

BLACK BEAUTY'S RAINBOW: HYPERSPECTRAL IMAGING OF NORTHWEST AFRICA 7034. K. M. Cannon¹, J. F. Mustard¹, C. B. Agee², J. H. Wilson³ and R. N. Greenberger¹. ¹Brown University, Department of Earth, Environmental, and Planetary Sciences, Providence RI, 02903, kevin_cannon@brown.edu, ²Institute of Meteoritics, University of New Mexico, Albuquerque NM, ³Headwall Photonics, Inc., Fitchburg MA.

Introduction: Measuring martian meteorite spectra in the laboratory should be a powerful tool to bridge the gap between detailed rover measurements and global coverage by orbital remote sensing. However, previous efforts to do this have seen mixed results. *Hamilton et al.* [1] compared thermal emission spectra of six martian meteorites with global Thermal Emission Spectrometer data and concluded that those meteorites are not a good match for the martian surface. More recent studies using visible near-infrared (VNIR) reflectance spectroscopy [2,3] identified many promising source *regions* on Mars from a larger more representative spectral sampling of martian meteorites. Others have taken the bold step of trying to pinpoint specific source *craters* for the martian meteorites [4,5]. All these studies are based on point spectra of (usually powdered) meteorites, and the SNC samples used do not appear to be chemically representative of bulk martian crust [6]. We now have available the materials and instrumental techniques to address both of these issues, and we will present spatially resolved hyperspectral imaging data for NWA 7034, the first breccia from Mars, and the first meteorite that matches the major element composition of the martian crust as determined by the Spirit Rover at Gusev Crater [7].

Samples and methods: Northwest Africa 7034 ("black beauty") and its pairings is a polymict breccia containing up to six primary igneous lithologies that include basalt, trachyte, and andesite, as well as numerous spherules, pebbles, and quenched impact melt clasts, all set in a very fine-grained matrix [7-10]. Our sample is a 0.99 g piece with a 98 mm² exposed cut face (Fig. 1) that shows a large diversity of different clast types [7-10].

In preparation for hyperspectral imaging we measured VNIR and mid-infrared (MIR) point spectra of isolated spots on the cut face at the Reflectance Experiment Laboratory (RELAB) at Brown University (Fig. 1, 2). Reflectance point spectra were measured with a bidirectional spectrometer from 0.3-2.6 μm with a 5 nm sampling, and with a Nicolet NEXUS FTIR spectrometer from 0.8-25 μm (12000-400 cm^{-1}) with a 2 cm^{-1} sampling.

Hyperspectral imaging provides spatially resolved reflectance measurements of intact samples, adding a new dimension to laboratory and field spectroscopy [11,12]. We measured the cut face of NWA 7034 (Fig. 1) at Headwall Photonics with their high efficiency



Figure 1. Optical micrograph of the NWA 7034 chip used in this study. Circled areas represent spots chosen for spectral point measurements that are shown in Figure 2.

VNIR and shortwave infrared (SWIR) hyperspectral imagers. The VNIR imager covers 0.4-1.0 μm with a 1.785 nm spectral resolution at up to 44 $\mu\text{m}/\text{px}$, and the SWIR imager covers 0.95-2.5 μm with 12.0656 nm spectral resolution at up to 133 $\mu\text{m}/\text{px}$. To calibrate the images we subtract dark-current measurements and normalize to Spectralon® as a white reference. We are in the process of final calibration, processing and interpretation of these images.

Initial Results: Point spectra of various spots on NWA 7034 differ markedly from all other basaltic martian meteorites measured to date (Fig. 2). NWA 7034 spectra are characterized by low overall albedo, blue slopes in the near-infrared region, variation in the roll-off towards UV wavelengths due to Fe^{3+} - Fe^{2+} and Fe^{3+} - O^{2-} charge transfer absorptions, and for the most part a lack of deep pyroxene and olivine absorption bands seen in other martian meteorites (Fig. 2). Orthopyroxene is present in one of the spots as seen from distinctive broad absorptions at 0.95 and 1.9 μm (Fig. 2, B).

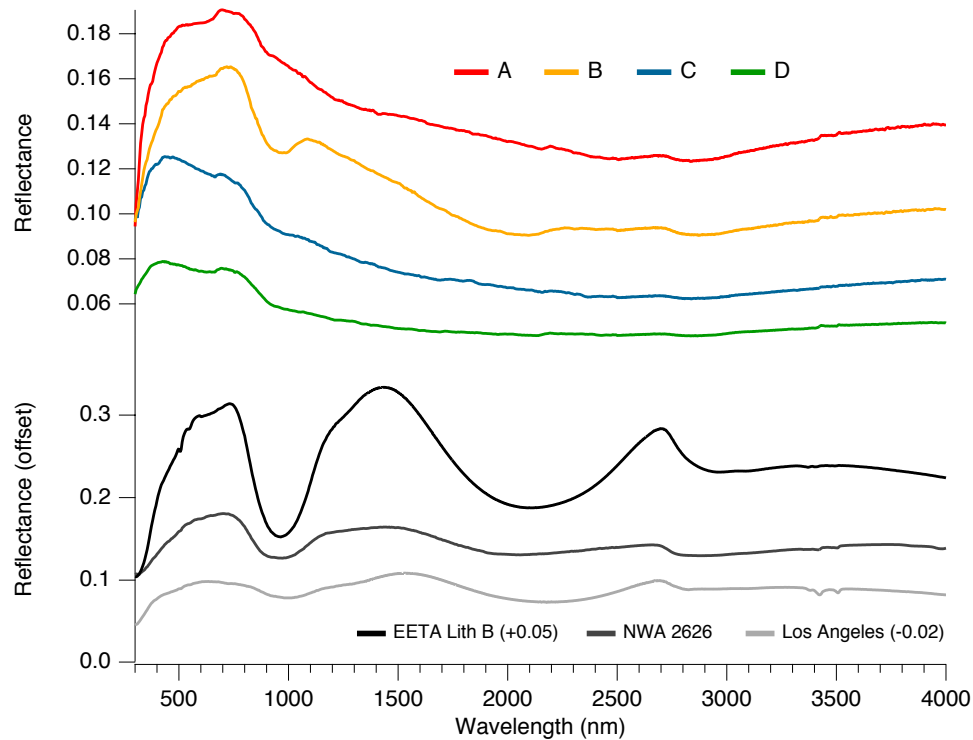


Figure 2. Merged VNIR and MIR point spectra from NWA 7034 (top, see Fig. 1 for locations) compared with spectra of other martian meteorites measured as solid chips with identical procedures in RELAB. Strong absorption features due to Fe^{2+} in pyroxene and olivine are mostly absent from NWA 7034 spectra, but are prominent in the other martian meteorites.

Blue spectral slopes have been noted in impact melt breccias from the terrestrial Mistasin crater [13], as well as from martian surface signatures interpreted as leached basaltic glasses [14]. *Craig et al.* [13] attribute blue spectral slopes in their melt breccias to dispersion of iron by the impact process. However, Fe^{2+} and Fe^{3+} are responsible for absorption features, not broad spectral slopes, and Fe^0 causes red slopes. Rayleigh scattering and Fresnel reflection can cause moderate blue spectral slopes at non-specular geometries from rough-cut surfaces [15], but as shown in Fig. 2 spectra obtained from cut surfaces of other martian meteorites are dominated by body scattering and not surface interactions. We tentatively attribute the blue slopes in the NWA 7034 spectra to a physical effect from the very fine-grained matrix of contrasting light and dark phases mixed on a scale on the order of the wavelengths of light used in the reflectance measurements [16]. It is interesting to note that the majority of the martian surface is not characterized by strong Fe^{2+} crystal field absorptions like in SNC meteorites, and that both bright and dark regions on the planet have blue spectral slopes similar to NWA 7034 [16,17].

We will present spatially resolved maps of these various spectral features and detailed characterization of the different clasts from our hyperspectral image cubes. NWA 7034 is particularly water-rich (up to

6000 ppm extraterrestrial H_2O [7]), and the $\nu_2 + \nu_3$ H_2O combination tone at $1.9 \mu\text{m}$ should be observable in the reflectance spectra if even minor amounts of water are present. Our point measurements (Fig. 2) do not show any such absorptions, but if the water is mostly concentrated in specific phases this can be resolved with hyperspectral imaging.

References: [1] Hamilton V. E. et al. (2003) *MAPS*, 38:6, 871. [2] Ody A. et al. (2013) *LPSC XLIV*, Abstract #2265. [3] Ody A. et al. (2014) *LPSC XLV*, Abstract #2207. [4] Barlow N. G. (1997) *Proceedings, SPIE Annual Meeting*, 26-35. [5] Werner S. C. et al. (2014) *Science*, 343, 1343. [6] McSween Jr. H. Y. et al. (2009) *Science*, 324, 736. [7] Agee C. B. et al. (2013) *Science*, 339, 780. [8] Humayun M. et al. (2013) *Nature*, 503, 513. [9] Santos A. R. et al. (2014) *LPSC XLV*, Abstract #2621. [10] Muttik N. et al. (2014) *LPSC XLV*, Abstract #2763. [11] Greenberger R. N. et al. (2014) *GSA NE Section Meeting*, Paper #3-6. [12] Greenberger R. N. et al. (2014) *LPSC XLIV*, Abstract #1543. [13] Craig M. A. et al. (2014) *LPSC XLIV*, Abstract #2417. [14] Horgan B. and Bell J. F. (2012) *Geology*, 40:5, 391. [15] Yon S. A. and Pieters C. M. (1988) *LPSC XVIII*, 581. [16] Fischer E. M. and Pieters C. M. (1993) *Icarus*, 102, 185. [17] Mustard J. F. et al. (2005) *Science*, 307, 1594.