IMPACT AND THE EVOLUTION OF MARTIAN PERMAFROST ENVIRONMENTS.

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Recent studies made possible by instruments onboard the Mars Global Surveyor mission indicate that volcanic resurfacing may have played an even larger role in shaping the Martian crust than previously anticipated. The Thermal Emission Spectrometer has revealed two primary bedrock surface compositions on Mars [1], roughly following the crustal dichotomy: a basaltic composition dominated by plagioclase feldspar and clinopyroxene (augite) within the older southern hemisphere and an andesitic composition dominated by plagioclase feldspar and volcanic glass in the younger northern plains. No areas of carbonate or sulfate have been found. The ubiquitous presence of laterally extensive layering along the walls of the Valles Marineris system, which in its entirety spans more than a quarter of the equatorial girth of Mars, indicates that the upper crust in this region consists primarily of volcanic flows [2] rather than megaregolith, fluvial deposits or eolian sediments. This, in turn, suggests that Late Noachian/Early Hesperian volcanism was much more voluminous than previously believed [2].

The capacity of such massive, low-porosity media -- in their pristine form -- to house either liquid water (in a warmer earlier era) or ice (at present) seems quite limited. Increasing this potential to hold water, and thereby directly heightening the prospects for harboring life, requires subsequent processing of these crustal units. One of the fundamental ways primordial crust on all planetary bodies in the Solar System has been modified is by meteorite impact. Indeed, impact might enhance the biological potential of volcanic materials in at least six important ways:

1. Impact produces a local depression. The enclosed basin and elevated rim generated by impact captures and holds available surface/subsurface water and establishes a stable lacustrine environment independent of regional physiography or level of geomorphic maturity. Of the ~160 terrestrial impact structures identified to date, the majority of those at the surface contain lakes. These lakes are typically deeper than lakes formed by other geological processes [3]. The current view of the potential water budget on Mars (e.g., [4]) has prompted considerable interest in paleolake sediments within martian craters (e.g., [5]; [6]; [7]; [8]; [9]). Recently, Cabrol and Grin [10] catalogued 179 paleolakes in Martian impact craters/basins representing open, closed, and lake-chain fluviolacustrine systems. The sediments within these dry lakes could yield important new information on Martian climate history and possible biological activity and possible biological activity. Martian crater lakes are among the most popular candidate sites for future Mars lander missions (e.g., [11], [12]; [13], [14], [15])

2. Shock damage hastens weathering. Impact-induced shock damage to basic volcanic minerals enhances their alteration, and, particularly in the presence of water, the formation of phyllosilicates and zeolites that hold cations and nutrients required for microbial vitality. This is particularly true for the allogenic deposits that cover the crater floor; these units, consisting of breccias and coherent melt rocks have experienced the highest levels of shock deformation (in excess of 35 GPa; e.g.[16]) and undergo rapid weathering in the presence of water. Terrestrial studies have demonstrated that the presence of water (and presumably ice) in the impact target significantly reduces the volume of the coherent melt sheet retained within the crater. Instead, considerably more of the highly shocked (melted) material is dispersed regionally as ash and glass which would increase the martian inventory of phyllosilicates at the surface.

3. Impact produces a long-lived near-surface heat source. In the presence of fluids, residual heat deposited within the upper crust beneath a crater initiates near-surface hydrothermal activity. This can mix aqueous fluids of different compositions and oxidation states far from thermodynamic equilibrium to provide a source of free energy that can drive organic synthesis from CO_2 and H_2, and potentially supply a source of geochemical energy to chemolithoautotrophic organisms [17]. Hydrothermal activity also hastens alteration (e.g., [18]) and the release of nutrients such as Fe, N, P, S, Ca, etc. in forms that are biologically accessible. Finally, the impact generated heat source within a crater lake could provide a local warm, nutrient-rich microbial refuge that remains unfrozen over time-scales of millennia even in the recent cold Martian environmental regime.

4. Large-scale impacts bring deep crustal rocks into the near-surface environment. Uplift of deeper crustal materials in the crater center affords greater access to any deep, water-saturated materials [19] that might be capped by the impermeable volcanic materials of the upper crust. In layered targets, these deep rocks could also be compositionally distinct from the near surface layers. As tremendous amounts of impact-generated residual heat is deposited in rocks of the central uplift, a dynamic, chemically active environment is produced that is far from chemical or thermal equilibrium. This hastens weathering of the uplifted material and could provide additional important constituents for initiating and maintaining biological activity. For instance, graphite is a common, albeit minor, constituent of deep mafic-ultramafic rocks on Earth and, given the surface compositions observed by TES [1], the same probably holds for Mars. In the presence of reactive hydrothermal fluids, graphite could be an important local source of carbon for organic activity, particularly within large crater lakes, whose uplifted centers comprise rocks from the deep crust.

5. Impact produces deep and extensive structural damage. Fracturing and faulting within, beneath, and around the crater allows the infiltration of these nutrient-rich waters into the subsurface, where any microbial life forms could be preserved in dormant states after the thermal anomaly has decayed. Subsurface porosity is a major ecological niche on Earth and is likely to be on Mars [20]. The subsurface is a possible refuge from the intense UV and other ionizing radiation that the Martian surface sustains in the absence of effective ozone shield [21] or strong magnetic field. With respect to recent impacts into a frozen Martian crust, such fractures would allow circulation across a steep thermal gradient where temperature decreases rapidly with distance from the impact heat source. This is a classic 'cold-trapping' situation where warm nutrient- (organic?) rich fluids circulated to the distal regions of the fracture system would become cooled and frozen in place, progressively, as the thermal anomaly decays with time. In deeper fractures where the system is fluid-filled, the frozen material filling the fracture would thus contain all components of the original fluid. Deeper, fluid-saturated fracture systems might preserve these materials indefinitely. However, if the fractures are near the surface, i.e., in communication with the atmosphere or are above the the limit of crustal dessication [19], the water within this frozen assemblage will ultimately sublimate, leaving a residuum of previously dissolved or particulate material as a coating on the fracture surfaces. Consequently, impact-induced fractures around the crater may hold important clues to the nature and extent of organic, prebiotic, and possibly biological activity on Mars.

6. Impact generates particulate material. Impacts produce and regionally distribute copious amounts of fine-grained, poorly consolidated ejecta (e.g. the ejecta deposit of the Hershel Basin; [22]). Experience with terrestrial craters indicates that, depending on the nature of the target and the distance from the crater rim, this ejecta can be course-grained and permeable (proximal ejecta) or very fine-grained and impermeable (distal deposits) and it consists of both highly shocked (melt/vapor condensate) and weakly shocked target materials, which comprises the vast majority of the proximal, continuous ejecta deposit. Such fine-grained, unconsolidated impact deposits are easily reworked by wind and water and may be the a major contributor to the sediment inventory within vast outwash plains (i.e., the Pathfinder landing site) and broad crustal sags (i.e., the Elysium Basin), as well as the extensive circumpolar deposits.

References: [1] Banfield, J.L. *et al*. (2000) *Science 287*, 1626-1630.. [2] McEwen, A and M. Malin, (1997) *Meteoritics & Planet. Sci., 32*, A74. [3] Dence, M.R. (1972) *Proc. 24th Internat. Geol. Congr*. Sect. 15, 77-89. [4]Clifford, S.M. (1992) *J. Geophys. Res. 98*, 10,973-11,016. [5] DeHon, R. (1992) *Earth Moon Planets*, 56, 95-122.[6] Farmer, J. D. and Des Marais, D. J. (1994) In: *Microbial Mats; Structure, Development and Environmental Significance*. (L. Stal and P. Caumette, eds.) Springer-Verlag, 61-68 [7] Newsom, H.E., et al. (1996) *J. Geophys. Res. 101*, 14,951-14,955.[8] Cabrol, N.A. et al. (1998) *Icarus, 133*, 98-108.[9] Cabrol, N.A. et al. (1999) *Icarus, 139*, 235-245.[10] Cabrol, N.A. and Grin, E.A. (1999) *Icarus, 142*, 160-172.[11] Barlow, N.G. (1998) In *Mars Surveyor 2001 Landing Site Workshop* (V.C. Gulick, ed.), pp. [12] Cabrol, N.A. and Grin, E.A. (1998) In *Mars Surveyor 2001 Landing Site Workshop* (V.C. Gulick, ed.), pp. 86-87. [13] Forsythe, R.D. and Blackwelder, C.R. (1998) In *Mars Surveyor 2001 Landing Site Workshop* (V.C. Gulick, ed.), pp. 76-77. [14] Newsom, H.E. (1998) In *Mars Surveyor 2001 Landing Site Workshop* (V.C. Gulick, ed.), pp. 40-41. [15] Zimbelman, J.R. (1998) In *Mars Surveyor 2001 Landing Site Workshop* (V.C. Gulick, ed.), pp. 92-93. [16] Melosh, H.J. (1989) *Impact Cratering: A Geologic Process*, Oxford University Press.245 p. [17] Shock, E. L. and Schulte, M. D. (1998) *J. Geophys. Res. 103*, 28513-28527 [18] Newsom et al. (1986) *J. Geophys. Res. 91*, 239-252. [19] Clifford, S.M. (1998) *LPSC XXIX*, 1922-1923. [20] Stevens, T.O. (1997) In *The Microbiology of the Terrestrial Deep Subsurface*, (P.S. Amy and D.L. Haldeman, eds), CRC Press, Boca Raton, 202-222. [21] Kuhn, W.R. and Atreya, S.K. (1979) *J. Mol. Evol*., 14, 57-64. [22] Edgett, K.S. (1991) Proc. Lunar Planet Sci. Conf. 21, 657-668.