Raman spectroscopic study of Terrestrial geological samples: Possible Analogs for Lunar Breccia. Prateek Tripathi[1] and Rahul Dev Garg[1], [1]Geomatics Engineering lab, Department of Civil Engineering, Indian Institute of Technology, Roorkee, India, (ptripathi@ce.iitr.ac.in, rdgarg@ce.iitr.ac.in)

Introduction: Spectroscopic studies of minerals on Earth and the moon will help establish a human base for upcoming human and robotic missions to the moon. This work reviews the Raman spectra from terrestrial samples for characterizing minerals on the Lunar Surface. Seven sedimentary and metamorphic rock samples; Slate, Quartzite, Reddish sandstone, Sandstone (heavy quartz Minerals), Sandstone (course-grained), Phyllite (iron), Schist were analyzed with Raman Spectrometer. Spectral analysis shows that the peaks from Raman spectra along are playing a vital and additive role in the characterization and identification of minerals with respect to lunar samples.

Methodology: These rock samples were procured from the Department of Earth Sciences, Indian Institute of Technology, Roorkee, who collected them from Udaipur, Rajasthan, India. Powdered samples with a grain size of 10-50µm were analyzed using a Renishaw In-Via Reflex Raman Spectrometer with two excitation frequencies [1] (514 nm and 785nm). Spectra derived from Raman spectrometer (Figure 1) were compared with their counterpart spectra of Apollo returned samples.

Discussions: The Raman spectra for four Apollo samples (Apollo 11, 12, 14, and 15) previously investigated and available from the literature [2]–[5]. Few standard spectra of minerals (Figure 2 and Figure 3), including quartz, orthoclase (K-feldspar) and ilmenite from the RRUFF database, were also used because of the compositional similarity [6],[7]. Spectral features corresponding to olivine were observed in lunar samples 14301,20 and 12009,48 [2],[3]. Broadband (peak) around 500-450 cm^{-1}, which lies in the bending region of Si-O-Si and also a characteristic of lunar glasses. Here it can be linked with possible nanophase iron (npFe0) found in the lunar regolith, which results in variation in opacity of samples as observed in Taylor et al., 2001. Comparison with the RRUFF database was made to show specific lunar minerals in all terrestrial samples except Sample 1.

A peak around 1010-1000 cm^{-1} found in samples 10058, 12002, 12065, 14310, which shows a decrease in wavelength as the iron content increases[2], [3]. This band was also seen in some lunar glasses [8]. The doublet peak around 850 cm^{-1} also shows the presence of glass or impurities. Multiple spectra feature (peaks) similar to ilmenite also observed in the range of 700-250 cm^{-1}, as shown in Figure 3. The shift of peaks [3] at 1015 and 650 cm^{-1} can also be linked to variation in iron content. Apollo 12 samples show broader soft peaks of pyroxenes [9].

On comparing the Raman spectra of terrestrial samples with Apollo samples, few bands were observed, near 128 cm^{-1}, 200 cm^{-1}, 470 cm^{-1}, 1100 cm^{-1} for all samples, doublet at 450-470 cm$^{-1,}$ and the available broadband near 620 cm^{-1} for schist (Figure 1). The band at 1100 cm^{-1}, which shows di-silicates is sharp for slate and quartzite compared to others. A peak similar to Si-O-Si at 620 cm^{-1} for schist was also found in Apollo samples spectra in the range 500-450 cm^{-1} (16 µm), which is also responsible for the same type of bending (Figure 1). However, the frequency shift may depend on the composition, i.e., iron content. The capability of Raman spectroscopy to detect OH peaks/bands in terrestrial minerals is of great use to analyze the content of volatiles and gaseous inclusions in minerals and glasses on interplanetary surfaces [10]. Raman spectra from both terrestrial and lunar minerals provide detailed information about different silicate polymorphs. Also, a few peaks/bands and their properties matched unambiguously.

Conclusion: Breccia is composed of pieces of old rock and mineral fragments separated from underlying bedrock by the meteorite bombardment. Lunar rocks do not have abundant quartz, but breccia formation is the closest to the terrestrial sedimentary rocks [11]. However, there can be a possibility that silicon and oxygen found on the lunar surface might have been produced due to meteorite impacts and small amounts of gases (e.g., hydrogen) implanted by the solar wind ion [11],[12]. The rock fragments in a breccia can include Mare basalts and material from the lunar Highlands [13],[14]. There is a high chance of elemental substitution in breccia. It has been found that spectral features like Si-O-Si stretching in Raman spectra, identification of impurities, and location of elemental substitution are the same for both terrestrial and lunar samples in this work. The mineral composition of the samples considered in this work is almost the same as rocks and minerals found in the Delhi Aravalli range and other parts of Northern India. This study shows that the rocks from the Delhi Aravalli range and Deccan Traps (silicates) can be considered analogs for lunar breccia. However, more field base study is needed. It also depends on that which part of a planetary body we want to explore. As most of the spectral features, including breccia (elemental substitution), basalts, and silicates, are found similar. To characterize the planetary analogs' efficiently on Earth, remote chemical detection based on Hyperspectral Imaging is needed.

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References: [1] Zhou, 2015, http://bwtek.com/wp content/uploads/2015/07/raman-laser-selection application-note.pdf. [2] Perry et al.,1972, The Moon, 4, 315-336. [3] Perry et al., 1972, LPSC Proc. , 3, 3077. [4] Seddio et al., 2013, Am. Mineral., 98, 1697–1713. [5] Seddio et al., 2015, Am. Mineral., 100, 1533–1543. [6] Downs, 2006, 19th Gen.Meet. of the Intern. Min. Ass. ,117. [7] Ahmad et. al (2020) , 51st LPSC, 2326, 2059. [8] White et al.,1971, 2nd Ann. Lunar Sc. Conf. [9] Robens et al., 2008, J. Therm. Anal. Calorim., vol. 94, 627–631. [10] Klima et al., 2011, J. Geophys. Res. E Planets, 116, E00G06. [11] Heiken et al.,1991, Lunar Sourcebook. [12] Taylor 1982, LPI, 3303. [13] Sarantos et al., 2012, J. Geophys. Res. Sp. Phys., 117. [14] Albee 1971, Eos, Trans. Am. Geophys. Union, 52, IUGG 90-IUGG 100, 1971. [15] Pieters 1986, Rev. Geophys., 24, 557–578.

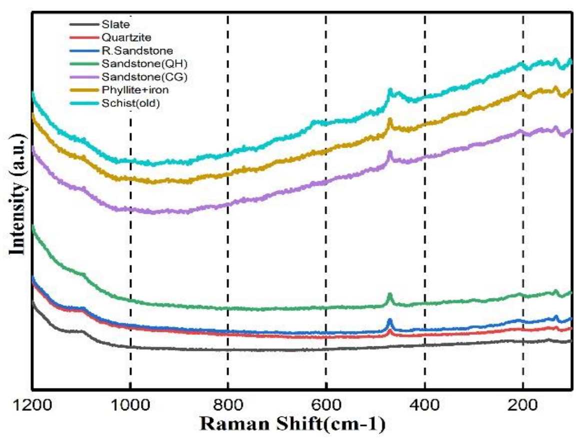

Figure 1: Raman spectra from seven terrestrial samples considered in the study

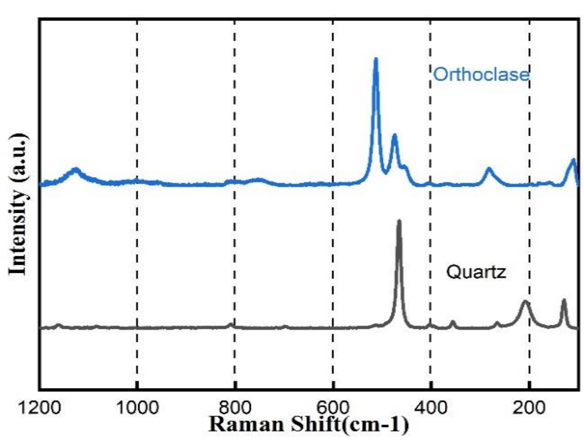

Figure 2: Raman spectra of standard minerals from the RRUFF database [6] .

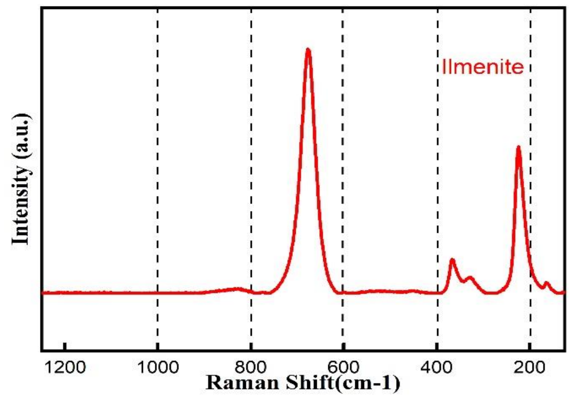

Figure 3: Raman Spectra for ilmenite from RRUFF database [6]. Due to different wavelength interval it is shown separately.