NOT JUST FRESH BASALT: A RANGE OF SHOCKED ALTERATION PRODUCTS AND SOIL FROM LONAR CRATER, INDIA

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Summary: With three processes analogous to Mars (basaltic volcanism, aqueous alteration, and shock), Lonar Crater shocked basalts are excellent analogs for instrumentation sent to Mars. ~80 kg of "intermediately" (20-80 GPa) shocked basalt, which exist as clasts in the uppermost, suevite breccia layer at Lonar Crater, India [1], along with float that were former breccia clasts, were collected during a 2-month field season. These add to a large collection of unshocked basalts and impact melts/glasses (aka Class 5 [1]). Petrographic and electron microprobe images reveal of range of shock pressures (deduced by phases and mineralogies of labradorite and augite); various protoliths such as fresh Deccan basalt, altered basalt (altered before shock) (Table 1) showing hematite, calcite, and silica veins/pockets (Figure 1); and what we interpret as a consolidated soil or a sample from weathering horizons in-between individual basalt flows (Figure 2). A shocked hematite-rich sample is likely from a "bake zone" in-between basalt flows. Impact melt veins and pockets were also found.

age	"strata":
formed ~65 Ma – 570 ka	**thin layer of soil (Figure 3)**
emplaced ~65 Ma	**3 flows of "fresh" basalt**
emplaced ~65 Ma, then aqueously altered	**3 flows of "altered" basalt:** **primary → secondary** **augite, pigeonite → chlorite, serpentine, celadonite** **labradorite → zeolites** **volcanic glass → palagonite** **titanomagnetite → hematite** **deposited: quartz / silica calcite, hematite**

Table 1. Pre-impact stratigraphy is shown along with primary and secondary minerals seen in the altered basalts. The fresh basalts contain solely primary minerals. Lower, slightly older flows are likely subjected to more aqueous alteration (Figure 2) over ~65 million years prior to impact ~570 ka [2]. Groundwater level is suggested by a white line. All three of these materials have been shocked to various pressures to exist as clasts in a suevite breccia unit.

Figure 1. Cut slice of a shocked-altered basalt that was altered before shock metamorphism. Bright-white and off-white alteration products were deposited before shock. The groundmass is Class 2 (maskelynite-bearing) [1]. A hematite vein is on left.

Shocked Soil: One light gray clast from the suevite breccia has a frothy, "fluffy" appearance with very low density. Petrography revealed a texture not like basalt: schlieren calcite amongst an occasional augite or labradorite grain (Figure 2). The majority has poor petrographic properties suggestive of oxides and alteration products. The comparison to petrography of unshocked soil (Figure 2) revealed its protolith. Isotopic geochemistry of the shocked soil, including C^{14}, are forthcoming to compare to unshocked soil and examine the effects of shock on the preservation of biota.

SOILS:

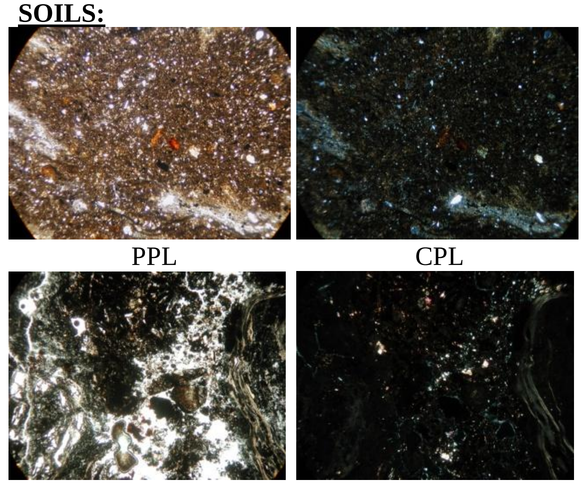

Figure 2. Petrography of unshocked (top two) and shocked (bottom two) soils in PPL (left) and CPL (right). The same view is on left and right with 5X magnification.

Rarity / Preservation: Unbeknownst a decade ago, there are a handful of terrestrial impact structures in basalt [4]. All except Lonar Crater are millions to tens of millions of years old, meaning that pristine ejecta and thus clasts of shocked basalt have been eroded away. Lonar Crater, being just ~570,000 [2], still has ~10 outcrops of a thin, ~1 m suevite ejecta layer [1], and thus this sample collection is likely the only one of its kind.

Figure 3. Natural and cut surfaces showing "decompression cracks" in a Class 2 shocked-altered basalt (~8 cm across) [3]. Petrography and SEM data shown in Figure 4.

Hand Sample Texture: [3] and Figure 3 show the foliated-like texture of some Class 2 shocked basalts that we term "decompression cracks". Decompression cracks seem to be limited to Class 2 shocked basalts with protoliths of altered basalt. Recall that Class 2 shock levels never reach the melting of labradorite or augites; labradorite converts to maskelynite via solid state transition, and clinopyroxenes are fractured [1]. We suggest that decompression cracks form when the rock is decompressed after shock compression (without melting). Because this is only a feature of altered protoliths, volatiles, whether they be pockets of air or hydrous/altered minerals, likely play a role.

Spectroscopy: As our only samples of Mars are ~55 shocked basalts, along with the wealth of spectral data from Rovers, orbiters, and future (MSL, ExoMars) instrumentation, it would be fortuitous to collect and understand the spectroscopy of these samples from techniques and instruments used for Martian meteorites and/or sent to Mars. TIR emission spectroscopy of Lonar basalts provide constraints to Mars data [5]. With a smaller "spot size", scanning micro-FTIR and Micro-Raman data of various slices show new, unique glass end-members [6]. Some VNIR data has been acquired [7], and further characterization using other instrumental analyses is needed to understand the VNIR spectra. Mossbauer spectroscopy [8] is ongoing to study the behavior of Fe (in glass, pyroxenes, and oxides) at various shock pressures. Concerning alteration minerals, chlorite and serpentine (Table 1) are amongst the most abundant on Mars [9,10].

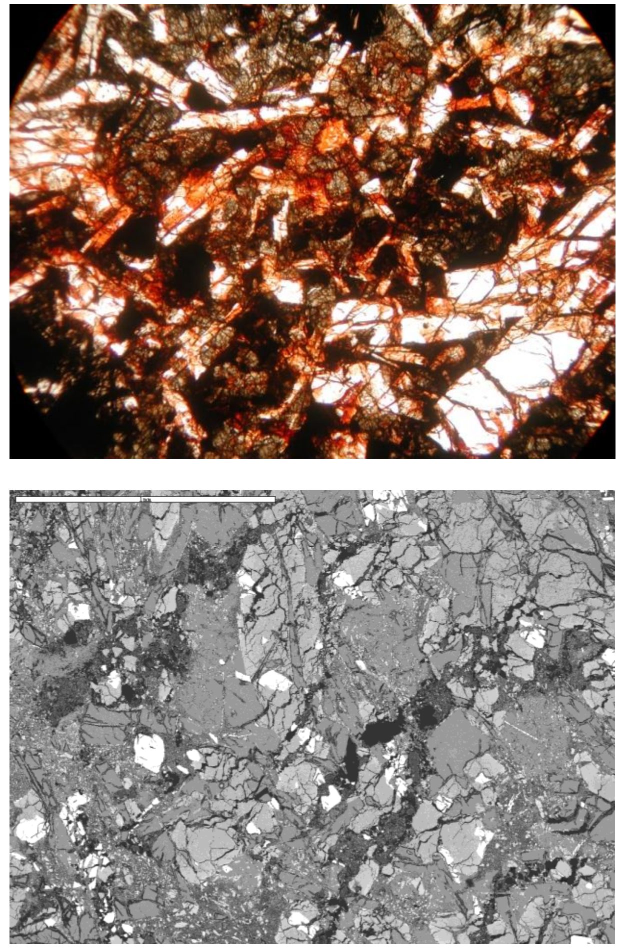

Figure 4. Petrography (top, in PPL) and BSE image of an altered Class 2 shocked basalt. Sample is same as the hand sample in Figure 3. "Feathery" textures in the BSE image are phyllosilicates. All needles are now maskelynite. Black voids running SW-NE are decompression cracks (Figure 3). Scale bar measures 1 mm.

Implications: Only data of few shocked-altered basalts and the shocked soil are shown here. There are a wealth of shocked-fresh basalts and shocked basalts that have altered *since* being shocked, which is evident as impact glass altering and alteration minerals filling the cracks of fractured/shattered augite grains. Sample and spectral data will be shown and compared to Mars data sets.

References: [1] Kieffer et al. (1976) *7th LPSC*, 1391-1412 [2] Jourdan et al. (2011) *Geology 39*, 671-674 doi: 10.1130/G31888.1 [3] Newsom et al. (2011) *LPSC 42*, #1298 [4] *Earth Impact Database* (2012) [5] Wright et al. (2011) *JGR-Planets*, doi:10.1029/2010JE003785 [6] Glotch et al. (2011) *LPSC 42*, #1566 [7] Ehlmann et al. (2008) *LPSC 39*, #2437; Wright et al. (2004) *2nd Conf. on Early Mars*, #8067 [8] Verma et al. (2009) *ICAME*, 897-904, doi: 10.1007/978-3-540-78697-9_124; Morris et al. (2004) *Science*, 833-836 [9] Ehlmann et al. (2011) *Nature 479*, 53-60 [10] Ehlmann et al. (2011) *Clays & Clay Minerals 59*, 359-377.