THE SIGNIFICANT CONTRIBUTION OF IMPACT GLASS TO THE MARTIAN SURFACE RECORD.

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Introduction and Background: The surface of Mars displays a well-preserved record of impact bombardment extending back billions of years. Unlike on Earth, remnant ejecta products from these impacts are collected and preserved on or near the present-day Martian surface. Depending on factors such as target properties and depositional environment, the diverse nature and fate of such materials will produce a wide-range of products draped over a variety of geologic surface units.

Previous estimates, based on observations of impacts into soft sediments (loess) in Argentina (prime terrestrial analog for Martian sediments), suggest that the accumulation of global distal melts on the Martian surface since the Hesperian should be considerable [1]. This study quantifies these predictions. It integrates hydrocode models of impact melt generation with calculations of ballistic ejecta delivery across a rotating Mars in order to estimate post-Noachian melts on the present-day surface accumulated over the last 3 to 4 Ga [2].

The mafic crust of Mars should yield a wide assortment of impact products, e.g., distal glasses, rapidly quenched melts, and crystalline melts, that have experienced varied degrees of crystallization along with influences of chemical and physical weathering (thus resulting in a diversity of spectral signatures) [1, 3]. Identification of these products distinctly as mafic impact glasses, as opposed to volcanic remnants, is therefore challenging. Regardless, the present results indicate that melts generated from the mafic crust will contribute widespread breccias and tektitic glasses to the near-surface record.

Procedure: This study uses a combination of analytical and computational approaches to model impact-glass generation and distribution on Mars. The CTH shock physics hydrocode package [4] is used to determine melt generation mass estimates, ejection angles, and ejection speeds for impacts modeled under ambient Martian conditions (12 km/s impacts of a dunite projectile into a basaltic target surrounded by a Martian atmosphere, see Fig. 1). A series of detailed equations of ballistic motion, adapted to accurately account for planetary rotation effects [see 5], are then applied to yield global cumulative melt estimates as distributed by all mapped large impact craters (>100 km in diameter) produced since the Hesperian (~3.5-0 Ga), 22 craters in all.

The results presented here incorporate only fully melted, distal ejecta products (e.g., tektite-like glasses with ejection velocities of ~2.7 km/s and greater). However, impacts into unconsolidated sedimentary targets have been found to generate more complex assemblages of melted ejecta, such as breccias containing small percentages (as little as 10-20%) of actual melt volume due to inclusion of mineral clasts [6]. In addition, recent studies have indicated that porous targets may generate five times more melt mass, relative to non-porous targets [7]. Taken these factors into account, the results from our code calculations (impacts into non-porous crustal materials, see Fig. 1) should be viewed as highly conservative estimates.

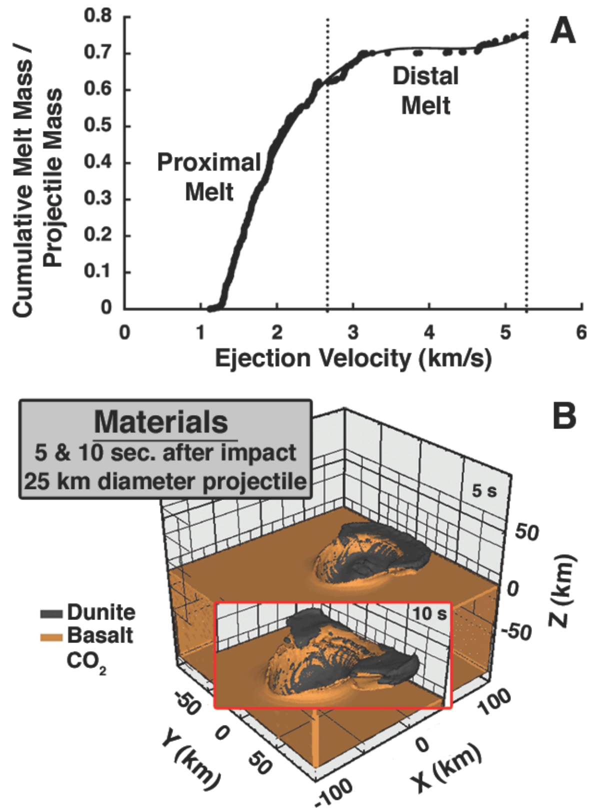

Figure 1. Results from a computational CTH model simulating a 12 km/s Lyot-sized (220 km diameter crater at ~50°N, 30°E) impact on Mars. Angle of impact is modeled at 45° for this particular example. **A.** Plot of cumulative melt mass fraction as a function of ejection velocity (km/s). Distal melt products with flight paths most affected by planetary rotation are ejected at velocities ranging from ~2.7 km/s to ~5.2 km/s (escape velocity). **B.** Material plots at 5 s and 10 s after impact. Actual mesh dimensions extend far beyond what is plotted.

Results and Discussion: The accumulation of distal impact melt as mapped here results not only in a widespread dispersal of deposits but also in marked concentrations coinciding with prominent regions of low-albedo surface materials (see Fig. 2).

Surface Manifestation of Martian Impact Glass. The results in Figure 2A reveal that mafic impact melts will cover the surface of Mars, traversing geologic or lithologic boundaries as well as large topographic variations. The preservation history of these distal ejecta products will differ, however, eventually leading to either more focused/concentrated accumulations or hidden deposits.

The cratered highlands, for example, provide numerous traps within craters, valleys, and thick sediments where glasses remain preserved. In many cases, such as the example shown in Figure 2C, dark layers and dunes can be seen emerging from such traps due to exhumation and deflation of the present-day surface. These particular deposits in Figure 2C (located in the Oxia Palus (OP) region), previously identified as type I basaltic materials [e.g., 8-10], may represent mobile glasses originally deposited just northeast of OP (see Figs. 2 and 3). Substantial meter-thick melt accumulations are mapped to this region from the massive crater Lyot (220 km diameter crater at 50.5°N, 331°W), providing an ideal source for these OP type I deposits.

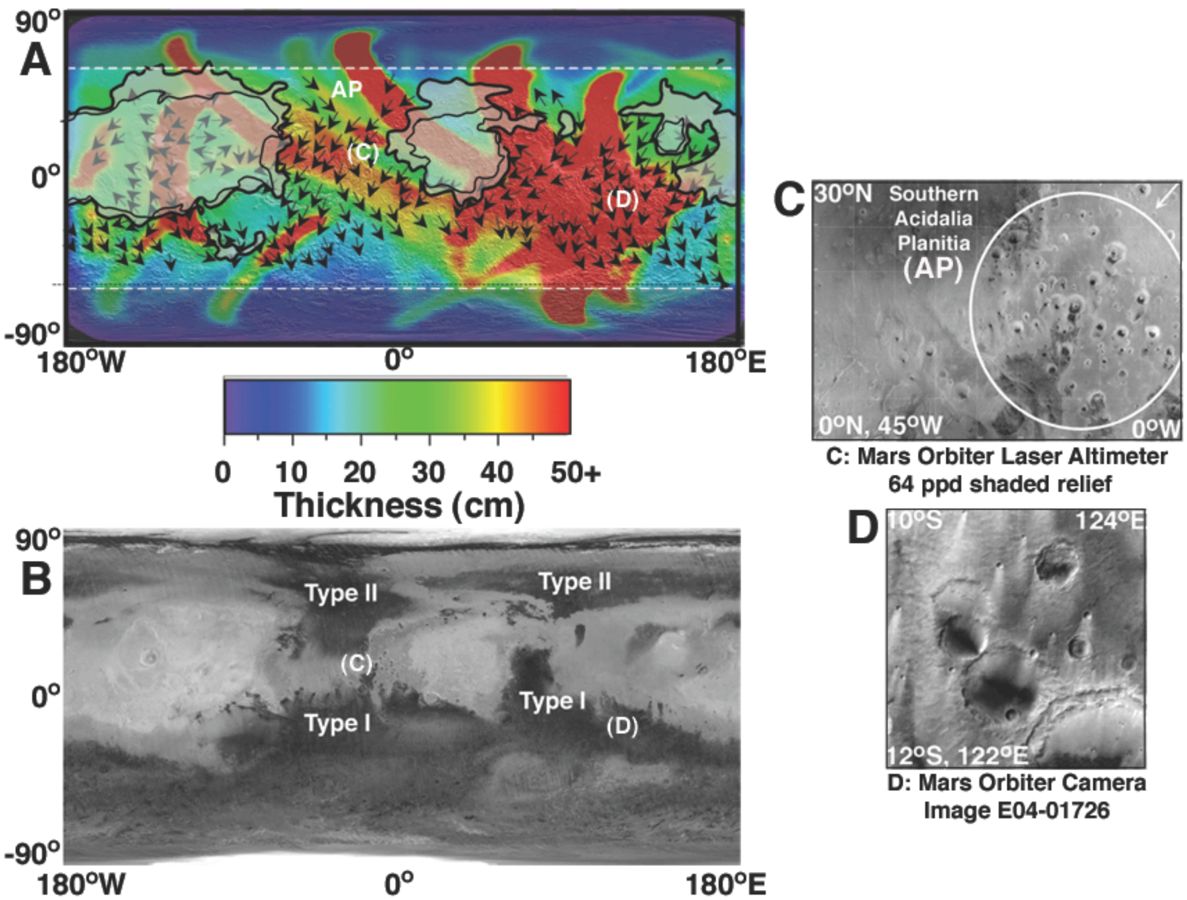

Figure 2. A. Mapped thickness of cumulative ejecta melt across the Martian surface originating from all large (>100 km in diameter), young (~3.5-0 Ga) craters. Purple shading indicates negligible concentrations of melt and red denotes accumulations of 50 cm or greater. **B.** Albedo map of Mars. Differences between mapped melt concentrations and low-albedo deposits can be explained by dust cover or depositional traps in thick sediments (highlighted, transparent areas in **A**: approximate regions of low thermal-inertia) and eolian redistribution (arrows in **A**: current wind patterns, after Thomas [17]). Changing depositional and erosional regimes due to orbital forcing also would have extensively reworked glasses at high latitudes. **C.** Examples of emerging dark layers/dunes/streaks in the Oxia Palus region [10] located just southwest of one the most substantial mapped concentrations of melt (particularly evident in Fig. 3). **D.** Lower albedo type I deposits currently being exhumed out of crater floors in Hesperia Planum, the region hosting the greatest accumulation of distal products.

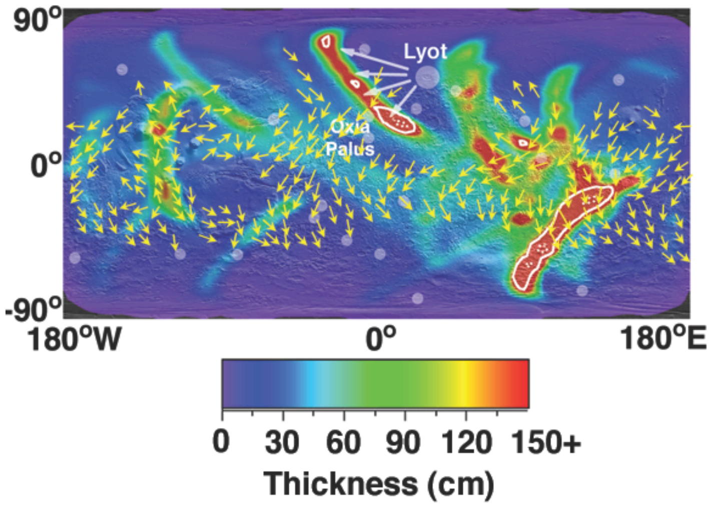

Figure 3. Cumulative ejecta melt map as described in Fig. 2A. Color gradient now extends to 150 cm or greater (red). Current wind patterns are now represented by yellow arrows. Locations of craters studied are denoted as small, faint circles. Regions highlighted by solid white lines contain melt accumulations at least 2 m thick and dotted lines indicate deposits in excess of 4 m. The white arrows designate the crater Lyot as the likely source of the large concentration of mafic melt breccias and glasses in the region of Acidalia Planitia/Oxia Palus.

Impact glasses generated from sediments in the northern lowlands will be subjected to a very different history due to eolian processes of redistribution, saltation, erosion and/or deflation. Remnant products may be evident today as wind-driven fragments of melt-breccias or as concentrated near-surface lag deposits [11] of coarse, vitreous wind-resistant glasses [1]. Cyclic periods of deposition and erosion (or enhanced weathering), however, may mask the existence of such products.

Previous studies suggested that impact glasses from the Lyot crater should be evident today as immobile surface lags within the AP region, perhaps contributing to the more enigmatic type II surface deposits in this location (largest concentration of type II materials on Mars) [1]. The results presented here support these predictions and could account for one of the most substantial accumulations of glasses mapped to the AP region. The type II spectra from AP may simply be indicative of altered impact glasses with poorly expressed signatures or weathered impact products.

The greatest concentration of distal melt mapped in Figures 2 and 3 occurs across the Hesperia Planum region, another prominent area of low-albedo surface materials. Glasses deposited in this region are spread across very diverse geologic units. Dark layered deposits found here are primarily exposed in scarps near large craters and in exhumed terrains and crater floors (see Fig. 2D). Again, these materials could be interpreted as mobile glasses (possibly recrystallized or devitrified) being weathered out of thick, previously protective sediments.

Nature of Martian Impact Glass. The documented survival of terrestrial impact glasses [e.g., 12-14], in conjunction with the lower severity of weathering processes on Mars, suggests that both high-silica distal tektite-like glasses and low-silica proximal glasses should have survived on or near the present-day Martian surface since the Hesperian, unless mechanically broken down. In addition, several other conditions may serve to enhance the generation and preservation of impact glasses on Mars, relative to Earth: no oceans presently (greater glass-generating lithologies), less atmosphere (reduced disruption during re-entry), and greater thickness of sediments (shear heating of particular targets enhances melt production [15-16] and thicker materials allow for a more gentle capture of deposited glasses) [1].

The diverse spectral record of low-albedo Martian surface materials may reflect a range of different types of dispersed impact products, spanning from vitreous impact glasses to crystallized melts [1]. For example, some low-albedo deposits exhibiting Fe^{2+} bands and crystalline hematite signatures could be mafic impact melts that underwent rapid crystallization (low viscosity of mafic melts permits rapid crystallizations) during cooling or high-temperature alterations [1, 3, 15]. The dark mantling deposits of Meridiani Sinus/Arabia Terra, at least some of which are stemming from the crater Schiaparelli [1] (see Fig. 4), exhibit such a signature and may represent newly exposed crystalline and glassy melt products.

The existence of a basaltic signature for some low-albedo materials (i.e., type I) does not define their origin but merely their composition. Impact glass-bearing breccias with basaltic signatures have been identified at numerous sites on Earth [e.g., 12-13]. Remnant impact glasses on Mars could thus easily be mistaken for volcanic products [1].

3 Billion Years Later. Many processes will serve to mask and alter the predicted contribution of impact debris to the current Martian surface record. For example, deposits in high-latitude regions (> +40° or < -40°) will be continually altered, mixed, and/or hidden due to cyclic climate changes (denoted in Fig. 2A).

Shifting wind patterns also will re-distribute exposed, near-surface materials. The arrows in Figs. 2A and 3 depict the current wind patterns on Mars [17]. Subsequent to deposition, such redistribution will serve to concentrate impact melt products. For example, exhumed materials originally trapped in sediments on the floors of old craters in OP could be contributed to the distinct low-albedo intra-crater wind distrincts in this region.

The degree of preservation (or alteration) of distal impact products on or near the present-day surface is indicative of the extent of specific geological processes occurring since the Hesperian, e.g., erosion and deposition rates. Similarly, the state of melt accumulations resulting from the major basins (currently being studied) should be particularly diagnostic of early Martian processes.

Conclusions: The post-Noachian surface of Mars should be coated with re-crystallized, devitrified, or altered impact glasses. Acknowledgement of the presence of these glasses, their signature and locality, is fundamental regarding the history of the Martian surface, present-day surface processes, and future sampling strategies.

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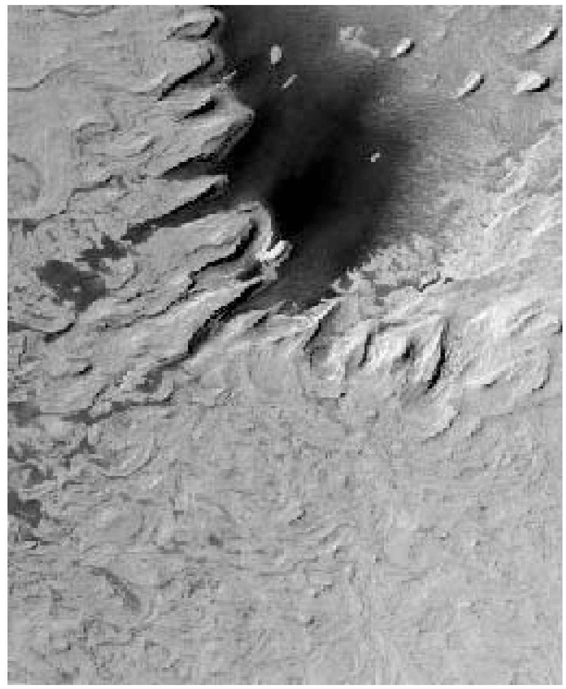

Figure 4. Mars Orbiter Camera narrow-angle image E03-00728. Example of dark mobile materials being exposed from the floor of an impact crater within the Noachian-aged Schiaparelli impact basin (~460 km in diameter centered at ~3°S, 17°E). Illumination is coming from the upper left and north is up. Image spans ~3 km in width.