SHOCKED FELDSPAR IN MARTIAN METEORITES: EVIDENCE AGAINST PERVASIVE MELTING AND RESETTING

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Introduction: Majority of the Martian meteorites includes moderate to strong shock-metamorphic features. Accurately estimating the corresponding shock conditions is essential for interpreting the geochemistry and geochronology of meteorites. The shock effects in plagioclase, including deformation, amorphization and transformation/crystallization, are pervasive and indicative of shock pressure-temperature conditions in Martian meteorites. In particular, diaplectic feldspar glass from solid-state amorphization during shock (maskelynite), is a major constituent of many shergottites. An alternative model for the amorphization of plagioclase, involving melting and quench, has been proposed [1]. This model implies much higher shock and post-shock temperatures, which are inferred to extensively reset the isotope chronometers in most Martian meteorites and lead to young ages from impacts [2]. In this study we investigated the shock amorphization of plagioclase in different types of highly shocked Martian meteorites. We focus on the textural indications of possible melting of plagioclase and discuss the implications for thermal effects.

Samples and Methods: We investigated a thick section of olivine-porphyritic shergottite NWA 6234 and a thin section of augite basalt NWA 8159. We employed optical microscopy, Raman spectroscopy, scanning electron microscopy and synchrotron micro X-ray diffraction.

Results: Along the shock-induced shear or melt veins, crystalline plagioclase, diaplectic glass, shear-induced glass and fused glass are present.

NWA 6234. A 10 to 150 μm thick shear vein, indicated by offset minerals in the host-rock, cuts across the 1.5 cm long section of NWA 6234. A small portion of the shear vein consists of crystallized shock melt (Fig. 1). The feldspar clasts in the host rock near the shear vein are subhedral with well-defined outlines. The radial fractures in pyroxene around the clasts extend into the feldspar (Fig. 1). In the shear vein, the feldspar is highly deformed into sheared irregular shapes. The boundaries between the feldspar and surrounding pyroxene are curved and smooth. The clasts are elongated along the shear direction. The feldspars in the host-rock and shear vein both have Raman spectra with the same ~490 cm^{-1} broad peak as in amorphized laboradorite (Fig. 2). The pyroxenes in the shear vein also show amorphization suggested by the broadening of 670 and 970 cm^{-1} peaks in Raman spectrum (Fig. 2). The olivine clasts in the shear vein are partially transformed to ringwoodite. In localized areas, the olivine transformation occurs along the boundary with feldspars. These feldspar clasts also include smeared droplets of sulfide and oxide.

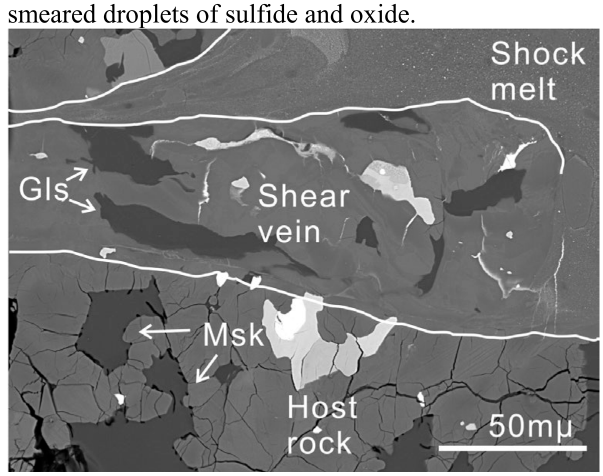

Figure 1. SEM BSE image of the diaplectic glass (Msk) and fused glass (Gls) of plagioclase (dark contrast) in the host rock and shear vein in NWA 6234. The medium gray phases contacting the feldspar are pyroxenes. The fine-grained shock melt matrix is associated to the shear vein.

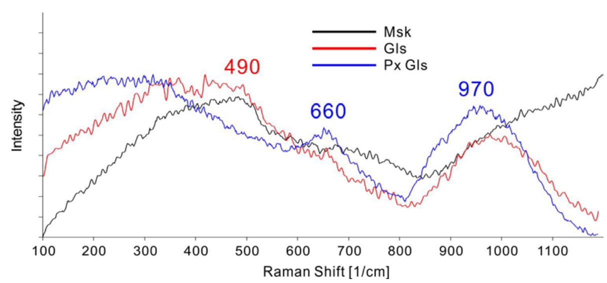

Figure 2. Raman spectra of the diaplectic glass (Msk) and fused glass (Gls) of plagioclase and glassy pyroxene (Px Gls).

NWA 8159. The thin section includes a shock melt vein that is 50 μm thick and 5 mm long. Garnet is the predominant mineral crystallized from the shock melt. Olivine clasts in the shock melt are transformed to either ringwoodite or pyroxene plus oxide. The plagioclase clasts adjacent to the shock melt are partially amorphized (Fig. 3). The crystalline part preserves the original twinning. The amorphous part is commonly close to the shock melt. There are fractures inside the amorphous part without extending to the exterior host-rock. The crystal shape and straight outline of the whole clast are preserved in both parts. Synchrotron

XRD shows the amorphous part is complete glass with no hint of nano-crystallites.

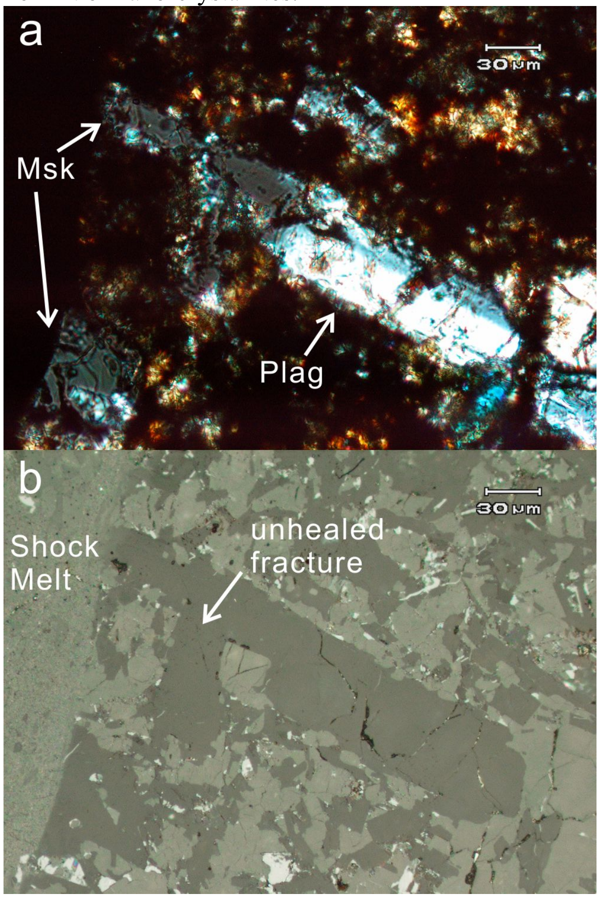

Figure 3. Cross-polar (a) and reflective (b) optical micrograph of a partially amorphous plagioclase in NWA 8159. Twinning in the crystalline plagioclase (Plag) is shown by difference in extinction. A small deviation from orthogonal polarization is used in the xpl image to make the diaplectic glass (Msk) visible.

Discussion: The diaplectic glass and fused glass of plagioclase have very similar spectroscopic properties. However, Jaret et al. (2015) distinguished diaplectic glass (Maskelynite) from fused glass by slight anisotropy in micro-FTIR spectra [3]. This is evidence of a solid-state origin of maskelynite. Kubo et al. (2010) and Tomioka et al. (2010) produce feldspar glass from laboradorite and albite by diamond-anvil cell compression [4, 5]. The experiments suggest An_{50} plagioclase can transform to glass at 200 °C and 20 GPa, which is a reachable shock pressure for many Martian meteorites. Liquidus temperature is not necessary for the amorphization.

In this study, we observed different morphologies and textures of feldspar glass. In the host rock of NWA 6234, the feldspar is commonly surrounded by radial fractures. These fractures cut cross the boundary of feldspar and pyroxene, suggesting the feldspar was in solid before decompression. Although quenching of feldspar melt could occur at high-pressure, it would result in a high temperature gradient in the surrounding pyroxene and may lead to eutectic melting along the pyroxene boundary, which is uncommon in the sample. In the shear vein, the plagioclase and pyroxene are more deformed. The pyroxenes are partially amorphous and the pyroxene-feldspar boundary diffuse. Nevertheless, eutectic melting is limited. The localized feldspar with smeared oxide/sulfide is more likely evidence for melting and acts as a hotspot that drives high-pressure transformation around it. However these melted clasts only occur in small areas within the shear zone and would not heat up the surrounding rock further than tens of microns [6]. In NWA 8159, the partial amorphization is likely a combination of shear along the shock shear-melt vein and heat conduction from it. The small fractures inside the Maskelynite portion suggest incomplete healing of the plagioclase during amorphization under moderate to low temperature.

Based on our results we suggest that abundant feldspar glass is not evidence of extensive melting that enhances chemical exchange in large volume in Martian meteorites. High temperature in sheared and deformed feldspar only occur locally with distinct textures and these areas can be avoided for *in situ* chemical analysis.

References: [1] Chen M. and El Goresy A. (2000) *EPSL, 179,* 489-502. [2] El Goresy A. et al. (2013) *GCA, 101,* 233-262. [3] Jaret S. J. et al. (2015) *JGR: Planets, 120,* 570-587. [4] Kubo T. et al. (2010) *Nature Geoscience, 3,* 41-45. [5] Tomioka N. et al. (2010) *GRL, 37,* 1-5. [6] Langenhorst F. and Poirier J.-P. (2000) *EPSL, 184,* 37-55

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