Modeling the Formation of Large Desiccation Polygons on Earth: Possible Relation to Intermediate-Sized Polygons on Mars and Implications to Mars Hydrology.

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Introduction: There are very few well-documented examples on Earth from the geological record of giant desiccation polygons [1]. The spacing of desiccation polygonal cracks on Earth is usually centimeters up to several meters at most. However, there are reported cases of giant desiccation polygons that reach up to 300 meters in size [2] (Fig. 1). Owing to their rarity, modeling or experimental work to explain these large features is lacking. In contrast, polygonal cracks are ubiquitous on the surface of Mars [e.g., 3,4]. El Maarry et al., [5] carried out global mapping of Crater Floor Polygons (CFPs) using high-resolution images (0.25-6 meters/pixel) from instruments currently orbiting Mars. The CFPs, in this study renamed to Intermediate-sized Polygons (ISPs), morphologically resemble Terrestrial thermal contraction polygons and desiccation cracks (Fig. 2). However, their large size (70-350 meters) is significantly different from that of thermal contraction polygons that are ubiquitous in the martian high latitudes [3]. An analytical model based on fracture mechanics of crack extension in a frozen soil under current climatic conditions on Mars suggests that it is not possible to form such large polygonal networks using seasonally induced thermal stresses alone [5]. As a result, desiccation was suggested as an alternative (main) mechanism for the formation of intermediate-size polygons inside craters, while not ruling out contributions from thermal stresses [5]. In this meeting we present a pre-fracture incrementally non-linear elastic-hydric model to constrain the models of formation of giant desiccation cracks on Earth, and possibly ISPs located in many impact craters on Mars in an attempt to explore the desiccation hypothesis and its applicability in a martian climatic setting.

Model: The model makes use of the extensive body of work present in literature on modeling desiccation for civil engineering and agricultural purposes [e.g., 6,7,8,9] since such work in the planetary literature is still lacking (compared to the body of work on simulating thermal-induced processes for example). The main idea behind the model is to solve the following stress-strain relation:

$$0 = \frac{1+\nu}{E}\overset{*}{\sigma} - \frac{1+\nu}{E^2}\frac{\partial E}{\partial w}\overset{*}{w}\sigma + \alpha\overset{*}{w}$$

where σ is stress in pascal, ν is Poisson's ratio, E is young's modulus, α is the hydric expansion coefficient,

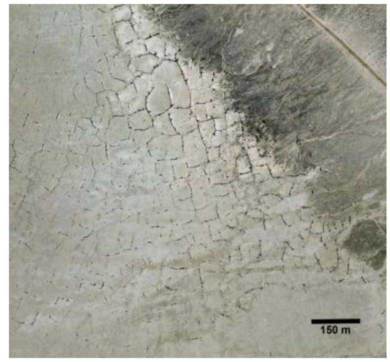

Fig. 1. Desiccation cracks in Coyote Lake in California US (35.1° N, 116.7 ° W). Crack spacing ranges from 30 to 75 meters. Mineralogical investigations of soils that display such large features show them to be predominantly fine soils (2μm grain size on average) containing clay minerals (mainly montmorillonite, illite, vermiculite, and chlorite), carbonates, and analcites [2]. Credit: Google Earth.

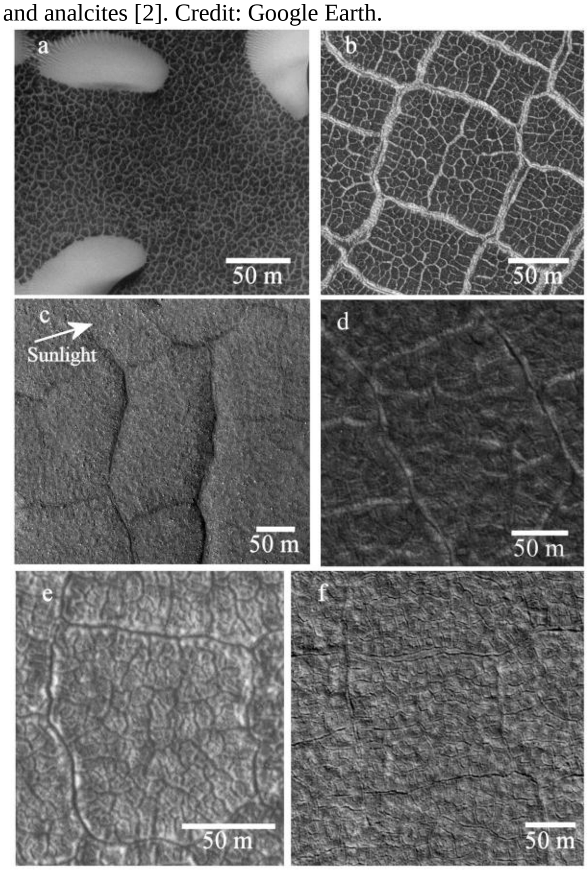

Fig. 2. Typical ISPs on Mars and comparison to thermal contraction polygons (TCPs). TCPs on Mars (a) are typically 5-10 meters wide and are ubiquitous in the high latitudes. ISPs, on the other hand, are usually associated with impact

craters and range in size from 70 to 350m. In the higher latitudes the fractures, usually 1-10 meters wide, are occasionally filled with frost or permanent ice (b) making it easier for visual detection as opposed to ice-free ones (f) and usually display two distinct size groups (b, d, e, and f): Large 70 to 350 meter-sized polygons with an average polygon diameter of 120 meters, and a smaller group, not always present, ranging in size from 5 to 20 meters which are most likely TCPs. At lower latitudes, CFPs appear to be devoid of embedded features (c). Image IDs: a) PSP_008165_2505, b) PSP_007372_2475, c) PSP_001942_2310, d) PSP_007573_2435, e) PSP_008456_2460, f) PSP_010412_2475 (Credit: JPL/NASA, HiRISE camera).

and *w* is the gravimetric water content of the soil. In this equation, the strain is set to zero since we are interested in pre-fracture conditions, and stress is generated through elastic means as well as hydric ones due to loss of volume through desiccation. The water content is allowed to diffuse away (mainly downward through gravitation) with time and is described by Fick's second law of diffusion. Finally, we investigate whether the resulting stresses, which are modeled for various soil diffusivities, are capable of inducing cracking using empirical equations for computing the failure/tensile strength of an analog material (Werribee clay) [7] at different water contents as given by [9]. The material properties such as Younge's modulus are similarly derived from experiments on Werribee clay.

Results: The results of the model (Fig. 3) show that tensile stresses rise monotonically with desiccation. However, in soils with diffusivities below 10^{-4} m^2/s, it is not possible to generate high enough stresses to cause fracturing. On the other hand, intermediate values between 10^{-2} and 10^{-4} m^2/s create optimum conditions for the formation of cracks at the time scales suggested for the formation of giant desiccation polygons on Earth of 1 to 2 years [2]. Furthermore, these diffusivity ranges agree excellently with expected values of clayey soils in general [10] and with actual measurements (2×10^{-2}) taken at hydrothermal lakes [11] which has interesting implications for Mars [5]. Our model clearly shows that for typical diffusivity values of clayey soils with a considerable amount of smectites (20-30%) enough stress can build up to stimulate cracking of various spatial scales. Finally**,** these results also corroborate earlier assumptions that giant desiccation polygons on Earth occur through lowering of the water table rather than surface evaporation. Extending the model to Mars shows that soils would crack within similar diffusivity limits but in slightly longer periods of time owing to the lower gravity.

Discussion and Future work: The results presented here not only highlight the feasibility of modeling the formation of desiccation cracks with a simple hydro-elastic model, but also constrain an important soil factor such as diffusivity for creating large desiccation cracks as well as the mineralogy capable of displaying such features.

In the case of Mars, we can conclude that two main conditions are needed to be met for desiccation cracks to occur: the thermal and soil diffusivity conditions should be well constrained in order to (1) allow for the formation of an unsaturated zone with a considerable thickness while at the same time keeping the zone warm enough to (2) slow the growth of the permafrost (where our stress-strain calculations are not valid) till cracking occurs.

We intend to buildup up on these results by applying them into developing a more complex numerical model that takes into account the expected thermal fluctuations in a martian setting, as well as carrying out physical experiments on soils to investigate desiccation under terrestrial and martian climatic conditions to offer new insights into planetary hydrology in general.

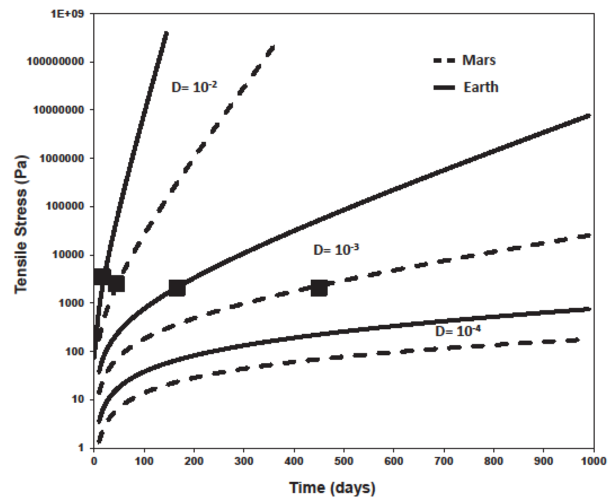

Fig. 3. Results of modeling stress buildup in a pre-fracture state under Earth-like (solid lines), and Mars-like (dashed) gravitational settings. Black squares signify the corresponding expected onset of cracking. This compilation of all the stress results shows the consistently longer durations computed for a martian setting compared to Earth.

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