INVESTIGATION OF A HYBRID LUNAR FELDSPATHIC BRECCIA NORTHWEST AFRICA 11515: MINERALOGY AND SHOCK HISTORY. Y. Li[1,2], P. J. A. McCausland[1,2], R. L. Flemming[1,2], P. Christoffersen[2] and G. R. Osinski[1,2], [1]Department of Earth Sciences and [2]Institute for Earth and Space Exploration, Western University, London, ON, Canada N6A 5B7. *yli2889@uwo.ca*

Introduction: The newly discovered lunar meteorite, Northwest Africa 11515, was initially found in Morocco in 2017. A 1 gram slice of NWA 11515, ~4.1 cm in length (Fig. 1) was purchased by Y. Li from a meteorite dealer in 2019. The meteorite is classified as a lunar feldspathic breccia [1]. Preliminary petrographic description of NWA 11515 in the Meteoritical Bulletin notes the presence of lithic clasts of basaltic, noritic, and gabbroic types. Mineral clasts are dominated by high anorthositic felspar, ferroan olivine, and exsolved Ca-rich and Ca-poor pyroxene. The matrix is reported as being glassy or partly glassy and recrystallized, displaying a fabric or flow texture in the rock. The sample is reported as moderately shocked [1], and is petrographically similar to another newly found lunar breccia, Northwest Africa 10986, that has been classified as an impact melt breccia (clast-rich impact melt rock) [2].

In this study, we used *in situ* X-ray fluorescence (μXRF) to classify the lithology of the clasts and matrix, and we further examined the clasts using micro X-ray diffraction (μXRD).We find five distinctive anorthositic clast groups in the sample, identified by XRF and XRD, as suggested by the variation of Fe-Mg-Ca content and textures. Preliminary shock metamorphism is also recognized by the XRD patterns on these groups. Together they will help to reveal the impact histories of the sample.

Methods: This study used a Bruker M4 Tornado Micro X-ray Fluorescence instrument at Western. It provided non-destructive fast elemental mapping of the whole sample within 18 to 20 hr, with a beam size of 17 μm, enabling preliminary observation of clast compositions and textures based on the variation of relative elemental abundances. Data were further assessed by XMapTools that is developed in Matlab® [3]. Micro X-ray diffraction provides *in situ* examination of mineralogy of rock samples with a range of surfaces, from irregular fractures to cut surfaces and polished thin sections or probe mounts [4]. This study used the Bruker D8 Discover μXRD at Western with a Co Kα X-ray source (λ Co $K\alpha_1$ = 1.78897 Å) and Vantec-500 detector, with General Area Detector Diffraction System (GADDS) software, which obtains 2D diffraction patterns similar to Debye-Scherrer film. Shock can be indicated by X-ray diffraction textures on 2D images. Crystal strain-related mosaicity (SRM) or misorientation of subdomains or 'mosaic blocks' in a single crystal due to non-uniform strain (plastic deformation) exhibits streaks or asterism for large subdomains [4-8]. The streaks in these diffraction patterns lie along the arc of Debye rings, or chi dimension (χ) for each lattice plane with Miller index (hkl). XRD data for all samples were collected in omega scan mode. To maximize collecting area, we used $\theta1 = 14.5^o$, $\theta2 = 20.5^o$ and $\omega = 10^o$ for Frame 1; $\theta1 = 37^o$, $\theta2 = 43^o$ and $\omega = 16^o$ for Frame 2. Each frame was collected for 1 hour, making 2 hours per target.

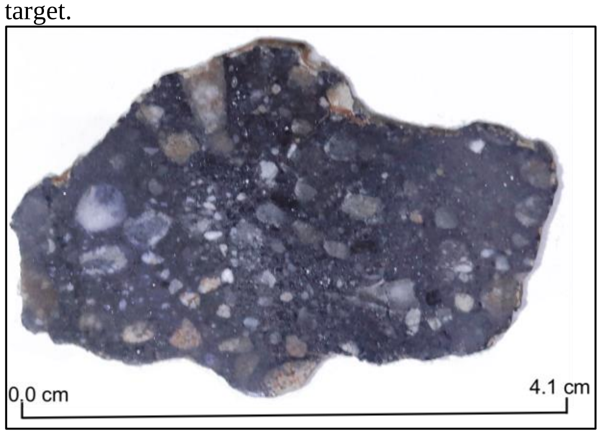

Figure 1. Lunar Breccia Northwest Africa 11515 as a thin slice ~1 mm in thickness. Light brown-Fe weathering stained and light grey (fresher) feldspathic and igneous-textured clasts are dominant by hand sample observation, along with darker clasts, all set in a fine-grained grey matrix.

Results:

Overall, NWA 11515 is dominated by ferroan and calcium rich minerals and depleted in magnesium (Fig. 2). Among the five clast groups, two groups show low magnesium and calcium content that could be of basaltic origin whereas the rest with high magnesium and calcium suggest a highland origin. X-ray diffraction shows fine-grained streaking and ring patterns for anorthositic clasts that could result from shock metamorphism. Ferroan-magnesian clasts containing olivine and pyroxene grains primarily show streaks or streaky diffraction spots, also indicating shock metamorphism.

Five distinctive clast groups are identified by their chemical variations: 1) high calcium anorthositic clasts, 2) ferroan-magnesian anorthositic clasts, 3) noritic-troctolitic clasts, 4) low calcium anorthositic clasts and 5) ferroan rich clasts.

Type 1 clasts are highly feldspathic and enriched in calcium with depletion of magnesium and iron. They are found in sizes from 1 to 7 mm with irregular angular shapes. Type 2 clasts show both enrichment in iron and magnesium with slightly lower amount of calcium. They are 1- 2 mm in size and are less abundant in this sample. Type 2 clasts may represent the Mg-suite in Apollo sample collection. Type 3 is found to have an igneous texture with subhedral to anhedral high-calcium anorthite and ferroan-magnesian silicates similar in size forming the rounded or subrounded noritic-troctolitic clasts (3- 5 mm in diameter, Fig. 2). Type 4 low calcium feldspathic clast is the least abundant clast group in the sample; it is recognized by its lower calcium content compared to Type 1 clasts and lower magnesium content compared to Type 2 clasts. Type 5, the ferroan rich clast, shows similar enrichment in iron as Type 3, however it is depleted in magnesium (Fig. 2B). Magnesium enrichment is found in Type 2 ferroan-magnesian anorthositic clasts and Type 3 noritic-troctolitic clasts.

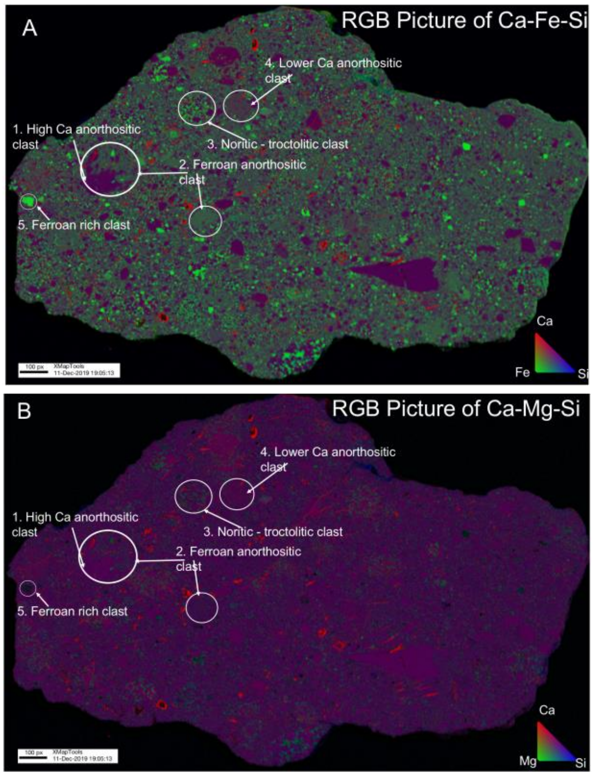

Figure 2. Micro-XRF maps. 2A. RGB picture of Ca-Fe-Si map. Examples of the five clast groups are denoted on the map: 1) high calcium anorthositic clast, 2) ferroan-magnesian anorthositic clast, 3) noritic-troctolitic clast, 4) lower calcium anorthositic clasts and 5) ferroan rich clast. **2B.** RGB picture of Ca-Mg-Si map. Overall the sample has low magnesium content with local enrichment is found in Type 2 clasts, ferroan-magnesian anorthositic clasts and Type 3 clasts, noritic-troctolitic clasts. Maps are exported by XMapTools [3].

Diffraction patterns obtained by µXRD for Type 1 to Type 4 clasts identified in this study are shown in Fig. 3. High Calcium anorthositic clasts (Type 1) and ferroan anorthositic clasts (Type 2) show extreme streaking patterns along Debye rings, which may indicate pervasive shock metamorphism. Type 3, noritic-troctolitic clasts display XRD patterns with diffraction streaks and spots and weak powder rings. The mineral assemblage is anorthite and olivine as identified by XRD; anorthite shows long diffraction streaks whereas olivine shows smaller streaks or spots, suggesting a mild to moderate shock history for this clast. Type 4 low Ca anorthositic clast (Fig. 3) shows nearly homogeneous diffraction rings; it is finer grained compared to Type 1 clasts.

As with NWA 10986 [2], the variety of clasts in NWA 11515 may represent the sampling of a wide range of source regions on the Moon. Further, more detailed investigation of clast and matrix mineralogy, chemistry and shock deformation is needed to determine their origin regarding the current dichotomy of the moon as well as its impact history.

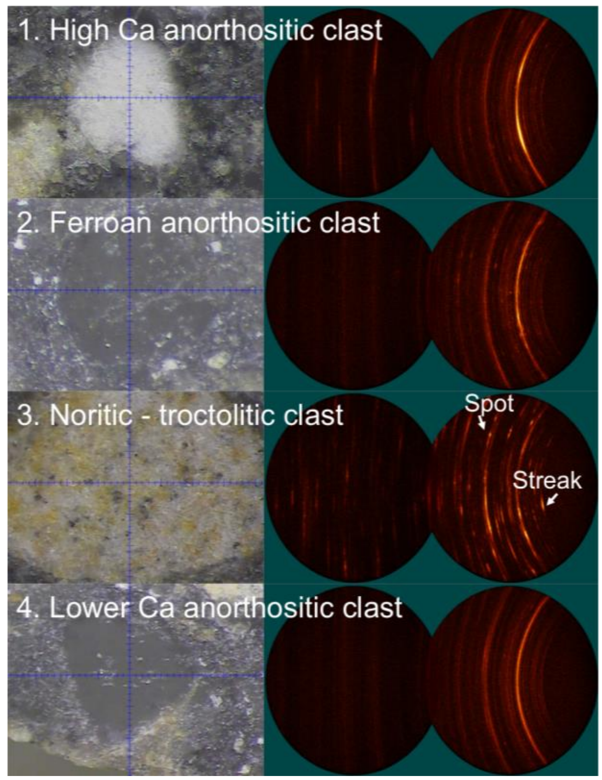

Figure 3. Representative diffraction patterns for Type 1 to Type 4 clasts. Anorthositic clasts with different Ca content show extreme streaks and rings along the Debye ring. The ring patterns in Type 4 indicates a smaller grain size (<5 µm) with little preferred orientation. Type 3 clasts show various XRD patterns: spots, streaks and weak powder rings.

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