GENERATION AND DISPERSAL OF IMPACT GLASSES ON MARS: IMPLICATIONS FOR THE NATURE OF MOBILE DARK MATERIALS AND BURIED DARK HORIZONS.

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Introduction: Dark mobile material on Mars is widely considered to be volcanic or volcanically derived wind-blown particulates. Such a conclusion is supported by obvious volcanic source regions and the assumption that a volatile-rich crust would not favor melt products. Several post-Viking discoveries, however, provide a new perspective for reconsidering the impact origin of at least some of the mobile dark veneers and materials at the Pathfinder landing site. Here we reconsider the effect of target material on the generation of impact glass and suggest that they could contribute to the dark markings of Mars and materials at the Pathfinder landing site.

Impact Glass Generation: The generation of impact melts on Mars has largely focused on their possible role in melting ground ice or creating conditions conducive for primitive life (1). The possible effect of water and carbonates on the impact process has led several studies to conclude that large melt sheets would be less likely on Mars (2) and that ejecta would be hydrothermally altered during entrainment in the expanding vapor cloud (3). This conclusion is largely based on field and theoretical studies of terrestrial craters where impacts into sedimentary sequences typically result in dispersed glasses, rather than melt sheets. Although coherent melt sheets may not be produced sediments, large impacts on Earth do generate large quantities of impact melt, as evidenced by tektite strewnfields (4). Because such products are rapidly buried, weathered to clay, or widely dispersed in oceanic sediments, they gain attention largely as tracers of a distant event.

Most of the martian surface preserves an impact record dating beyond about 0.8 Ga. Consequently, debris from impacts on Mars collects over a time equivalent to the Proterozoic into the Archaean of the Earth. Surfaces on Mars however, accrete ejecta from each successive impact and preserve these deposits, unless reworked by wind or in situ weathering. The recovery of tektites and meteorites in the Australian deserts illustrates an analogous terrestrial accretion surface over the last 750,000 years.

There are three types of impact debris expected on Mars: distal clastic debris (breccias, fall-out dust), distal glasses (tektite and microtektites), and proximal glassy impactites. Possible global accumulations of distal ejecta over time on Mars can be inferred from the cratering record. Since the early Amazonian period (0.7 to 1.8 Ga depending on the assumed cratering flux), a single crater about 150 km in diameter would contribute a global fall-out layer about 10 cm thick, comprising almost 25% of the total possible accumulation from all craters. Since the Late Hesperian (1.8-3.1 Ga), however, a single large 250 km-diameter crater such as Lyot should have blanketed Mars with almost 0.4 meters of debris with a total contribution from all craters larger than 100 km (about a dozen) to the martian regolith of more than 2.5 meters. This debris would have contributed to deposits mantling the northern plains, e.g., Acidalia. Still farther back in time, the ridged plains dating from the Early Hesperian could have received almost 5 meters of distal ejecta.

What is the nature of either distal or proximal ejecta? It is usually assumed that the sedimentary nature of the martian crust would preclude formation of significant impact melts on Mars (2, 3). There are, however, three relevant terrestrial analogs that provide evidence to the contrary. First, tektites are believed to be derived from loess or weathered soils (5). These glasses exhibit a range in silica contents (60-75%), reduced alkali volatiles, low iron contents (2-6%), and variable MgO and CaO concentrations. In spite of the initially light brown color, tektites typically appear dark whether as small microspheres or as cm-size Australasian tektites. Tektites are not distributed uniformly but are concentrated in strewnfields, perhaps due to an oblique trajectory (4). Second, impact glasses from the K/T Chicxulub impact and the Eocene Popigai and Chesapeake Bay impacts now demonstrate impact contributions to the terrestrial sedimentary record over the last 65 Ma on Earth and the role of chemical weathering in masking this record (6). And third, recent discoveries of widespread impact glasses derived from Argentine loess provide further evidence that particulate targets and soils not only can generate small tektite-like materials but can produce large blocky vesicular masses (up to 2 m) as well (7). The thick (>300 m) loess deposits provide soft capture for fragile glasses. Subsequent deflation and erosion can create surface lags that concentrate the glass. Their dark color is derived from variable amounts of aeolian transported iron oxides melted into the glassy matrix. Lighter colors result from lesser amounts of iron oxides and greater amounts of silica.

The presence of volatiles (carbonates, water) does not preclude glass formation and does not generate only oxidized debris. Moreover, not all of the Argentine loess is derived from direct aeolian transport from the Andes. Some are derived from multiple stages of fluvial transport and deposition by major rivers originating in the Andes followed by aeolian erosion and deposition to distant sites (7). One consequence of this indirect pathway for the particles comprising the loess is the enhancement of lighter, high silica fractions. Based on this perspective, the generation and dispersal of impact glass even from sedimentary lithologies and soils should be expected on Mars. An exact match of major element mafic chemistries should not be expected if derived locally from aeolian fall-out or if the source craters have sampled non-volcanic crustal materials at depth.

Martian Impact Glasses: Impact glasses occur as globally dispersed tektites/microtektites launched at high velocities and remelted during re-entry (just as on Earth) as concentrated deposits (strewnfields) created by an oblique impact. Laboratory experiments document the downrange high-velocity component of vapor and melt created during oblique impacts (8). These early-stage products decouple from the late-stage crater excavation stage; consequently, molten target material is sprayed downrange even from a crater with relatively symmetric near-rim ejecta deposits. The distribution of this early-stage material does not follow standard ejecta scaling relations for gravity-controlled growth. Concentrations downrange (e.g., strewnfields) can be much more concentrated relative to predictions from excavation flow. For example, the 225 km diameter Hesperian crater Lyot should have contributed a strewnfield 17 m thick over the northern plains of Acidalia and Vastitas Borealis if concentrated in a 10^6 km^2 area. If such a crater had directed its strewnfield over the entire northern lowland formation of Vastitas Borealis (and the polar layered terrains), the thickness would still exceed 1 m. The oblique impact crater Hale, in fact, could be related to an along-trajectory dark streak halfway around the planet (crossing Utopia/Elysium Planitia). In this case the distance of the streak would be comparable to a ballistic range of 1500 km if it had occurred on Earth. There are over 17 craters on Mars larger than 100 km in diameter that retain secondary craters and are not heavily channeled (e.g., modified by an early epoch of enhanced gradation), consistent with extrapolations from statistics of craters smaller than 50 km dating the Late Hesperian times.

Should we expect tektite-like strewnfields and glassy impact deposits from such impacts to be preserved over 1.8-3.0 Ga? On the Earth, obsidian weathers to clay in 1000 to 10 Ma years depending on depositional environments. Glass bombs (fladen) and suevites from the 15 Ma old Ries Crater and the North American strewnfield from 35 Ma illustrate the survivability of high-silica glasses. But glasses from the Chicxulub impact 65 Ma typically have largely weathered to smectite or glauconite depending on original composition and environment (6). The martian environment since at least the Hesperian has been subjected to much less severe chemical weathering processes due to the general absence of surface water. Consequently, both high-silica (60-75%) distal tektite-like glasses and low-silica (45-60%) proximal impact glass should survive as dark veneers unless mechanically broken down during aeolian transport.

Conditions on Mars may not be suitable for the generation of tektites in the strictest sense of the definition. Laboratory experiments, however, suggest that high strain rates created during oblique impacts can enhance the heating process and drive products downrange. The relatively low viscosity of mafic impact melts, however, permits rapid crystal growth, thereby reducing the glass content and hence inconsistent with a strict definition of a tektite. Rapid crystal growth during cooling is also observed in the more mafic Rio Cuarto glasses and in impact glasses produced experimentally. For us, however, the distinction between pure glass products and crystallized melts is of less importance except to identify different types of dispersed impact materials.

Several processes and conditions should enhance impact glasses and byproducts on Mars relative to the Earth: lower impact velocity (more melt, less vaporization), no oceans at present (reduced carbonate sequences and greater glass-generating lithologies), lower gradation rates (higher concentrations from distal sources), less atmosphere (reduced dispersal/disruption during ejection and re-entry), and greater thicknesses of loess (greater survival after impact and contributions to lag deposits after deflation).

Supporting Evidence: Is there evidence for strewnfields of impact glass on Mars? We suggest that there are three types of occurrences: dark, mobile surface veneers downrange from young oblique impacts, dark debris entrained in ejecta and associated with secondaries, and dark mounds and mobile veneers around craters on the northern plains. The fate of this proposed impact glass depends on the depositional setting and age. The heavily cratered highlands provide numerous permanent traps whether within a crater, in the intercrater valleys, or in thick accumulations of loess. Dark layered deposits can be seen in exposed scarps near large craters (e.g., Schiaparelli and etched terrains near Antoniadi) and on crater floors undergoing exhumation (e.g., on the periphery of Arabia). In contrast, the northern lowlands have existed for more than 3 Ga and have received both fluvial (from the outflow channels) and aeolian sediments. Impact glasses from such deposits could have different fates: immobile surface lags of larger impact materials (glasses), aeolian saltation of heavier comminution products (oxide-bearing fractions), and aeolian deflation of lighter dust. Consequently, identification of young impact-related deposits will implicate different types of occurrences elsewhere and at different times on Mars.

Orbital (9) and Earth-based (10) spectral reflectance data of pristine dark surface materials on Mars generally indicate a mafic to ultramafic composition, consistent with volcanic emplacement styles inferred from the surface record. Rigorous modeling of complex systems of several mineral components showed that the simplest acceptable fit between laboratory and orbital ISM data for some low-albedo regions consisted of low- and high-calcium pyroxenes and ferric oxides (9). Many dark plains and mobile materials in certain regions (e.g., Acidalia Planitia), however, do not exhibit the expected absorption features (10). Thermal inertia measurements indicate that Acidalia Planitia is covered by 5-20% “rock” (i.e., solid debris 4-50 cm in diameter). The natural assumption is that this dark rocky material represents a mafic material such as lava flows. Curiously, however, this dark material does not exhibit the expected absorption bands in the reflectance data leading to the conclusion that this material may be characterized by “...abundant high-Ca pyroxenes and/or olivine, mafic glass, ... coatings or other physical factors” (11). These plains appear to represent thick light-colored sediments covered by a dark veneer (meters thick). Subsequent impacts by even small (100m) craters penetrate the darker veneer and deposit the underlying substrate, thereby creating its distinctive mottled appearance. Such regions are consistent with the hypothesis of glasses, rather than crystalline materials, and could represent glass accumulations or lag deposits.

References: (1.) Newsom, H.E., 1980, *Icarus, 44*, 207-216. (2.) Kieffer, S.W. and Simonds, C., (1980), *Rev. Geophys. Space Phys., 18*, 143-181. (3.) Blaney, D.L. (1998) Lunar Planet. Sci. XXIX, LPI, Houston, TX, 1655, (4.) Glass, B.P. and Pizzuto, J.E. (1994), J. Geophys. Res., 99, 19,078-19,081, (5.) Taylor, S.R. (1962), *Geochemica et Cosmoch Acta, 26*, 915-920. (6.) Izett, G. A., (1990), *Geol. Soc. Sp.Paper 249*, 100pp. (7) Schultz, et al., *Science* 282, 2061-2063. (8.) Schultz, P.H., (1999). *Lunar Planet. Sci.* XXX, 1898. (9.) Mustard, et al, (1993), *J. Geophys. Res., 98*, 3387-3400. (10.) Merényi, E., et al., (1996), *Icarus, 124*, 280-295. the Rio Cuarto, Argentina, crater field, *Geology, 22*. (11.) Bell, et al., (1997), *J. Geophys. Res. 102*, 9109-9123