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Modelling the Formation of Crater Floor Polygons on Mars using a Desiccation Mechanism

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1. Introduction

Crater Floor Polygons (CFPs) have been mapped thoroughly on Mars using all the available relevant imaging data and were shown to have diameters ranging in size from 15 to 350 meters [1, 2] (Fig. 1). Morphological investigations, aerographic distribution and analytical modelling have laid support to a desiccation mechanism of formation for these polygons as opposed to thermal contraction [1, 2], implying the past existence of lakes in the crater basins. A specific desiccation pathway is still yet to be formulated to account for these features under current Martian conditions. In this work, we shed light on our current efforts as well as presenting a preliminary model of formation for the CFPs.

1.1 Crater lakes and impact-generated hydrothermal systems

Crater lakes on Mars can form either through breaching of the crater wall by channels or shortly after the impact process. The impact event can cause ground water sapping if the impact was relatively small, but sufficient in size to breach the ice/water table, or it could be a result of the impact-generated hydrothermal system if the target material was volatile rich, and the impact was large enough to sustain such a system [3, 4].

2. Terrestrial analogs

Though desiccation cracks found on Earth are commonly sub-meter in scale, a comprehensive work on giant desiccation polygons [5] lists numerous localities in the Great Basin playas in the USA that have desiccation-crack polygonal patterns attaining a width of up to 300 meters (Fig. 2). On Earth, such features usually occur in clay playas, but can also occur in other geological materials such as sandstone. The formation of these polygons is attributed to desiccation of the once water-rich materials related to the lowering of the ground water table and intense evaporation [5].

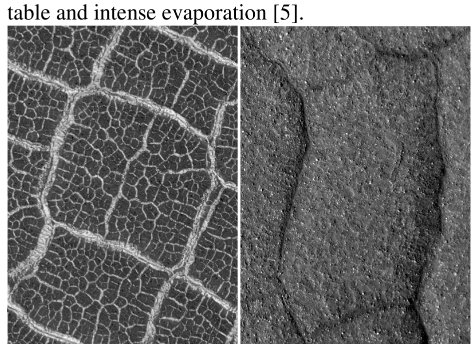

Figure 1: HiRISE sub-images of crater floor polygons. Left: 100 meter-wide polygon with 6-8 meter-wide, frost-filled troughs surrounding it. Secondary troughs within the primary polygons form polygons with an average diameter of 10 meters. Image ID: PSP_007372_2475 (67.2N, 47.8E). Right: 125 meter-wide polygon with frost-free troughs. Note the lack of secondary troughs. Image ID: PSP_001942_2310 (50.7N, 341.6E).

Desiccation tensional cracks tend to initiate at depth irrespective of their size [5, 6, 7]. In the giant cracks' case, they usually initiate at the capillary fringe zone above the water table [5]. Later, they either make their way to the surface or aid in the linear collapse of the ground above [7].

3. The desiccation model

The processes that result in creating giant desiccation polygons are complex to model even in terrestrial cases. In addition, the lack of information about soil properties on Mars at the time of formation of CFPs makes it even more difficult to carry on a numerical analysis. Nonetheless, making several assumptions and using a simplified model of desiccation we can obtain at least qualitative results as described below. We adopt an elasto-hydric pre-fracture model as a starting point. In doing so, we assume that the desiccation process is fast enough to cause the soil to behave elastically. In addition, we assume that volumetric shrinkage is the main cause of tensional stress build-up prior to fracturing and we ignore viscous relaxation of stress. As a result we can describe the total strain ε in the soil to be

$$\dot{\varepsilon}_{ij} = \frac{1+\upsilon}{E}\dot{\sigma}_{ij} + \alpha \dot{W}_{ij} \tag{1}$$

where υ is Poisson's ratio, E is Young's modulus of the soil, σ is the stress tensor, α is the shrinkage coefficient, W is the water concentration, the subscripts indicate components of the various tensors, and the dot superscript indicates differentiation with time. Certain parameters are simplified in this equation, and will be discussed further in the meeting. The desiccation process which is implicit in the second term on the right hand side of equation (1) can be adequately described through a diffusion law (without considering the effects of soil densification with desiccation)

$$\dot{W} = \kappa \nabla^2 W \tag{2}$$

where κ is the hydrous diffusivity. In the meeting we plan to elaborate more on this model and report on the numerical results.

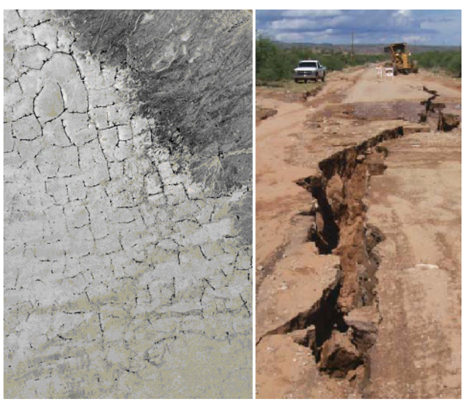

Figure 2. Left: Desiccation cracks in Coyote Lake in California US (35.1° N, 116.7 ° W). Crack spacing ranges from 30 to 75 meters. (Image: Google Earth). Right: A giant desiccation crack insitu in Arizona (Image adapted from Arizona Geology journal. Credit: R.C. Harris)

4. CFPs formation mechanism

While desiccation polygons are readily explainable on Earth's warm and wet weather, it is challenging to incorporate the same mechanism to the case at hand assuming current Martian conditions. As a result, we propose the following preliminary model for formation (Fig. 3): In the first stage, a crater lake exists inside the impact basin due to the melting of the subsurface water ice. This lake is kept in a liquid state with the heat energy from the impact generated hydrothermal system and in some cases, heat from the central uplift. Under current conditions, an ice layer is expected to form on top of the lake thereby further extending the longevity of the lake through latent heat of freezing and restricting the lake's heat losses to conduction through ice [3]. In the second stage, the hydrothermal system is too weak to support any further fluid circulation, yet the subsurface is still at temperatures above freezing. On the surface, the lake has completely disappeared and the top layer consists of frozen soil.

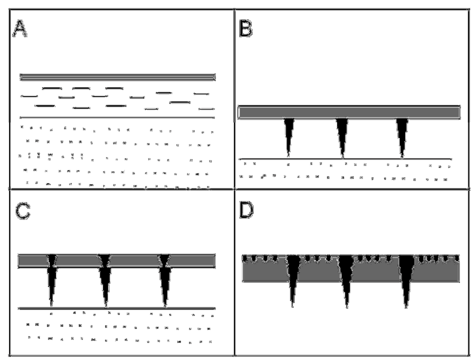

Figure 3. Plausible formation pathway for CFPs. A: A lake (dashed lines) lies above a saturated zone. A thin ice layer may form on top (grey zone). B: As the lake dries/sublimates away, the water table falls down due to waning of the hydrothermal system. A dried-up zone forms in the middle as water is either draining downwards or vapour is rising to thicken the ice layer on top. Fractures initiate at the boundary between the ice and the dried zone. C: Thermal contraction processes eventually lead to cracking of the upper frozen soil layer preferably above the fractured weakened zones thus exposing the fractures. D: Further thermal cycles may form the secondary thermal contraction features within the larger polygons.

Water is gradually being desiccated from the previously saturated zone either through migration downwards or through diffusion of water vapour upwards to the permafrost zone. If enough desiccation occurs, the tensile stresses should be enough to initiate cracks at the boundary between the permafrost zone and the resulting unsaturated zone. As desiccation continues, fractures deepen by extending downwards as the permafrost acts like a barrier due to its higher tensile strength (by 2 or 3 orders of magnitude). If the unsaturated stressed zone is thick enough, it can yield deep fractures resulting in a large spacing between the cracks to form the large 70 to 300 meter sized polygons. In the third stage, the hydrothermal system is now extinct, and the whole region is almost back to ambient conditions. Periodic thermal contraction stresses build up until they fracture the frozen soil. However, they tend to initiate at the weaker zones above the subterranean cracks eventually merging with them. In this respect, the thermal contraction acts in the same way that rain may do on Earth by exposing the subterranean cracks. In the final stage, subsequent episodes of seasonal thermal contraction can act to widen the primary fractures and add shallower secondary cracks at the surface, while the freezing front can extend further in the crust due to the cooling of the hydrothermal system.

5. Conclusions

We present for the first time a model of formation for the hundred meter-sized polygons on Mars that can be viable even under current Martian climatic conditions. The presence of a thermal source and liquid water in a confined basin could be the reason for these features being mainly concentrated in impact craters. The numerical model of desiccation should yield some insights into the limits and implications of the proposed formation hypothesis.

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