IMPACT-INDUCED LIQUEFACTION IN WATER-RICH, UNCONSOLIDATED, NEAR-SURFACE SEDIMENTS ON MARS? G. Komatsu[1], G. G. Ori[1], S. Di Lorenzo[1], A. P. Rossi[2] and G. Neukum[3], [1]International Research School of Planetary Sciences, Università "G. d'Annunzio", Viale Pindaro 42, 65127 Pescara, Italy; [2]ESA Research and Scientific Support Department, Keplerlaan 1, Postbus 299, ESTEC/SCI-SM, 2200 AG Noordwijk, The Netherlands; [3]Institut fuer Geologische Wissenschaften, Freie Universitaet Berlin, Malteserstr. 74100, Bldg. D, 12249 Berlin, Germany.

Introduction: Liquefaction due to shockwave propagation has been observed on Earth. Earthquakes that propagate through water-saturated cohesionless sediments are known to cause liquefaction. For example, the liquefaction during the Niigata Earthquake and the Alaska Earthquake that occurred in 1964 [e.g., 1] caused substantial building damages and produced landforms such as sand volcanoes. Some synsedimentary deformation features in Utah involved liquefaction and they have been attributed to an impact event [2] that resulted in the formation of the Upheaval Dome, a purported impact structure [3, 4]. It is reasonable to assume that impact-induced shockwave produces a significant amount of liquefaction in water-rich near-surface sediments.

On Mars, water in the permafrost zone tends to diffuse to the atmosphere over long geological time scales [e.g., 5, 6]. However at a higher latitude range this process is less effective and a large amount of ice may reside in the near-surface layer. On Mars, extensive liquefaction due to impact events is considered to be possible [7, 8] based on the comparison with terrestrial earthquake-induced liquefaction. Liquefaction may occur due to the shockwave propagating outward through the water-rich part of the near-surface sediments during the early excavation stage. The liquefaction should involve shock-induced meltwater and liquid water stored in shallow aquifers. There are probably a variety of unconsolidated sediments near the surface of Mars. Such unconsolidated sediments may constitute a loosely packed grain framework, but it suddenly collapses and the grains become temporarily suspended in the pore water under the stress.

Formation Mechanisms of Outer Layered Ejecta Structures: Impact craters on Mars often exhibit features that are not observed on the essentially volatile-free, airless lunar surfaces. The most unusual is the ejecta blanket morphology [e.g., 9, 10]. Martian ejecta blankets are in general characterized by a terminal low concentric ridge (rampart) or a flat-topped plateau (pancake), or radial grooves. This type of ejecta morphology collectively called “layered ejecta structures (LESs)” [11] is in general attributed to various ejecta emplacement processes due to involvement of volatiles derived from the subsurface [e.g., 12, 13, 14, 15, 16, 17] or of atmosphere [e.g., 18, 19, 20, 21] or a combination of both processes [22].

Some Martian impact craters have two clearly separated ejecta layers called DLE (double layer ejecta)-type (Figure 1). The formation of the outer LESs should have occurred either before the emplacement of thicker inner LESs [23], or after [23, 24]. It is also possible that the outer LESs are made of materials formed both before and after the formation of the inner LESs. We hypothesize [23] that the thinner outer LESs were formed by various combinations of primarily three processes; 1) liquefaction of water-rich, unconsolidated, near-surface sediments (Figure 2), 2) emplacement of ballistic ejecta entraining volatiles, and 3) interaction of ejecta curtain and atmosphere. Each process could be dominant in some instances, or equally important as others in other cases. The first process we discuss here should occur before the emplacement of the ejecta curtain, and the outer LES component explained by this process is not conventional ejecta.

It has been found that the DLE-type impact craters exist preferentially in high northern latitudes (>30°N) [22, 25, 26]. Minor concentrations of the DLE-type were noted also in the southern hemisphere (<30°S) [22, 26]. This trend can be explained in the light of the liquefaction hypothesis applied to some outer LES formation. These high latitude areas are where large amounts of ground ice are expected [e.g., 5, 6, 27]. In the case of the northern hemisphere, also large amounts of unconsolidated sediments derived from the Tharsis bulge and the southern highlands may have accumulated [e.g., 28, 29, 30]. These two conditions are favorable for the liquefaction by shockwave propagation. In addition, increased insolation due to high obliquity [e.g., 31] could enhance melting of existing water ice and/or help maintaining liquid water at high latitudes. The general lack of the DLE-type beyond 60°N [25] may be attributed to a probable deeper hydrosphere unreachable for small impact events and inability of water to remain liquid during the impact cratering.

Origin of Mounds near Impact Craters: DLE-type impact craters in high latitudes, particularly in Acidalia Planitia, are often associated by mounds of various sizes within the areas of outer LESs or in their vicinity (Figure 2). The mounds (some of them appear to have a summit crater) are a few hundred meters to a few kilometers wide. In contrast to small impact craters in the area, these mounds are darker in THEMIS nighttime images and this probably indicates that their surfaces are made of relatively fine-grained materials.

The origins of these small mounds are unknown. Possible interpretations based on their morphology (dome-shaped edifices and occasional occurrence of summit craters) and relatively fine-grained surface materials include; 1) pingos [e.g., 32], and 2) sand and/or mud volcanoes [e.g., 33]. Other mound morphologies such as rootless cones [e.g., 34, 35] and tumuli [e.g., 36] are unlikely explanations for these features because of a lack of associated volcanic landforms and difficulty in producing fine-grained surface materials. If 1) pingo or 2) sand and/or mud volcano interpretations are valid, their presence indicates that a large area of Acidalia Planitia is rich in water and unconsolidated fine-grained sediments. Such grounds are prone to liquefaction. If the mounds are sand and/or mud volcanoes that were formed by shock-induced liquefaction, at least part of their formation could be linked with impact events. And some mounds observed in the vicinity of the outer LESs might be a manifestation of such events. Water escape vents have been observed in an impact experiment into a water-saturated sandy target [e.g., 37] and a similar process may have occurred also on Mars. At least within the areas of our investigation, there is no statistically proven increased correlation of their spatial occurrence with respect to any specific DLE-type impact craters. However, for one example of DLE type, there is an observed indication of a continuum of a process responsible for both the outer LES and the mounds.

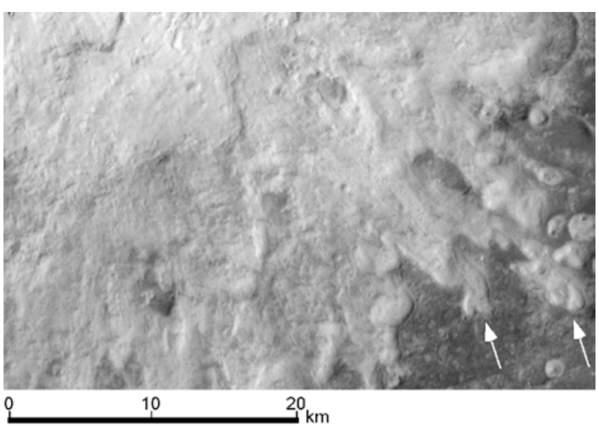

Figure 1. Double layer ejecta structure and small mounds (arrows). Acidalia Planitia. THEMIS VIS mosaic image (V04457004, V05206007).

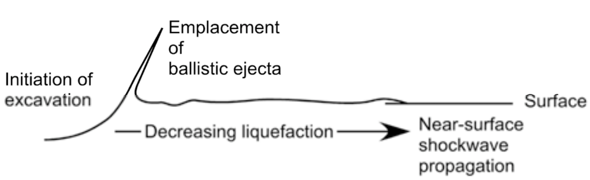

Figure 2. Hypothesized impact-induced liquefaction during the early phase of impact cratering.

Conclusions: Liquefaction due to impact shock-wave propagation in water-rich, unconsolidated, near-surface sediments of Mars is a viable process that deserves investigations. We conclude that some, if not all, outer layered ejecta structures and small mounds in the vicinity of impact craters in high northern latitudes could be explained by this mechanism.

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