CONTROL OF IMPACT CRATER-RELATED FRACTURE SYSTEMS ON THE SUBSURFACE HYDROLOGY AND GROUND COLLAPSE.

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Introduction. Mars is a planet enriched by ground-water [1,2]. Control of the subsurface hydrology by tectonic and igneous processes is widely documented, both for Earth and Mars [e.g., 3]. Impact craters result in extensive fracturing of the ground, which includes radial and concentric peripheral fault systems, which in the case of Earth have been recognized as predominantly strike-slip and listric extensional, respectively [4]. In this work we propose that, basement structures of Mars largely result from impact-related tectonism, except in regions that are dominated by magmatic-driven activity such as Tharsis [e.g., 5] and/or possible plate tectonism during the extremely ancient period of Mars e.g., [6]. However, complex basement structural fabrics in magmatically active regions such as Tharsis are the result of both impact and magmatism. In many cases, impact-induced faults appear to have been reactivated and/or displaced by subsequent magmatic-driven activity [7].

Fractured impact crater floors: Fractured impact crater floors are concentrated in the ancient cratered highlands along the margins of plain regions and within the lightly cratered plains near the Valles Marineris Canyon system [8]. Moats within these craters of varying diameters and relative ages, surround plateaus and contain broken material (Fig. 1). The moats appear to be restricted to the margins of highly degraded crater rims. Only certain craters in a given region, however, display these characteristics. Schultz and Gliken [8] propose that modificational processes were localized by the impact structures and restricted to the crater interiors. They interpret this to be the result of heat generated by a tabular magmatic intrusion injected beneath the brecciated zone of an impact crater, which raises the temperature of the overlying material. Thawed materials would then subsequently escape through the peripheral fracture system surrounding the crater, or alternatively, a metastable state of liquification could occur, if the material is confined or the rate of thawing exceeds the rate of escape. The collapsed material within a moat marking a highly degraded impact crater rim forms ridges around the central plateau region (Fig. 1B). This suggests that the degradational processes may have been controlled by extensional concentric faults, possibly initiated during the inward collapse of the transient crater walls [4] and/or by concentric fractures produced by the uplift of the crater floor, which might have resulted during the injection of a tabular magma body under the crater floor [8]. The water-enriched source region, which may have contributed to the formation of the features shown in Fig. 1A,B, has been destroyed, suggesting that the formation of the moat may have involved hydrologic processes. In addition, a depression that transects an impact crater (Fig. 1B) forms part of a longer valley, which terminates in the Western margin of the Hydaspis Chaos (Fig. 1, V-B). This scenario may not be necessarily explained solely by processes, triggered in the case of tabular intrusions being injected under crater floors and/or by processes exclusively controlled by structures localized within impact craters [8].

Progressive highland subsidence and collapse: Rodriguez et al. [9] described the progressive highland subsidence and collapse of the late Noachian subdued crater unit [10], in the region of interest (Fig. 1). They propose that regional subsidence and collapse was related to compensational sinking, resulting from the release of pressurized water in confined caverns. The release of water described in [9] served as an important, and so far unaccounted water source to carve the outflow channels. Terraced terrain marked by both chaotic terrain and channel bedforms (Fig. 2) may also indicate the release of large quantities of water and related collapse. These observations suggest that the plateau material was degraded and removed at a faster rate from within craters, than from the surrounding country rock (Fig. 3).

Crater-related fracture networks: Layered materials are pervasive on Mars [11]. These layered materials may contain numerous impact craters (Fig. 3). We propose that impact-induced fracture systems dominate the fracture population in the ancient highlands, except in the Tharsis and Elysium regions [7]. We propose that intermingling concentric and radial fracture systems from multiple impact crater events will result in complex crater fracture networks (CRFN). Individual fractures of CRFN will tend to converge onto buried craters. Periods of rapid and/or extended surface burial, or periods of lesser bombardment, will result in regions with relatively smaller buried impact crater population. As a consequence, the CRFN will be less developed. We have called these regions, Regions of Low Fracture Density (RLFD). On the other hand, the period of heavy bombardment coupled with rapid degradation and burial are expected to result in higher buried crater populations and highly developed CRFN. We have called these regions, Regions of High Fracture Density (RHFD). We propose that the highland plateaus are stratified into RLFD and RHFD. Since heat flow is transferred more rapidly and effectively along fracture planes, a consequence of this scenario is that heat pulses will result in a highly unisotropic heat flow distribution. Convergence of fractures onto buried craters might result in higher heat flow to these regions, and therefore in their preferential warming. The existence of valley networks dissecting the crater rims in the ancient highlands [1] suggests that crater interior deposits may have contained large amounts of water-laid sediments. We propose that buried craters are likely to be ice-enriched regions within the Martian permafrost [2]. Warming of the crater interior deposits might have resulted in melting large volumes of water and intensive hydrothermal circulation. Regional hydrothermal circulation within the CRFN might result in fracture enlargement, forming conduits that allow subsurface distal migration of volatiles as well as escape to the surface or enter the atmosphere. We propose that circulation within CRFN regions will be highly effective at removing crater materials, possibly forming cavities, and resulting in the storage of large amounts of water within the subsurface conduit systems and porous media. Lateral interconnection will be enhanced by subsequent impacts. For example, impacted-induced basement structures and reoriented bedding planes that dip away from the crater will interconnect regions with different permeability and volatile content.

We propose that the progressive levels of collapsed terrains in the plateau (Fig. 2) can be explained by the successive collapse of RHFD levels. The relative thickness of both the RHFD and RLFD will determine the number of collapsed plateau levels in a given highland region. If collapse occurs to great depths, or the thickness of the collapse region is relatively thin, the plateau surface might respond by simple crustal warping and fracturing. Truncated impact craters that are preferentially preserved at distinct levels of subsidence (Fig. 2) and collapse features are more prominent on the floors of crater floors (when compared to the surrounding plateau material; Fig. 1) collectively add credence to our hypothesis that suggests preferential removal of subsurface crater interior deposits. Our model implies that the processes responsible for the fracturing and collapse of crater floors were not localized to individual impact structures. Non-uniform heat flow may explain why only certain craters display the characteristics described above for a given region. The formation of moats encompassing central fractured plateau regions (e.g., Fig. 1) suggest that impact-induced fractures are more densely packed around the periphery of the crater rather than beneath the central plateau. Subsequent magmatic and tectonic activity, particularly related to the evolution of Tharsis rise, led to an increase in the complexity of the CRFN, possibly resulting in reorientation of preexisting fracture systems into random patterns, so that the Martian fracture distribution was stratified into laterally extensive high density and low-density regions.

References:
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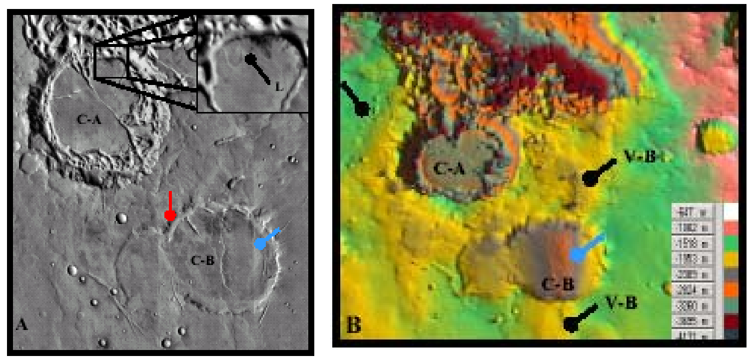

Fig. 1. *A: THEMIS day infrared composite. B: MOLA based DEM. North is up. Crater A is 50 km in diameter. Impact crater whose collapsed floor forms a moat around a central plateau, near the western margin of the Hydaspis Chaos (CA). Lobate features occur on the margin of the central plateau region (L). Impact crater that has a less developed moat (Red arrow) and fractured floor when compared to crater C-A. Also, shown is a depression that transects the crater 30 km wide, 300 m deep (Blue pointer).*

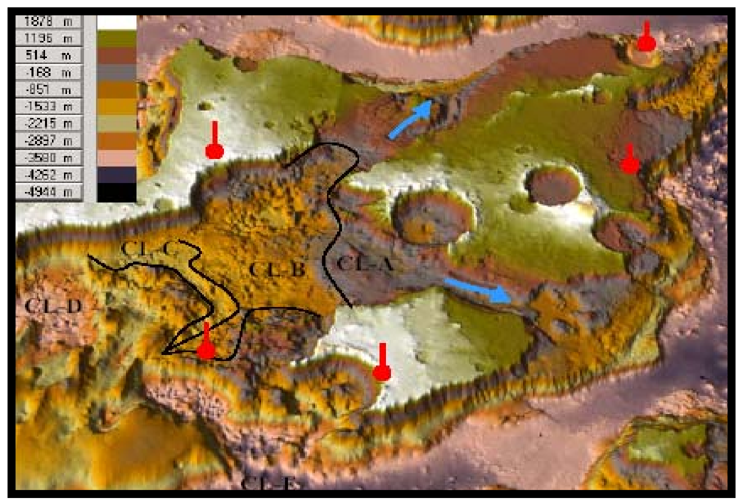

Fig. 2. *MOLA based DEM. Image is 350 km wide. Noachian plateau region located to the north of the Eos Chasma. Here, chaotic materials occur at several levels indicating progressive collapse (CL-A to E). Both the chaotic terrain and channel bedforms (blue arrows) may indicate hydrologic activity. In addition, numerous arcuate scarps are visible, interpreted here to be the remains of impact crater walls (Red pointers).*

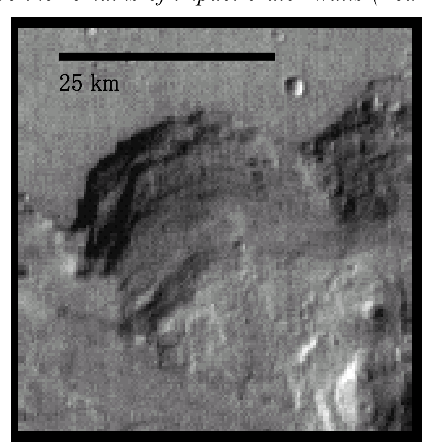

Fig. 3. *THEMIS day infrared composite subframe. Noachian plateau near the Hydaspis Chaos. Arcuate scarp, 1000 m deep shows clear layering exposed. North is up.*