RAMAN STUDY OF SHOCK EFFECTS IN LUNAR ANORTHITE FROM THE APOLLO MISSIONS T. Xie[1], S. R.Shieh[1], G. R. Osinski[1, 2] 1Dept. of Earth Sciences / Centre for Planetary Science and Exploration, University of Western Ontario, 1151 Richmond Street, London, ON, Canada, N6A 5B7 (txie23@uwo.ca, sshieh@uwo.ca) [2]Dept. of Physics and Astronomy, University of Western Ontario, 1151 Richmond Street, London, ON, Canada, N6A 5B7 (gosinski@uwo.ca)

Introduction: Earth's moon, our nearest neighbor, preserves a rich and extended geological history due to minimal erosion and lack of crustal recycling. As such, it is a primary exploration target for space agencies around the world and the only planetary body, other than Earth, from which samples have been purposefully collected and returned to earth. The Moon records and preserves key information about fundamental process that shape planetary crusts such as impact cratering, particularly early in solar system history [1].

The effects of shock metamorphism on quartz have been extensively studied - to understand how impact events modify rocks and minerals. However, on the surface of the Moon, Ca-rich plagioclase feldspar is much more abundant than quartz, making the understanding of shock effects in feldspars vital for serving as an excellent shock barometer.

The objective of this study is to better understand shock processes in plagioclase feldspar using Raman spectroscopy, building upon earlier work using optical microscopy and X-ray diffraction (XRD) [e.g., 2].

Methodology: 18 polished thin sections from lunar samples were selected from Apollo missions 11, 12, 15, 16, and 17 between 1969 and 1972. Mainly anorthosite, with some gabbro, basalt, impact melt rock, and breccia, were specifically selected to collect the widest possible range of optical deformation (shock effects). All the lunar samples contain plagioclase with composition of An89–99 as reported in previous studies [3].

Optical petrography was used to separate samples into broad categories of shock level. A Renishaw In-Via Reflex Raman Spectrometer with a 514 nm wavelength laser was used in this study. Sample excitation and Raman scattering collection were performed using a 50X objective on the Raman microscope. Spectra were collected from 126 to 2000 cm^{-1} with 1800 g/mm grading, and calibrated using silicon crystal. The baselines of the spectra were removed by using software WiRE.

For comparison, we also collected spectra from unshocked terrestrial anorthite with composition An96 (Miyake-Jima, Tokyo, Japan) and a laboratory synthesis glass with composition An100.

Results: A wide variety of optically shocked signals of was observed in Apollo samples, ranging from uniform extinction to fully isotropic mineral melt glass (Table 1) and Raman spectra were collected (see figure 1).

Table 1 summary of shock effects in lunar samples

Shock Stage	Shock effects	Structural state
S1 Unshocked	Sharp optical extinction, little irregular fractures	Crystal
S2 Weakly shocked	Slight undulose extinction, irregular fractures	Diaplectic crystal
S3 Moderately shocked	Undulose extinction, partially isotropic	Diaplectic crystal & glass
S4 Strongly shocked	Fully isotropic	Diaplectic glass
S5 Very strongly shocked	Shock induced melt	Normal glass

Among the Raman spectra of unshocked lunar anorthite samples there are approximately 14 distinct Raman peaks and several weak peaks observed in 126-2000 cm^{-1} range. For a typical unshocked lunar An_{96} plagioclase sample, peaks at 144, 197, 246, 283, 383, 427, 486, 503, 554, 682, 761, 959, 983, 1076 cm^{-1} were observed (Figure 1) with the peak intensity varying with its orientations. The intense and diagnostic peaks occur near 486 and 503 cm^{-1} are assigned to T-O-T stretching modes [4].

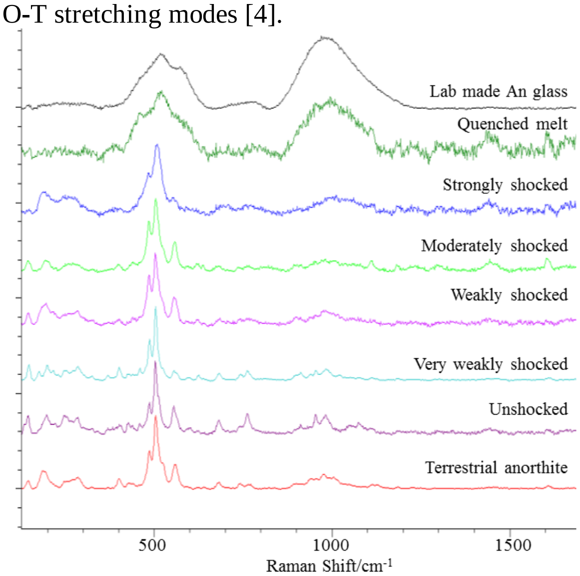

Figure 1 Raman spectra of terrestrial anorthite, lunar samples and lab synthesis An glass. Intensity values with arbitrary scales and offsets to aid in comparison.

From unshocked to weakly shocked, grains show more irregular fractures, and the two diagnostic Raman peaks' width slightly increase; whereas other peaks became weaker and broader.

From moderately to strongly shocked, grains change from partly isotropic to fully isotropic, with the two diagnostic Raman peaks shifted tohigher wavenumbers with significent peak width increase; whereas other peaks became more broader and mostly diminished.

For melt glass, the two diagnostic peaks have merged to form a large hump centred at around 510 cm^{-1} together with the other peak around 980 cm^{-1} also changing into a broad peak with the peak intensities decreased greatly.

It is appareant that the Raman spectrum of melt glass reflects the composition as shown in Figure 2. Spectrum A was collected from plagioclase melt glass and B was collected from pyroxene melt glass, showing the distinct Raman features. Note that peak intensity of A is actually much weaker than B.

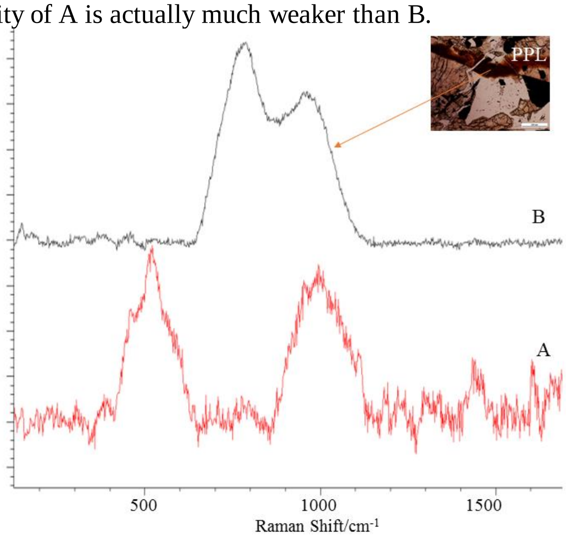

Figure 2 Comparison between pyroxene melt glass (A) and feldspar melt glass (B). Intensity values with arbitrary scales and offsets to aid in comparison.

Some fibrous crystals between the shocked crystal and isotropic melt glass were observed in thin section 60015,114, which is also described by Sclar and Bauer (1974) in the same rock, maybe indicating very high shock-induced temperature (>1500 degree C) [5]. Spectra were collected in both the crystal and the melt domains, but no amorphous glass spectrum was detected even in the fully isotropic area (see Figure 3). Spectrum A collected from a relatively weakly shocked crystal while B from a moderately to highly shocked showing major peaks broadening. Spectrum C collected from the fibrous crystal and D from the matrix in between the fibers showing a mixture of anorthite and orthopyrexene.

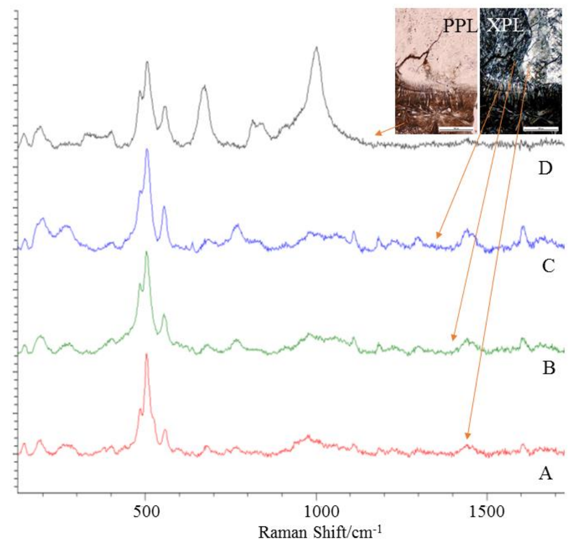

Figure 3 Some representative Raman spectrum of thin sections 60015,114. Intensity values with arbitrary scales and offsets to aid in comparison.

Conclusions: Our results suggest that Raman spectroscopy is a promisng tool in discerning shocked feldspathic materials and can resolve internal crystal deformation precisely. The smaller laser beam size of Raman spectroscopy can help to understand trends or clusters which are not distinguishable in earlier X-ray diffraction studies [6].

Also, the changes in peak width and peak intensity from unshocked to strong shocked lunar samples show similar trend when comparing with earlier Raman study using plagioclase samples from Mistastin Lake [7]. Note that there is no maskelynite-like plagioclase found in Mistastin Lake was observed in the lunar samples and no such Raman spectra was detected neither.

Although Raman spectra can show the difference between grains with a variety of shock effects, it is still challenging to determine the time-temperature-pressure history of the samples, more stimulating experimental study is needed.

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