LOW-PRESSURE MASKELNYZATION OF POROUS BASALT: IMPLICATIONS FOR BASALTIC ACHONDrites AND PLANETARY IMPACTS. Jinping Hu¹, Paul D. Asimow¹ and Yang Liu², ¹Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125, ²Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109. Email: jinpíng@caltech.edu

Introduction: Estimation of impact conditions experienced by many meteorites relies on the structural state of plagioclase. Constraining the pressure of shock-induced feldspathic diaplectic glass, i.e. maskelynite, is particularly essential. Previous shock-recovery experiments show maskelynization pressure thresholds for Ca-rich plagioclase with different sample textures, including plagioclase single crystals (25-40 GPa, [1]), non-porous basalts (20-40 GPa, [2, 3]) and coarsely powdered basalts (20-30 GPa, [4]). However, none of these textures resemble the pre-shock state of surficial basalt on Mars or 4 Vesta and so these experiments may not have defined the maskelynization pressure for martian and HED meteorites. Here, we report shock recovery experiments on Saddleback basalt with natural porosity (~5%), an analogue material that may offer more accurate pressure constraints.

Sample and Methods: We used Saddleback (SB) basalt sampled near Boron, CA. The starting material consists of olivine, diopside, enstatite, labradorite, Ti-Cr-Fe oxides (ilmenite, chromite and hematite), mesostasis, calcite and ~5% porosity. The pores occur as irregularly-shaped holes in the sample. The sample experienced a small degree of hydrothermal alteration, as shown by brown olivine grains [5].

Three shock-recovery experiments were performed on sample disks (~5 mm diameter, ~1 mm thickness) using a 20 mm propellant gun in the Lindhurst Laboratory at Caltech, similar to the procedure in [6]. Two experiments (SB2-5, SB3-8) had 1.30 km/s impact velocity. The front half of these samples were shocked to ~17 GPa for ~300 ns. The back half was reshocked by reflection from the back of the chamber to 28 GPa for ~100 ns. In a third experiment (SB3-12) with 1.52 km/s impact velocity, the front and back halves were shocked to 20 GPa and 33 GPa respectively for similar durations. These pressure calculations are based on the Hugoniot of dense gabbro and so represent an upper limit for a porous basalt target. After each shot, the steel chamber was cut from the middle along the impact direction. One side was polished and a piece from the other side was made into a thin section.

The sample investigation was performed on analytical facilities of GPS, Caltech. The petrography, mineralogy, and composition were analyzed by optical microscope, scanning electron microscope (SEM), electron microprobe, Raman spectroscopy and electron backscatter diffraction (EBSD).

Results: The three experiments generate similar shock metamorphic features except the high-velocity shot shows a significantly higher degree of melting.

Maskelynization of plagioclase. In the starting material, the plagioclase forms randomly oriented laths with twinning (Fig. 1a). The typical grain size is ~500 µm by 150 µm. In all three shocked samples, all plagioclase became completely isotropic, as maskelynite and feldspathic normal glass. The maskelynite grains become more equant (Fig. 1b), with Fe-Ti oxides and silicate inclusions (Fig. 1c). As in meteorites, the maskelynite is smooth and not heavily fractured in most areas. The boundaries between maskelynite and olivine/diopside are sharp and well-defined (Fig. 1c), whereas feldspathic normal glass shows round inclusions, flow textures, and curved boundaries (Fig. 1c).

![Fig. 1. a) Twinned labradorite in unshocked SB basalt. Cross-polarized light. b) Equant maskelynite (msk), brown olivine (ol) and diopside (cpx) in SB2-5. Plane-polarized light. c) Quenched basaltic melt in contact with feldspathic normal glass (gls) in SB3-8. The maskelynite has diopside (cpx) and ilmenite (ilm) inclusions. BSE-SEM.](image)

Microprobe analyses indicate that the maskelynite has 65 to 70 % An component. The composition is comparable to the An₅₅ to An₇₀ range of pre-shock plagioclase but is more homogeneous. Raman spectra (Fig. 2) of the maskelynite show decrease of the plagioclase peaks, broadening of 480 and 510 cm⁻¹ peaks and a small shoulder at ~580 cm⁻¹. These features are similar to the feldspar glass in shergottites [7].
Local melting. The three samples have ~3% (SB2-5, SB3-8) to 10% (SB3-12) shock-melt veins and pockets. For the samples from the 1.3 km/s experiments, the shock melt is glassy except for sparse nanocrystals of magnetite (Fig. 1c). For the 1.5 km/s experiment, olivine started to crystallize from relatively thick melt pockets (Fig. 3). Feldspathic normal glass near the melt pockets shows flow features and mixing with the basaltic melt (Fig. 1c), making it distinguishable from maskelynite. Some melt pockets have micron-sized vesicles (Fig. 1c). Shock melt with droplets of immiscible steel melt is commonly concentrated at the boundary between the sample and the steel chamber.

![Fig. 2. Raman spectra of plagioclase in SB basalt (unshocked) and maskelynite in SB3-8 (17 GPa).](image)

![Fig. 3. BSE-SEM images. Left: alteration texture (alt) of the brown olivine (ol) in SB2-5. Right: recrystallized olivine aggregate (pol) entrained in basaltic melt glass (bgls) in SB3-12. Olivine also crystallized from the melt on the boundary of the fragment.](image)

Olivine recrystallization. The shock metamorphism of olivine is correlated with its proximity to shock melt. In most areas, brown olivine and its alteration survived shock metamorphism (Fig. 1b, Fig. 3). In contrast, EBSD indicates that the olivine fragments entrained in the melt partially recrystallize to polycrystalline olivine (Fig. 3). Recrystallized olivine has internal BSE contrast, indicating compositional heterogeneity. Crystallization of olivine from the surrounding melt also occurs on the boundary of the fragment (Fig. 3).

Discussion: Our results show that 17 GPa is sufficient for complete maskelynization in natural porous basalt. Thus the pressure threshold for maskelynization is <17 GPa. This pressure is significantly lower than the ~25 GPa where labradorite single crystals start to amorphize [1] and is also lower than that of coarsely powdered (porous) lunar basalt (20-30 GPa, [4]). Although a powder may have total porosity similar to natural targets, the pores are tiny and homogeneously distributed, and thin glassy shock melt veins are produced mostly along the boundaries [4]. In contrast, collapse of local large pores in natural basalt can generate thick melt veins/pockets that allow for crystal nucleation (Fig. 3), similar to those in shergottites [8]. Olivine recrystallization, occurring exclusively within the melt (Fig. 3), is also consistent with shergottites [9]. It suggests the observed shock features in acondrite result from a combination of high pressure and initial texture. Porous basalt is a good analogue to reproduce shock features and calibrate their pressures.

The maskelynization pressure of <17 GPa can be used to better constrain the shock and impact conditions of martian and HED meteorites. Particularly for shergottites, pressure is used to estimate the overall shock temperature that is important for understanding shock metamorphism and geochemistry. It has been proposed that all maskelynite in shergottites is derived from melt and the presence of oxide and silicate inclusions in maskelynite were cited in support of melting of plagioclase [10]. The 1.52 km/s experiment suggests that extensive melting only occurs at pressure much higher than 33 GPa. The slower shots show fusing of adjacent plagioclase grains into one maskelynite grain (Fig. 1), entraining material along the former grain boundary as inclusions in diaplectic maskelynite.

For HED meteorites, the high-pressure assemblage of coesite, stishovite, garnet and partial maskelynite in eucrites suggests shock pressure of 8-13 GPa [11, 12]. Our calibration is more consistent with this range than the >25 GPa pressure for maskelynite based on single crystal experiments [1]. Also, the giant craters in the polar area of 4 Vesta require relatively low impact velocity to avoid disrupting the asteroid [13], consistent with a moderate shock pressure for HEDs.

In summary, shock experiments on basalt with natural porosity can reproduce the shock-induced pressure, temperature and metamorphic features in basaltic meteorites. The pressure for maskelynite-rich meteorite can be 17 GPa or even lower. Much higher pressure (>33 GPa) generates higher degrees of melting in porous basalts than is observed in most achondrites.


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