

**GLOBAL TEMPORAL AND GEOGRAPHIC STABILITY OF BRINES ON PRESENT-DAY MARS .** V. F. Chevrier<sup>1</sup>, E. G. Rivera-Valentín<sup>2</sup>, A. Soto<sup>3</sup>, T. Altheide<sup>4</sup>, <sup>1</sup>Arkansas Center for Space and Planetary Sciences, University of Arkansas, Fayetteville, AR, 72701; <sup>2</sup>Lunar and Planetary Institute (USRA), Houston, TX; <sup>3</sup>Southwest Research Institute, Boulder, CO; <sup>4</sup>Eastern Kentucky University, Richmond, KY; [vchevrie@uark.edu](mailto:vchevrie@uark.edu).

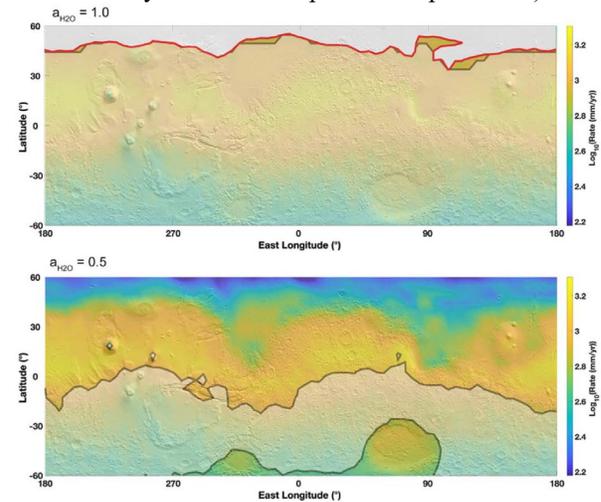
**Introduction:** The habitability of the surface of Mars depends on multiple factors, including, but not limited to, temperature, relative humidity, UV, and nutrients [1]. Of these parameters, temperature and relative humidity control the presence of liquid water, which is of primary astrobiological importance and has driven the exploration of Mars for the past two decades. Pure water is generally unstable on the surface of Mars, being subjected to freezing, evaporation and boiling (Fig. 1), but these processes are highly variable depending on the location and intrinsic properties of the liquid [2]. Indeed, the presence of abundant hydrated salts on the surface of Mars suggests the possible presence of brines [3,4], which present the advantage of stabilizing liquid water at lower temperatures [2,5]. Here we present results on the stability and formation of brines as a function of water activity on the surface of Mars, focusing on the processes that affect them: freezing, evaporation, boiling and deliquescence [6]. This study will help refine the regions of astrobiological interest or potential contamination risk, e.g., the “special regions” [1].

**Methods:** The stability maps presented in this study were determined by calculating the evaporation rate using our previously well-developed model of water diffusion modified by the buoyancy of H<sub>2</sub>O in heavier CO<sub>2</sub> [2]. This model is also adapted for highly concentrated solutions relevant to Mars, using the Pitzer model [2,5]. Moreover, the behavior of brines as a function of water activity allows comparing various salts on the same basis.

In addition, these maps are overlaid with the limits for boiling, e.g., where the saturation pressure of water overcomes the total atmospheric pressure. We also include permanent freezing, when the eutectic temperature is above the maximum yearly temperature. We used the Mars Weather Research and Forecasting (MarsWRF) general circulation model to simulate temperature and water mixing ratio (from which the atmospheric relative humidity is derived) at the surface on an hourly basis throughout a Martian year.

**Results and discussion:** We present three different maps in this abstract. The first maps (Fig. 1) are showing behaviors of freezing, boiling and evaporation for high water activity (pure water) and the lowest considered water activity (Ca-perchlorate for example). The second maps (Fig. 2) focus on total lifetime of brines on Mars, based on evaporation rates and a 10 μm thick layer of solution. Finally, the third maps (Fig. 3) show

maximum continuous stability over one Sol against all three processes (thus also including atmospheric relative humidity and when evaporation is prevented).



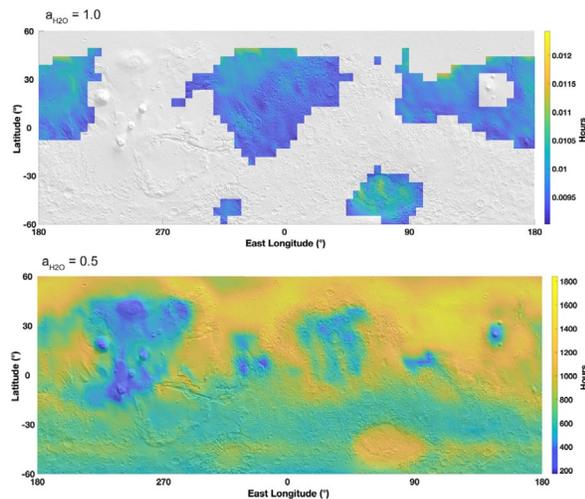
**Figure 1:** Stability map for pure water or poorly soluble salts (e.g., gypsum) on the surface (top,  $a_{\text{H}_2\text{O}} \sim 1$ ) compared to very low water activity  $a_{\text{H}_2\text{O}} = 0.5$  (bottom). Pure water is permanently frozen (grey zone bounded by the red line) or boiling (shadow area southern of the thick black line).

**Brines stability.** The first result is that pure water is never stable on the surface of Mars (Fig. 1). Not only does it undergo fast evaporation rates, but it also boils most of the time. Northern regions are permanently frozen, confirming previous observations by Phoenix. Brines with low water activity are never permanently frozen on the surface. Boiling will still occur in the southern latitudes except in large impact basins. Evaporation rates are relatively high but drop significantly at high latitudes.

These salty brines can nevertheless be stable in the subsurface because of their much lower eutectics. This allows them to remain permanently liquid in the low latitudes, but only for the lowest eutectics (CaCl<sub>2</sub>, Ca(ClO<sub>4</sub>)<sub>2</sub>, Mg(ClO<sub>4</sub>)<sub>2</sub>, Fe<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>). This happens because the subsurface temperature approaches the average annual surface temperature and is therefore much lower than the surface maximum temperatures. This is a tradeoff with the surface, brines are permanently stable at lower temperature but only for the lowest water activity values.

**Brines lifetime:** Brines exhibit a wide range of lifetimes on the surface depending on their water activity. This is not directly a result of the dependency of evap-

oration rates on water activity, which are not significantly different (e.g., Fig. 1), but rather on the fact that low water activity brines can stay liquid at much lower temperatures resulting in a much lower evaporation rate (which is exponentially dependent on water pressure). Thus, brines with high water activity are only stable for a few seconds in certain regions not bounded by freezing or boiling (Fig. 2). On the other side, brines with low water activity exhibit much longer total lifetimes, on the order of thousands of hours. Note, though, that this is an absolute time determined based on the average evaporation rate over a year. When reducing this to a diurnal cycle, brines with water activities below 0.6 can remain metastable over several hours per sol and even over an entire sol because of low evaporation rates. However, this does not represent the exact behavior of a brine over a diurnal cycle, where their stability might be limited by freezing at night or boiling during daytime.

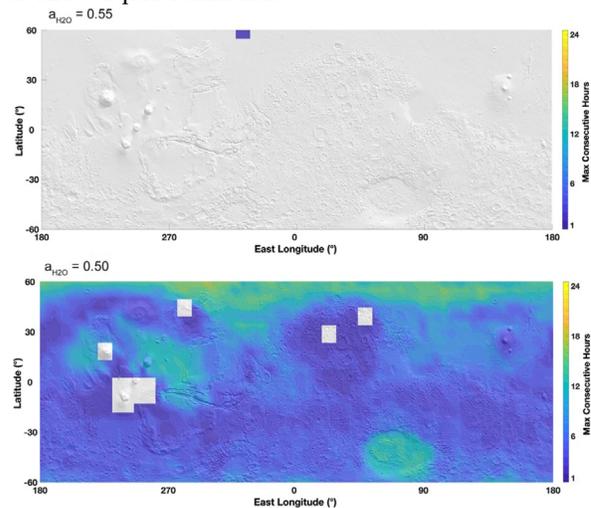


**Figure 2:** Map of brine lifetime at high water activity (top) and lowest water activity (bottom), based on average yearly evaporation rates. Grey zone indicates regions where brines are never metastable but either frozen or boiling.

**Diurnal behavior:** We also present maps of daily continuous stability against all processes (Fig. 3), which also includes when the brine is fully stable against evaporation (based on atmospheric relative humidity). Full stability is only possible for the lowest water activities (below 0.55) but increases very rapidly when the water activity gets close to 0.5. On most of the surface, brines can be stable at most for a few hours per sol (<6) and some specific regions up to 12 hours, such as in the Hellas basin and the high northern latitudes. However, nowhere on Mars are the conditions ever allowing brines to be fully stable over an entire sol (e.g. full 24 hours).

**Conclusions:** We find two globally distinct regimes for brine residence on Mars, depending on their overall

stability with respect to the processes investigated in this study. Above a water activity of 0.6 (sulfates, most chlorides), brines are highly unstable at the surface and subsurface, limited by fast evaporation and therefore unlikely to ever form in the current climate. On the other hand, below a water activity of 0.6 (some chlorides, chlorates and perchlorates of calcium and magnesium), brines are limited by occasional freezing and boiling, but are more stable on the surface and in the subsurface. In addition to exhibiting far lower evaporation rates (on the order of several sols or even weeks, but still bounded by freezing and boiling), we demonstrate that these brines can be consecutively stable for a significant part of the diurnal cycle. The regions most likely to see current brine activity are the high northern latitudes and deep impact basins. In the subsurface, these same brines would be stable in the equatorial regions, where the average temperature is high enough to allow liquid formation.



**Figure 3:** Map of brine continuous thermodynamic stability (against freezing, boiling and evaporation). Grey zone indicates regions where brines are never stable but either frozen, boiling or evaporating. Note that brines are never stable over an entire sol, but at most for about 12 hours.

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**References:** [1] Rummel J. D. et al. (2014) *Astrobiology* 14 (11), 887-968. [2] Chevrier V. F., T. S. Altheide (2008) *Geophysical Research Letters* 35 (L22101). [3] Chevrier V. F., E. G. Rivera-Valentin (2012) *Geophysical Research Letters* 39 (L21202). [4] Gough R. et al. (2019) *Icarus* 321, 1-13. [5] Chevrier V. et al. (2009) *Geophysical Research Letters* 36 (L10202). [6] Chevrier V. F. et al. (2020) *The Planetary Science Journal* 1 (3), 64.