

**MASKELYNITE: HOW ISOTROPIC IS IT?** Jaret, S. J.<sup>1</sup>, Woerner, W. R.<sup>1</sup>, Phillips, B. L.<sup>1</sup>, Wright, S. P.<sup>2</sup>, and Glotch, T. D.<sup>1</sup> <sup>1</sup>Department of Geosciences, Stony Brook University 255 ESS Building, Stony Brook, NY 11794-2100. <sup>2</sup>Department of Geology and Geography, Auburn University, Auburn, AL 36849  
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**Introduction:** Maskelynite, initially identified in Shergotty [1], is an optically isotropic and X-ray amorphous material derived from plagioclase that can form as the result of impact events [2-4]. Petrographically, maskelynite appears similar to plagioclase in plane-polarized light, preserving grain boundaries and texture of the target rock, but has a lower refractive index than unshocked plagioclase. In cross-polarized light, however, maskelynite is easily distinguished from unshocked plagioclase as it is optically isotropic. Based on calibrated shock experiments [5-6], the minimum shock pressure for maskelynite formation is between 28 and 34 GPa, although this is dependent on target composition and pre-shock structural state of the feldspars [5]. Despite nearly 50 years of detailed study of maskelynite, there is still considerable debate over the exact formation mechanism, specifically whether it forms as a diaplectic glass [4-5] or by quenching of a shock-induced high pressure glass [7].

Here we present optical microscopy, high energy X-ray pair distribution function experiments, nuclear magnetic resonance (NMR) spectroscopy, and micro-Fourier transform infrared (FTIR) spectroscopy on shocked labradorite from the Lunar Crater, India. All maskelynite (compositionally, An<sub>59</sub> - An<sub>71</sub>) grains were hand-picked from basaltic samples (LC-09-253 of [9]) of shock Class 2 [8-9].

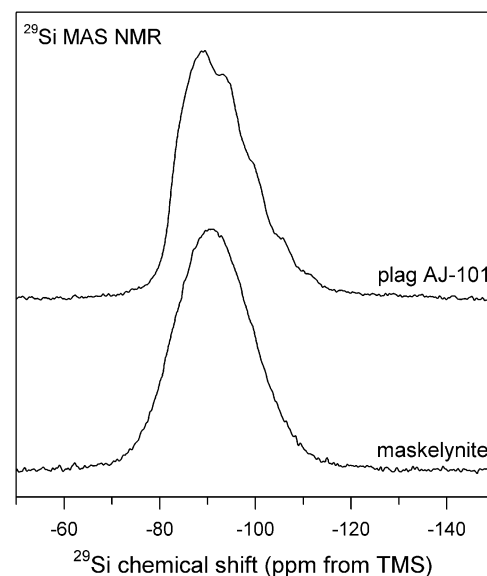
**Methods:** Optical petrography of doubly polished thin sections was conducted using a standard Olympus petrographic microscope. Micro-FTIR point spectra of single grains in thin section were collected with a Nicolet iN10MX FTIR microscope, equipped with a liquid nitrogen-cooled MCT array detector capable of acquiring images between 715 and 7000 cm<sup>-1</sup> (1.4-14 μm). Spot size for analyses was 25 x 25 μm. Additionally, single grains were mounted in epoxy and polished along multiple faces allowing for measurements of different orientations of the same grain.

NMR spectra were acquired for ca. 10 mg of separated maskelynite grains and a sample of crystalline labradorite of similar composition. The <sup>29</sup>Si spectra were obtained at 9.4 T and 10kHz spinning rate, and <sup>27</sup>Al and <sup>23</sup>Na at 11.7 T with a 20 kHz spinning rate.

High energy X-ray total scattering experiments were conducted on 10 mg of picked maskelynite grains at the Advanced Photon Source. The total scattering data was collected at the 11-ID-B beamline with a wavelength of 0.2128 Å (~58 keV), allowing for the collection of data to a Q<sub>max</sub> of 25 Å<sup>-1</sup>.

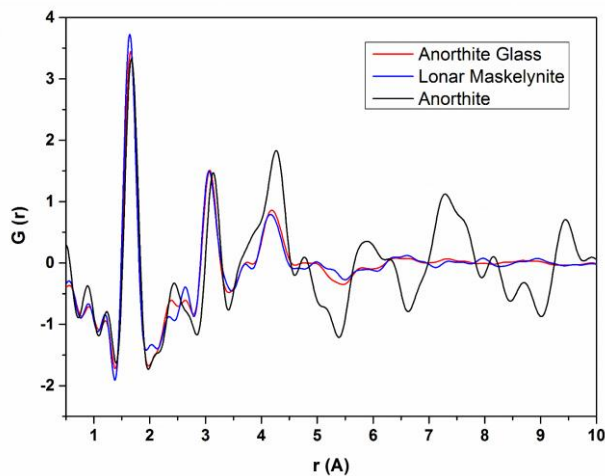
**Optical Microscopy:** In plane-polarized light, maskelynite occurs as both phenocrysts and within the groundmass and appears uniformly smooth, lacking fractures or planar deformation features (PDFs). Grains are euhedral to subhedral and show no textural evidence of melting. Based on optical shock classification schemes, these samples are low to moderate shock, Class 2 [8] or Stage I [10], indicating shock pressures between 25 and 28 GPa [9], as suggested by only minor cracking of adjacent pyroxenes.

**NMR Spectroscopy:** The NMR spectra of maskelynite contain broad, featureless peaks indicative of extensive short-range disorder beyond the first coordination sphere. For example, the <sup>29</sup>Si results (Fig. 1), show a broad, approximately Gaussian-shaped peak for 4-coordinated Si centered near -91 ppm with a width of 18.6 ppm FWHM. In comparison, the spectrum of plagioclase of similar composition is asymmetric and contains fine structure from resolution of distinct crystallographic sites and local environments with differing numbers of adjacent framework Al, typical for intermediate composition plagioclase feldspars [11]. The spectrum of maskelynite resembles those of albite- and anorthite-composition thermal glass [11], but with a peak position and width intermediate between these Na- and Ca-endmembers. Similar results were obtained from <sup>27</sup>Al and <sup>23</sup>Na NMR experiments.



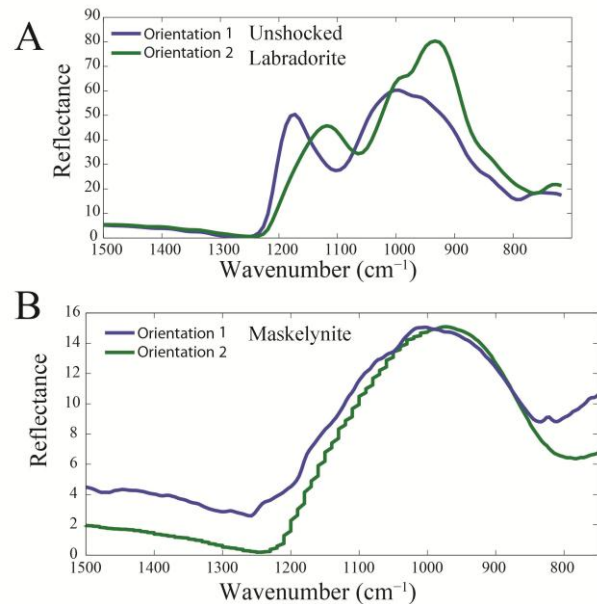
**Figure 1:** <sup>29</sup>Si NMR spectra of unshocked labradorite (top) and Loner Maskelynite (bottom).

**High Energy X-ray Total Scattering:** The total scattering data was Fourier transformed ( $Q_{\max}$  of  $19 \text{ \AA}^{-1}$ ) to give the pair distribution function, the average real space distribution of interatomic distances for maskelynite, crystalline anorthite, and anorthite thermal glass (Fig. 2). Though there are some compositional differences between the anorthite and the maskelynite (average An63), the thermal glass and maskelynite have a nearly identical average structure, typical of a thermal glass with no structural coherence beyond 7 angstroms. The first major peak is the Si-O bond from the tetrahedral units and the second major peak just larger than 3 angstroms is the Si-Si distance from connected tetrahedral. In the case of both the anorthite thermal glass and maskelynite, the Si-Si distance is shorter than in the crystalline anorthite indicating the ordered tetrahedral crankshaft structure has been broken up and the tetrahedral have moved closer together.



**Figure 2:** Pair Distribution Function –  $G(r)$  – of crystalline anorthite (black), anorthite thermal glass (red), and Lolar maskelynite (blue). The crystalline anorthite shows distinct distances propagating far into real space as it has long range ordering. The thermal anorthite glass and maskelynite have no structural coherence beyond 6-7 angstroms and have a nearly identical glass structure.

**Micro-FTIR:** Maskelynite exhibits one broad peak compared to two narrower peaks typical of crystalline labradorite. The peak position varies by nearly 40 wavenumbers depending upon orientation (960 wavenumbers at one orientation and 1000 wavenumbers once rotated). The amount of shift due to orientation is consistent with peak shifts in rotated crystalline labradorite. The maskelynite differs from both thermal glass, which has one peak independent of orientation, and is distinct from unshocked labradorite which shows two peaks, both of which vary with orientation (Fig. 3).



**Figure 3:** Micro-FTIR spectra of unshocked labradorite (A) and maskelynite (B) showing an orientation effect preserved in both samples. For each sample, spectra were acquired from two approximately perpendicular orientations of the same mounted grain. In the maskelynite, the peak position changes by 40 wavenumbers as a function of orientation.

**Discussion and Conclusions:** This maskelynite is optically isotropic, NMR and X-ray amorphous, and appears highly disordered with micro-FTIR spectroscopy. However, these grains are not isotropic in the infrared. When rotated and multiple measurements are taken of the same grain, the IR reflectance peak position shifts, consistent with the preservation of spatial and structural orientation within the grain. We suggest these grains formed by shock-disordering *without melting* whereby the grain was not internally homogenized and there was not large-scale movement of atoms within the grain. In contrast to previous infrared spectroscopic analyses of maskelynite [5], we show that shock glass is distinct from fused thermal glass.

**References:** [1] Tschermak (1872). Akad. Wiss. Wien Math.-Naturwiss. K1 Abt. I 65 122-165. [2] Milton and De Carli (1963). Science 140, 670-671. [3] Bunch et al. (1967). Am. Min. 52, 244-253. [4] Stöffler (1972). Fortschr. Miner. 49 50-113. [5] Ostertag (1983) JGR 88 Supplement, B364-B376. [6] Heymann and Horz (1990). Phys. Chem Mineral. 17 38-44. [7] Chen and El Goresy (2000) EPSL 179, 489-502. [8] Kieffer et al. (1976). Proc. Lunar Sci. Conf. 1391-1412. [9] Wright et al. (2011). JGR 116, E09006. [10] Stöffler (1971). JGR 76, 5541-5551. [11] Kirkpatrick et al. (1985) Am. Mineral. 70, 106-123.