VISIBLE AND SHORTWAVE INFRARED IMAGING SPECTROSCOPY OF MARTIAN METEORITES

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Introduction The Meteoritical Bulletin Database lists 196 named martian meteorites representing ~100-120 distinct falls. These meteorites range in age from 4.5 Gyr to 175 Myr, providing an opportunity to study variations in Martian crust and mantle composition with time [1] and complementing data from remote sensing and in situ investigation at Mars.

Studies using visible/shortwave infrared (VSWIR) spectroscopy of bulk meteorite powders have been conducted to correlate meteorite spectral properties with remote sensing data [2–5]. However, creating bulk powders is destructive, eliminates valuable textural information on the relationships between mineral phases, and obscures uncommon phases by mixing. We build on prior studies of single Martian meteorites with point-to-point spectra [6] and microimaging spectroscopy [7-8] by conducting a survey of >60 Martian meteorites using VSWIR microimaging spectroscopy. Imaging spectroscopy preserves the petrographic context of mineral phases, requires minimal sample preparation, rapidly (<1 minute/measurement) produces tens of thousands of independent spectra that can be used to identify minor phases diluted in bulk spectra, and is directly comparable to remote sensing data of Mars and other petrographic observations.

Methods: The Ehlmann lab imaging spectrometer used in this study has two sensors that measure reflected light at wavelengths of 0.4-1.0 µm (VNIR) and 0.87-2.6 µm (SWIR) at spatial resolutions of 71 µm/pixel (VNIR) and 212 µm/pixel (SWIR), respectively, and an effective spectral resolution of 5 nm (VNIR) and 6 nm (SWIR) with a signal to noise ratio >100 at all channels.

Meteorite samples cut samples, 0.5-5 cm on a side (unprocessed after cutting). 5 chassignites, 7 nakhlites, and 55 shergottites were measured (of which at least 11 were pairs); 7 additional samples provisionally classification as having come from Mars were also imaged. Prior work had imaged ALH84001 using a flight prototype instrument (UCIS) at JPL [9]. Images were produced line by line as a translation stage moved the sample beneath an area below the imaging spectrometer slit illuminated by a 180 W halogen lamp. The pair of VNIR and SWIR cubes were calibrated to reflectance with a Spectralon standard, spatially co-registered, and then stacked using the ENVI image analysis software. A MNF transform was performed to remove correlated noise. Spectral analyses were conducted manually, pixel by pixel; by use of semi-automated spectral analysis tools (e.g., n-d visualization, spectral angle mapper) built into ENVI; and/or by parameter mapping routines coded specifically for this study to identify and map absorptions.

Initial Results: Using imaging spectroscopy it is possible to identify rapidly primary olivine and pyroxenes in addition to alteration minerals in martian meteorites and to map spatially their distributions within a sample. For pyroxenes, it was also possible to distinguish and map zoning in solid solution chemistry using electronic absorptions due to iron centered at 1-2 µm. For example, poikilitic shergottite NWA 7397 shows

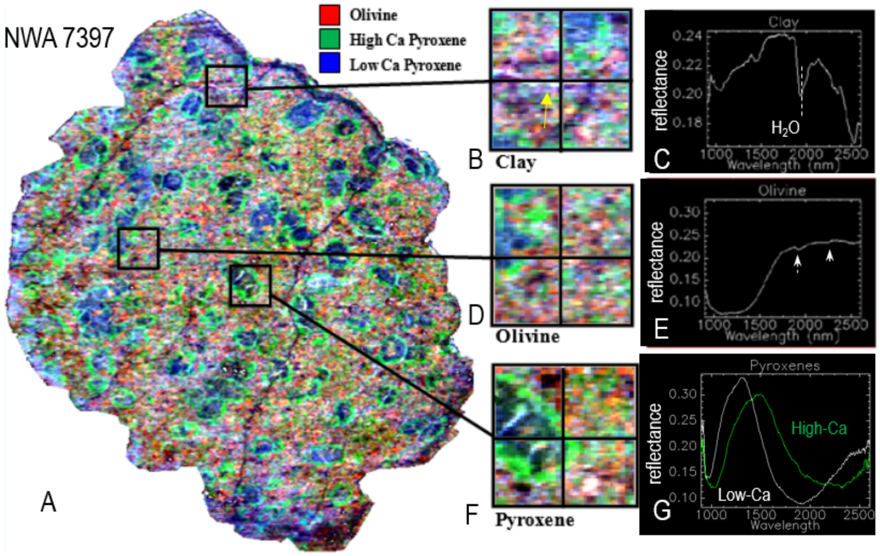

Figure 1. VSWIR imaging spectroscopy data from NWA 7397 from the Stolper collection. In this RGB false color infrared composite (R: 2.301 µm; G: 1.577 µm; B: 1.008 µm), high-Ca pyroxenes appear blue, low-Ca pyroxenes appear green, and olivine appears red. Example spectra from three locations representing typical clay-carbonates, olivine, and pyroxene spectra are displayed.

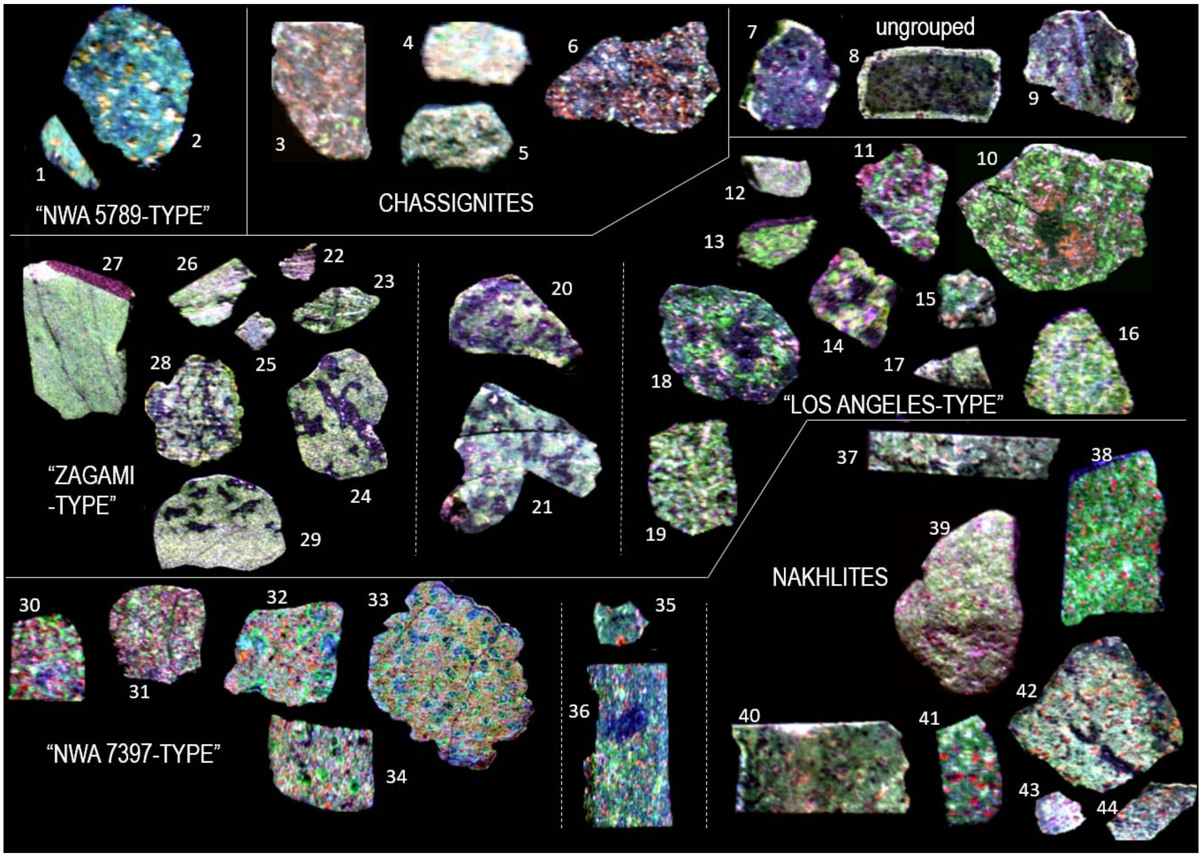

Figure 2. RGB false color infrared composite (R: 2.301 µm; G: 1.577 µm; B: 1.008) of select meteorites from the study, showing similarities in spectral properties that lead to distinctive groupings (scale was not preserved in figure construction). (1) NWA 6162 (2) NWA 5789 (3, 6) NWA 2737 (4-5) Chassigny (7) NWA 4222 (8) NWA 1195 (9) DaG 1037 (10-11) Los Angeles (12-13, 15) Shergotty (14) DHO 378 (16) NWA 10558 (17) NWA 1950 (18) NWA 7320 (19) NWA 1460 (20) NWA 1669 (21, 25) Tissint (22-23) NWA 5029 (24) NWA 10441 (26-27) Zagami (28) NWA 2626 (29) NWA 8656 (30) NWA 5990 (31) NWA 7032 (32-33) NWA 7397 (34) NWA 7387 (35) NWA 4480 (36) NWA 817 (37) NWA 1068 (38) Lafayette (39) Nakhla (40) DaG 476 (41) Governador Valadares (42-44) SAU 005

low-Ca pyroxene crystals rimmed with high-Ca pyroxene (Fig. 1). Fractures in NWA 7397 with carbonate minerals (likely terrestrial in this case due to exposure to Earth conditions) were mapped, and groundmass olivine was mapped and inferred to be altered based on the presence of 1.9 µm molecular H_2O and 2.3 µm metal-OH absorptions.

3-band SWIR false color composites of the meteorites visually sort into distinct "classes" given provisional names based on notable meteorites of that class (Fig. 2). In this false-color, Nakhlites exhibit a green pyroxene bulk with small, bright red olivine crystals. Chassignites have an orange-red hue due to olivine groundmass and light green to cyan pyroxene grains. The shergottites are diverse: the "Zagami-type" has a homogenous, olivine-poor gray-green pyroxene matrix with some dark purple, perhaps glassy, material in a marbled texture. "Los Angles-type" is similar but with distinct, larger oblong pyroxene crystals. "NWA 7397-type" has an olivine-rich orange/pink matrix with large pyroxene clasts with compositionally zoned rims. Additional samples may define additional provisional types or subtypes.

Future work: This work represents the first acquisition of a high-quality, high spatial resolution VSWIR spectroscopic dataset for martian meteorites, and it can be linked to spectral properties of Mars surface units. Future work will detail the mafic and secondary minerals observed with verification of select identifications with optical and electron-beam-based petrographic techniques. The spectral classes will be further analyzed, including examination of relationships with other known properties of the meteorites.

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References: [1] Nyquist et al., 2001, *Chronol. Evol. Mars* [2] Hamilton et al. 1997 *JGR* [3] Mustard & Sunshine, 1995, *Science* [4] McFadden & Cline, 2005, *MAPS* [5] Werner et al., 2014, *Science* [6] Bishop et al., 1998, *Met. Plan. Sci.* [7] Cannon et al. 2015, *Icarus* [8] De Angelis et al., 2014, *Planet. Space Sci* [9] Van Gorp et al., 2014, *J. Appl. Remote Sens*