CONSTRAINING EXOGENIC CARBONACEOUS MATERIAL ABUNDANCE ON (16) PSYCHE FROM LABORATORY SPECTRAL MEASUREMENTS.

D. C. Cantillo[1], V. Reddy[1], N. Pearson[2], J. A. Sanchez[2], D. Takir[3], T. Campbell[1], O. Chabra[4]. [1]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721, USA, [2]Planetary Science Institute, Tucson, AZ 85719, USA, [3]Jacobs Technology, NASA Johnson Space Center, Houston, TX 77058, USA, [4]Catalina Foothills High School, Tucson, AZ 85718, USA.

Introduction: (16) Psyche is a large M-type asteroid found in the main belt with a mean diameter of 233 km [1]. From radar and spectroscopic observations, Psyche's surface has been interpreted to be dominated by metal, silicate (low-Fe pyroxene) and exogenic carbonaceous chondrite impactor material [1,2,3,4]. In 2026, the NASA Discovery-class spacecraft *Psyche* is expected to arrive at the asteroid to study its topography and composition. Several meteorite analogs have been proposed based on Psyche's observed spectral reflectance, however these previous studies did not include exogenic carbonaceous material recently observed by ground-based telescopes [4].

Based on Dawn observations of exogenic carbonaceous material on asteroid (4) Vesta, Reddy et al. [5] constrained the hydrogen abundance on Psyche to be ~220 µg/gm, which is similar to Vesta (180 µg/gm) [6]. To independently constrain the abundance of exogenic carbonaceous material on the surface of Psyche, we obtained laboratory spectral measurements of tertiary mixtures of metal, pyroxene, and carbonaceous chondrite (CC). Our secondary goal is to simulate the most plausible regolith of Psyche in the laboratory by using the latest information from ground-based telescopes.

Sample Description: The metal component of our mixture comes from Gibeon, a IVA iron meteorite that was found in Namibia in 1836. Our pyroxene is a diogenite NWA 10446 and our final component of the mixture, the CM2 carbonaceous chondrite, is from Murchison. All samples are part of the University of Arizona collection located at the Lunar and Planetary Lab.

Sample Preparation: Crushing metal/metal-rich samples is a challenging task. Our Gibeon metal sample came in the form of metal shavings left over from slicing of larger individuals. These shavings were contaminated with oil that was used during the cutting process. To remove the oil, we placed them on a 45 micron sieve and dosed with acetone until dried. Once free of acetone and oil, we then used multiple sieves to isolate the grain size of the shavings to between 106 and 212 microns. Our pyroxene powder was obtained by crushing a fragment of NWA 10446 using a mortar and pestle. This material was then sieved to less than 45 microns grain size. Our Murchison sample was already in the form of a powder with grains smaller than 45 microns left over from a previous experiment.

Experimental Setup: Visible and near-infrared reflectance spectra (0.35-2.5 µm) of our samples was taken using an ASD FieldSpec Pro HR spectrometer at i = 30° and e = 0°, relative to a calibrated Spectralon standard, with a collimated 100W quartz-tungsten-halogen light source. Our spectrometer has a spectral resolution of 5-10 nm and capable of acquiring a spot size as small as 5 mm.

Results: Spectra of our three end members are shown in Fig. 1. The spectrum of CC Murchison (black) has a weak absorption band (depth ~6%) at 0.755 µm, the Gibeon metal is essentially featureless with red spectral slope (increasing reflectance with increasing wavelength) and the NWA 10446 diogenite (pyroxene analog) spectrum shows deep absorption bands (depth >20%) at 1 and 2 µm due pyroxene. The absolute reflectance (at 0.55µm) between the three end members is also different with the diogenite pyroxene at 0.54, Gibeon metal at 0.19 and Murchison CC at 0.06.

Figures 2 and 3 show spectra of the end members along with the five mixtures (Table 1). In Fig. 2, the spectra are shown on absolute reflectance scale and Fig. 3 shows the same data normalized to unity at 1.5 µm. The spectra of the mixtures show a weak absorption band at ~0.92 µm due to pyroxene on a red spectral slope (due to metal). A weak absorption band at 0.755 µm starts becoming evident in Mixture 4 and 5 as the amount of CC approaches 5%.

We extracted spectral band parameters for the end members (excluding metal) and the five mixtures to quantify the change in band depth as a function of end member abundance. The absorption band depth at 0.9 µm starts at ~4% depth in Mixture 1 and increases to 7% in Mixture 5 as the amount of pyroxene increases in the mixtures. The increase in CC from 1 to 5% between these two mixtures (1 and 5) does not seem to affect the band depth as much. Similarly, reflectance values at 0.55 µm (proxy for visual albedo in asteroids) shows a drop in reflectance from 0.14 in Mixture 1 to 0.12 in Mixture 3. However, the 0.55 reflectance starts to climb back up for Mixtures 4 and 5. This could be due to the increased abundance of pyroxene in these two mixtures or simply an artifact of the way the mixtures were created (heterogeneous mixing).

Implications for Psyche: Our simple three component mixture experiment is the first step towards understanding the complex regolith on asteroid Psyche. Based on our measurements we can conclude that the depth of the pyroxene absorption band is more a function of pyroxene abundance rather than carbonaceous chondrite abundance. Our original assumption was that with increasing CC abundance, the pyroxene absorption band would be subdued/masked in the mixture. However, this does not seem to be a major controller of band depth at CC abundances <5%. Sanchez et al. [3] obtained band depths of 1.0 and 1.5% for the 0.9 μm pyroxene band.

Based on the band depth and spectral slope, they estimated the pyroxene abundance to be 6% using a simple two-component metal + pyroxene mixture calibration. However, we now know that there is a third component (carbonaceous chondrite impactors) on the surface of Psyche based on the works of Takir et al. [4] and Sheppard et al. [1]. A 6% pyroxene would correspond to Mixture 3 with 3% CC material. The band depth of this mixture is ~6% which is significantly higher than the measured 1%. Even in Mixture 1 with 4% pyroxene and 1% CC, the band depth is 3%. This would suggest that the abundance of pyroxene on Psyche is lower than 4% or the abundance of CC is higher than 1%. Our next step is to create mixtures with pyroxene <4%. Another constraint is the albedo of Psyche (0.12), which can be used to constrain the abundance of CC in future mixtures.

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References: [1] Shepard M. K. et al. (2017) *Icarus, 281*, 388-403. [2] Hardersen et al. (2005) *Icarus, 175*, 141. [3] Sanchez et al. (2017) *The Astronomical Journal, 153*, 29. [4] Takir et al. (2018) *LPS XLIX*, Abstract #2624. [5] Reddy et al. (2012) *Icarus, 221*, 544-559. [6] Prettyman et al. (2012) *Science, 338*, 242-246.

Table 1. Ratios of metal, pyroxene and carbonaceous chondrite in our intimate mixtures.

	Metal (Wt.%)	Pyroxene (Wt.%)	CC (Wt.%)
Mixture 1	95	4	1
Mixture 2	93	5	2
Mixture 3	91	6	3
Mixture 4	89	7	4
Mixture 5	87	8	5

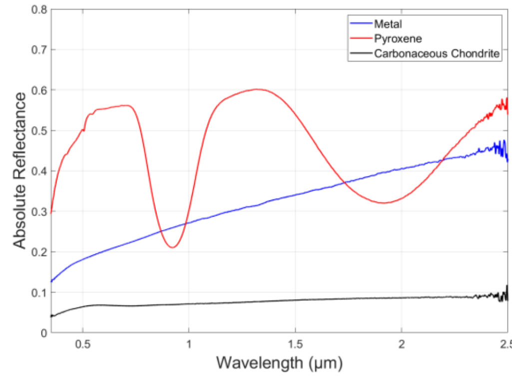

Figure 1. Visible, Near-IR reflectance spectra of the three end members shown in absolute reflectance.

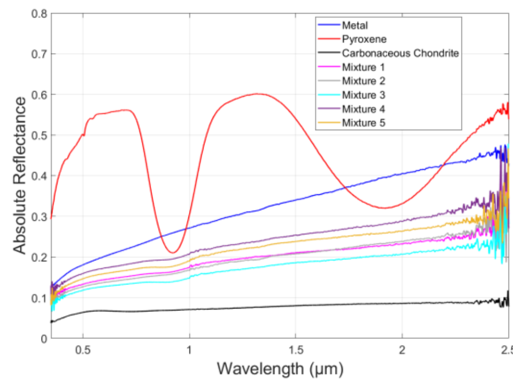

Figure 2. Visible, Near-IR reflectance spectra of the three end members and five mixtures shown in absolute reflectance.

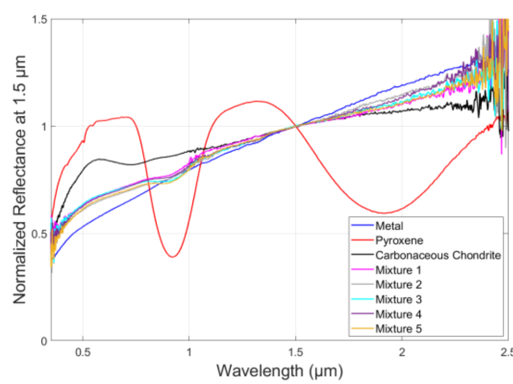

Figure 3. Visible, Near-IR reflectance spectra of the three end members and five mixtures normalized to unity at 1.5 μm.