amide II band, in the 1500-1600 cm⁻¹ range, resulting from the bending vibration of the N-H bond. If the features at 1652 and 1545 cm⁻¹ are the Amide I and Amide II bands, this could suggest biological contamination of the SM20 and SM30 samples, both of which were collected after the rain at sites ~1.5 km apart. If this organic matter is terrestrial contamination, isotopic measurements may be required to distinguish indigenous from contaminant organic matter in Sutter's Mill meteorite samples collected after the rain.

Mineral Samples. We obtained spectra of isolated spots dominated by single mineral phases. Figure 2 shows three spectra of areas of the SM20 sample dominated by olivine, which is identified by the pair of

features between 850 and 1000 cm^{-1} . The variation in the relative intensities of the two features results from different crystal orientations relative to the polarized infrared analysis beam, and suggests that each sample is dominated by either a single large crystal or multiple crystals all in similar orientations. In all cases the spots dominated by olivine exhibited either no detectable aliphatic C-H stretching absorption or very weak aliphatic C-H absorption. One of the samples showed the pair of features at 1652 and 1545 cm^{-1} , possibly the Amide I and Amide II bands.

The spots dominated by pyroxene and by clay generally exhibited deeper aliphatic C-H absorption features than those dominated by olivine.

Figure 3 shows five spots dominated by carbonate, identified by the strong absorption near 1450 cm^{-1} and the weaker, sharp absorption near 860 cm^{-1} , three in the SM20 sample and two in the SM30 sample. The shift in position of this band indicates that carbonates with different compositions are present in the Sutter's Mill meteorite. Organic matter exhibiting well-defined aliphatic $-\text{C}-\text{H}_2-$ and $-\text{C}-\text{H}_3$ features is seen in all the carbonate spectra we obtained, but the aromatic C-H absorption was below the detection limit. Shifts in the positions of the aliphatic C-H absorption features among the carbonates demonstrate variability in the types of organic matter in these samples (Figure 4). The ratio between the feature at 2924 cm^{-1} ($-\text{C}-\text{H}_2-$) and that at 2960 cm^{-1} ($-\text{C}-\text{H}_3$) indicates the mean aliphatic chain length in the samples with the weak $-\text{C}-\text{H}_3$ feature is comparable to most interplanetary dust particles (IDPs) but significantly longer than for the insoluble organic matter (IOM) extracted from Murchison [2]. The SM20 spot that has approximately equal $-\text{C}-\text{H}_2-$ and $-\text{C}-\text{H}_3$ absorptions is similar to Murchison IOM [2]. None of these carbonate spectra show a strong 1652 cm^{-1} feature. So if that feature indicates contamination, that form of contamination is low or absent in these spots. The $\text{C}=\text{O}$ absorption between 1700-1800 cm^{-1} is very weak or below the detection limit. Strong water absorption is seen in two of the SM20 samples and one SM30 sample, but is absent in the other two.

Conclusions: The positions and relative strengths of the aliphatic $-\text{C}-\text{H}_2-$ and $-\text{C}-\text{H}_3$ absorption features are generally consistent with those in IDPs [2] and in-situ analyses of Murchison [3]. However, the absence of strong $\text{C}=\text{O}$ absorption features near 1700 cm^{-1} distinguishes the organic matter in the Sutter's Mill meteorite from that in most IDPs and in Murchison [2], but is consistent with the organic matter in Tagish Lake [4]. Aromatic C-H was detected only in the spectra that also exhibited absorption features consistent with the Amide I and II bands, which identify more complex organic matter, possibly terrestrial contamination.

References: [1] Jenneskins et al. (2012) *Science*, **338**, 1583-1587 [2] Flynn et al. (2003) *GCA*, **67**, 4791-4806. [3] Flynn et al. (2010) *Astrobiology Science Conference 2010*, LPICo 1538, p. 5162F. [4] Matrajt et al, (2004) *Astronomy & Astrophysics*, **416**, 983-990.

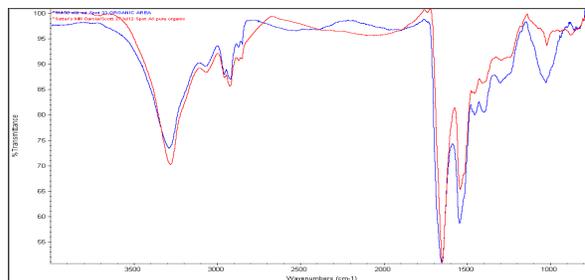


Fig. 1: Infrared absorption spectra of organic rich spots in SM20 (red) and SM30 (blue), with aromatic and aliphatic C-H stretching, aliphatic C-H bending and water absorptions.

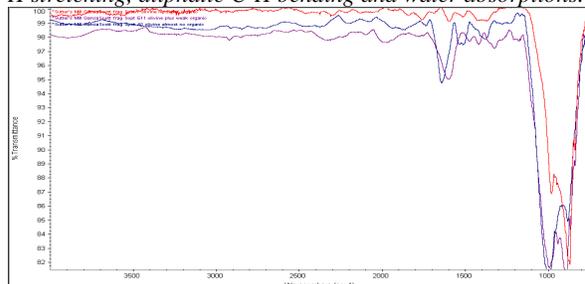


Fig. 2: Infrared absorption spectra of three $\sim 10 \times 10 \mu\text{m}$ spots dominated by olivine in SM20.

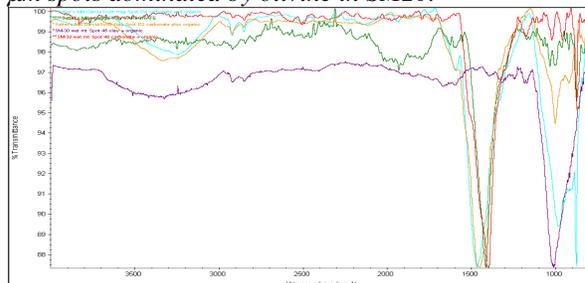


Fig. 3: Infrared absorption spectra of five spots, three in the SM20 sample and two in the SM30 sample, dominated by the carbonate absorption features and each showing deeper aliphatic C-H absorptions features than in the olivine.

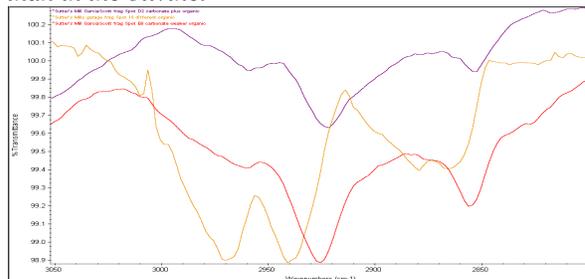


Fig. 4: Infrared absorption spectra of the aliphatic C-H stretching region of three spots in the SM20 sample dominated by carbonate