RAMAN SPECTROSCOPIC DIVERSITY OF LUNAR METEORITES.

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Introduction: Raman spectroscopy is a non-destructive technique for mineral identification and characterization. It is particularly proficient in identifying olivine, feldspar, pyroxene, and Fe-Ti oxides [1], and for constraining or quantifying their compositions. As the lunar surface is primarily composed of the aforementioned minerals, Raman spectroscopy would be an asset for ISRU identification on the Moon and geological mapping [2]. To date, there has not been a Raman spectrometer deployed on the Moon [3], though there are plans to deploy one on the future CNSA (China National Space Administration) Chang'e-7 lunar south pole mission [1].

Previous work investigated the practicality of Raman spectrometers for lunar mineral exploration such as mineral identification and detection of condensed volatiles [2].

Here, we present a discussion of selected Raman spectra collected on a suite of lunar meteorites. This database will aid in the interpretation of data collected by future Raman spectrometers deployed on the Moon.

Methods: A total of 7 lunar meteorites were included in this study (Table 1). The measured samples are a mix of exterior surfaces, interior broken and saw-cut and polished surfaces, saw-cut powders, and fine-grained powders.

The powdered samples used in this study were prepared by crushing a subsample of the whole rock in an alumina mortar and pestle. The samples were dry sieved using a <150 µm stainless steel mesh. We also included two unsorted fine-grained saw-cut powders of NWA 11474 and NWA 12593.

The samples were analyzed using a combination of reflectance spectroscopy, Raman spectroscopy, and X-ray diffractometry (XRD). A BWTek i-Raman spectrometer was used to collect Raman spectra from 175-4000 Δ cm^{-1}, using a 532 nm laser, and a spectral resolution of ~4 cm^{-1}. Spot size of each measurement is ~85 microns.

Results: Here we report results for Raman spectroscopy of powdered and whole rock slabs of Northwest Africa (NWA) 11303b (Figure 1), and NWA 12593-96 (Figure 2) lunar breccia meteorites, focusing on plagioclase feldspar detection and characterization. The spectra of the powders showed little to no discernible Raman peaks, while the whole rock slabs show peaks associated with plagioclase, olivine, and pyroxenes.

Both meteorites exhibit Raman peaks attributable to plagioclase feldspar around 505 ±3 cm^{-1}, corresponding to anorthite [4].

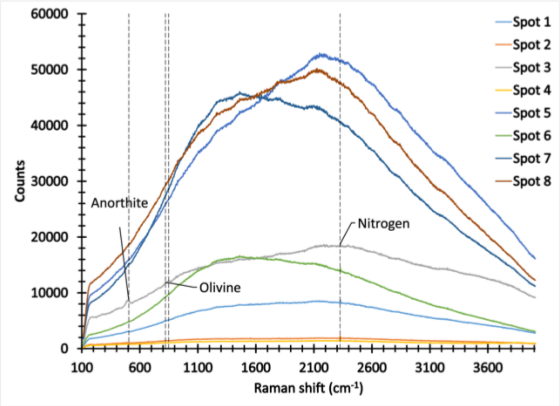

Figure 1: Raman spectra of lunar meteorite NWA 11303b slab collected at C-TAPE.

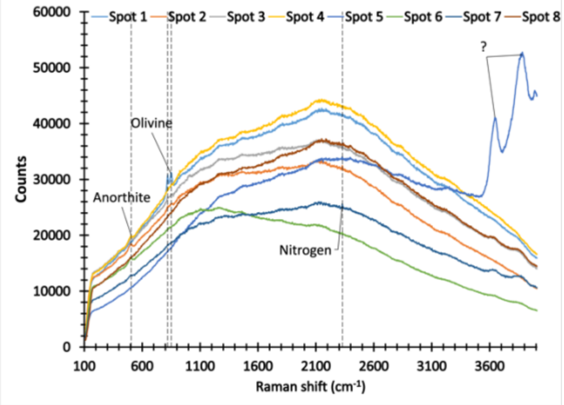

Figure 2: Raman spectra of lunar meteorite NWA 12593-96 slab collected at C-TAPE.

Olivine features a doublet peak around 800-880 Δ cm^{-1}. Depending on the position of the doublet and longer wavenumber peak, we can determine the %Fo. The olivine doublet feature in Figures 1 and 2 appear around 820 and 851 ±3 Δ cm^{-1} indicating the olivine seen here is forsteritic [5]. Forsterite (Mg_2SiO_4) is best identified by the second peak in the doublet using the following formula:

$$\%Fo = 0.18\lambda\frac{2}{2} + 310\lambda_2 - 1.34x10^5$$

Where %*Fo* is the molar amount of forsterite and λ_2 the second peak position of the olivine doublet [6].

Figure 3 displays the Raman spectra of NWA 11303b in powdered form. Like the whole rock spectra, it exhibits a minor Raman peak attributable to anorthite around 505 ±3 cm^{-1}. The anorthite feature in the powdered sample (Figure 3) is weaker than that of the whole rock (Figure 1).

Powdered samples can be compositionally complex, particularly given the size of the powder (<150 µm) versus the whole rock, where distinct clasts are clearly visible (Figure 4). The powdered samples may also include more weathered/exterior materials [7].

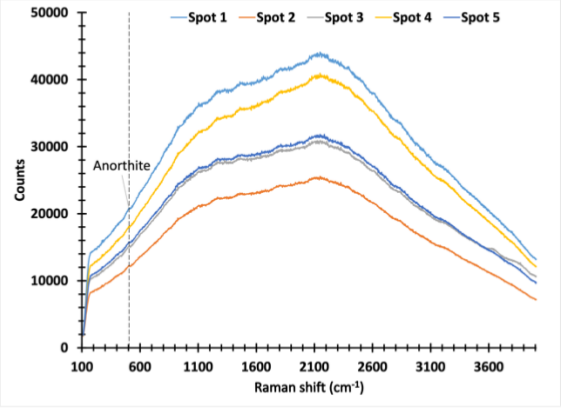

Figure 3: Raman spectra of powdered lunar meteorite NWA 11303b collected at C-TAPE.

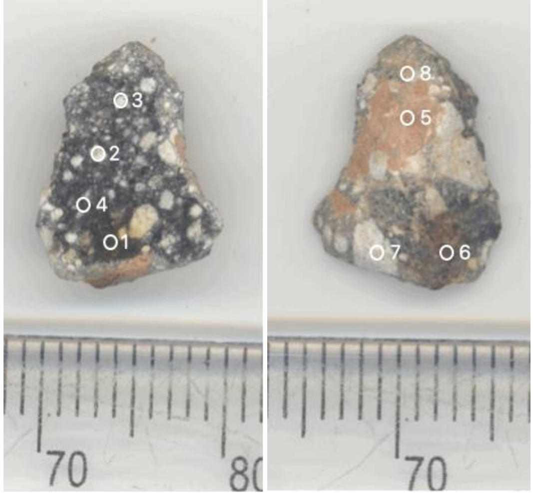

Figure 4: Images of NWA 11303b whole rock with markings where Raman spectra were collected.

Discussion: The results of this study provide evidence that a Raman spectrometer would be beneficial if deployed on the surface of the Moon in future lunar missions. A Raman spectrometer would be able to identify major lunar rock-forming minerals, and aid in identifying their compositions [6].

It could be determined that, while there are no significant differences between integration times of slabs vs powdered samples (no new evident peaks), longer integration times on fluorescing samples enables weaker Raman peaks to be discerned.. With higher signal to noise in the spectra, the easier it is to identify real peaks [7].

Determining the relative strengths and weaknesses of acquiring Raman spectra on whole rocks versus powders is ongoing. Our preliminary results suggest that Raman spectroscopy is more useful for rock interrogation. This may be due to a variety of factors, including light scattering effects, and single versus multiple minerals in the field of view.

Lunar meteorites provide a number of benefits for assessing Raman performance on the lunar surface, including previously unsampled lithologies, and materials with a range of shock levels and melting.

Conclusion: Raman spectra acquired on the lunar surface would address a number of lunar exploration objectives, including, but not limited to, mineralogical identification. [1]. This demonstration that Raman spectra of lunar meteorites yields resolvable and mineralogically-diagnostic peaks indicates that it can aid in geological mapping of the lunar surface. A Raman spectrometer could provide mineralogical information on whole rocks and regolith (integration time dependent).

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Table 1: List of lunar meteorite samples included in this study, and brief petrologic descriptions (NWA: Northwest Africa)

Sample Name	Origin	Rock Type
Lahmada 020	Western Sahara	Feldspathic breccia
NWA 8277	NWA	Breccia
NWA 11228	NWA	Feldspathic breccia
NWA 11303 (a-f)	NWA	Feldspathic breccia
NWA 11474	NWA	Feldspathic breccia
NWA 11788	NWA	Feldspathic breccia
NWA 12593 (96 and 110)	NWA	Fragmented breccia

References: [1] Caudill, C. M. et al. *LPSC 2021*; abstract #2548 (2021). [2] Cloutis, E. et al. *Frontiers Astron. Space Sci.*, *9*, 1016359 (2022). [3] Xie, T. et al. *Meteorit. Planet. Sci.*, *56*(9), 1633-1651 (2021). [4] Ling, Z. C. et al. (2011) *Icarus*, *211*(1), 101-113. [5] Weber, I. et al. (2014). *Planet. Space Sci.*, *104*, 163-172. [6] Cloutis, E. et al. *J. Chemometrics*, *37*(9), e3439 (2023). [7] Cloutis, E., *Planet. Space Sci.*, *159*, 66-83 (2018).