

Liquid Water at Crater Gale, Mars

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Abstract

Suspicion that Mars could have transient liquid water on its surface through deliquescence of salts to form aqueous solutions or brines is an old proposal whose inquiry was boosted by Phoenix Lander observations. It provided some images of what were claimed to be brines, which presence at its landing site was compatible with the atmospheric parameters and the composition of the soil observed. On the other hand, the so-called Recurrent Slope Lineae (RSL) often imaged by orbiters, were considered as another clue pointing to the occurrence of the phenomenon, since it was thought that they might be caused by it. Now, Curiosity rover has performed the first in-situ multi-instrumental study on Mars' surface, having collected the most comprehensive environmental data set ever taken by means of their instruments Rover Environmental Monitoring Station (REMS), Dynamic Albedo of Neutrons (DAN), and Sample Analysis at Mars (SAM). REMS is providing continuous and accurate measurements of the relative humidity and surface and air temperatures among other parameters, and DAN and SAM provide the water content of the regolith and the atmosphere respectively. Analysis of these data has allowed to establish the existence of a present day active water cycle between the atmosphere and the regolith, that changes according to daily and seasonal cycles, and that is mediated by the presence of brines during certain periods of each and every day. Importantly, the study shows that the conditions for the occurrence of deliquescence are favourable even at equatorial latitudes where, at first, it was thought they were not due to the temperature and relative humidity conditions. This study provides new keys for the understanding of martian environment, and opens interesting lines of research and studies for future missions.

Keywords: Mars; Liquid water; Brines; Perchlorates; Deliquescence; Curiosity; Water cycle

Introduction

Mars is undoubtedly a dry world as compared with Earth. Nevertheless, some scientists have maintained since more than a decade ago that, under certain conditions, it is possible that there is some liquid water on the martian surface [1].

The key process for this to happen is an extreme case of hygroscopy known as deliquescence, a property of some substances, among which several salts such as perchlorates stand out, to absorb water vapour from the environment up to the point of forming a liquid solution or brine, provided that the necessary conditions of relative humidity, temperature, and pressure are fulfilled. The absorption of water vapour proceeds while the water pressure within the hydrated salt is below the water vapour pressure of the environment and, once the solution is formed, it will stay in a liquid phase while the temperature is above its eutectic temperature, which marks its freezing point, considerably lower than that of pure water.

These salts are present on Mars, having being detected for the first time by the Phoenix Lander and, in particular, they are calcium-, magnesium- and sodium- perchlorates. In fact, some of the images obtained by Phoenix soon after its landing pointed out the possibility of brines formation, at least at the landing point. In the images there could be seen some spherical depositions on the strut whose reflectance at different times was changing, and that were claimed to

be splatters of soil in which deliquescence had taken place among other things (it was as well suggested that they could be fuel droplets) [2,3]. However, the matter was left aside cautiously given that the humidity sensor mounted in the meteorological unit did not provide sufficient data to corroborate the deliquescence hypothesis.

Since then, it has been inferred that perchlorates must be ubiquitous on the martian regolith. The review of the earlier experiments performed by the Viking landers has postulated that these were compatible with the presence of perchlorates. Although the direct detection by orbiters, which could have confirmed the fact is difficult, the Gamma Ray Spectrometer on board Mars Odyssey has registered a widespread equivalent signal of the chloride anion (Cl⁻), which suggests they are common all over Martian surface [4,5]. Perchlorates are highly oxidized compounds of chlorine that are probably generated through photochemical reactions on atmospheric aerosols and spread as a part of global dust. In any case their origin is an interesting and open topic of research. Now, a study performed using three instruments on board the Curiosity rover of the Mars Science Laboratory (MSL) mission, have provided information to complete the scenario in which perchlorate brines can be formed. These instruments are the Rover Environmental Monitoring Station (REMS), the Dynamic Albedo of Neutrons (DAN), and the Sample Analysis at Mars (SAM).

REMS has taken measurements along nearly every sol since the arrival of Curiosity to Mars in August 2012. The measurements are taken during five minutes per hour plus between three and seven

daily-extended measurements of one hour, having acquired so far the most comprehensive collection of Mars *in situ* environmental data. It is basically a meteorological station that measures the air temperature, the pressure, and the atmospheric relative humidity (RH) (Figure 1), as well as the ground temperature (Tg) and the UV radiation that reach the surface with their corresponding sensors. All of them can measure autonomously and simultaneously throughout every martian day or sol (it is one of the few instruments on board Curiosity that can work continuously overnight), allowing a coherent and accurate interpretation of the processes that take place in the atmospheric boundary layer. Being mounted on a mobile platform as it is Curiosity, REMS can monitor the daily evolution of all the environmental parameters along the rover traverse. During the course of the mission, REMS data have permitted, after a thoughtful analytical work, to study novel boundary layer processes hard to characterize, like hydrostatic fluxes caused by the mismatch between air temperature and pressure variations, just to give an example [6-8].

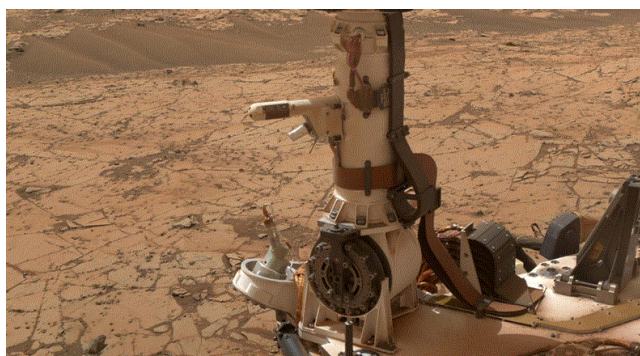


Figure 1: Image of REMS's boom 2 on Curiosity's Mast.

This boom includes one of the wind sensors (WS), the humidity sensor (HS) and one of the air temperature sensors (ATS) from top to bottom. The boom 1 which has the ground temperature sensor (GTS) and an extra ATS, is hidden behind the mast. The REMS UV sensor can also be seen on the rover deck.

Together with data gathered by DAN (an instrument designed to infer water within the ground up to a 60 cm depth by bombarding it with neutrons and analysing the way they are rebounded) and with SAM (a complex suite of instruments for chemical analysis that performs up to three different chemical procedures to identify and quantify different compounds in soil samples), it has been possible to discover a diurnal and seasonal water cycle at crater Gale that includes an active soil-atmosphere water exchange mediated by the presence of brines as described in Figure 2 [4,9].

Three reservoirs of water have been identified in the current Martian system: the polar caps, the regolith and the atmosphere (including clouds starting at heights of a few km's). The atmosphere is also the primary conduit of exchange between the other two reservoirs. The recent observations at Gale, near the equator, suggests that during night-time, when the temperatures drop and the RH increases, frost may be formed on the surface when saturation is reached. But in addition, for some intermediate RH values and because of the existence of salts such as perchlorates within the regolith, these salts get hydrated and eventually, if the temperature and water activity (i.e. RH/100) values are correct, they melt into a liquid brine.

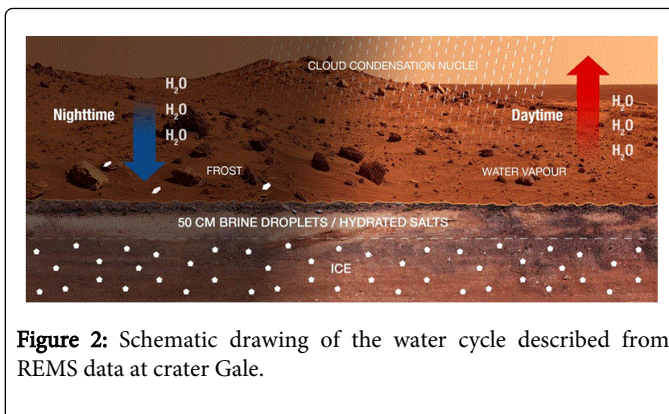


Figure 2: Schematic drawing of the water cycle described from REMS data at crater Gale.

The upper layer, which is exposed to the diurnal thermal wave, is involved in the daily water exchange with atmosphere. After sunrise, the temperature increases, and water vapour returns to the atmosphere. The deeper layer, whose temperature is slowly modulated through seasons in the seasonal thermal wave, allows for permanent hydration of salts in the regolith whose water content varies slowly along the year acting as a permanent water reservoir whose signal may be seen from above. In some Martian locations ice may exist at lower depths.

These data suggest that the values of temperature and relative humidity (at the martian pressures) allow the formation of perchlorate brines by absorption of atmospheric water vapour, and its stability in the liquid phase from sunset to dawn on the surface and within the uppermost 5 cm of the ground during the winter, (Figure 3). As for the rest of the seasons, brines could be as well present for shorter periods of the night. At sunrise, the increase of temperature causes the evaporation of the water that return to the atmosphere as vapour closing the cycle. But below 15 cm depth, conditions are more stable, so the hydration of perchlorates is permanent throughout the whole year. Therefore, it seems that there is a two-layer structure within the ground regarding water content: an upper layer involved in the water exchange with atmosphere, drier during the day and wetter at night, and a deeper, permanently hydrated layer, whose water content varies smoothly through seasons, as a combined analysis from REMS, DAN, and SAM data supports [10-12].

The shaded area marks the period in which these parameters are compatible with the formation of brines. The eutectic temperature of calcium perchlorate is indicated as reference.

On the other hand, REMS data have shown that, contrary to what was retrieved from orbiters observations and predicted by general circulation models, the conditions for deliquescence are favourable even on the equator, though for shorter periods of time during each sol than at higher latitudes.

All these results have been stated in a recent study published by Nature Geosciences magazine [13], which is based on the monitoring performed by REMS during one full martian year along the 9 km of rover traverse. It shows that the surface diurnal RH cycle is such that the water activity (a.w.=RH/100) varies from 0 during the day (at a maximal temperature between 255 and 285 K) to the RH and T points shown in Figure 4. The explored sites that are covered by sand have a lower thermal inertia, and thus are subject to larger thermal variations that in turn allow for higher nighttime values of surface RH. This large RH/T diurnal variation crosses several perchlorate phase-state

boundaries. Therefore, the environmental variation of RH/T within the ground through the different Ca-perchlorate hydration states (as well as other salts and mineral phases), should lead to an active soil-atmosphere water exchange process on diurnal and seasonal timescales.

Equatorial region that Curiosity is exploring. It is very plausible that the periods of transient liquid water will be different in local time and duration at different latitudes.

Habitability: The other factors

One of the main objectives of the MSL mission is to assess the habitability potential of the crater Gale, both past and present. Regarding the past, it is quite clear (not “sure” for a mere matter of scientific prudence) that Mars was a planet with plenty of water, which was in a liquid state under the cover of a thicker and more protective atmosphere some 3.5 billion years ago. There were oceans, lakes and rivers over the Martian surface which left their mark on it, as images from orbiters started to show when their cameras reached the appropriate resolution (Figure 5). In fact, one of the reasons why Curiosity was sent to crater Gale was that there were signs suggesting it used to be an ancient water basin, in application of the more basic leading criterion for any astrobiological research: “follow the water” [14].

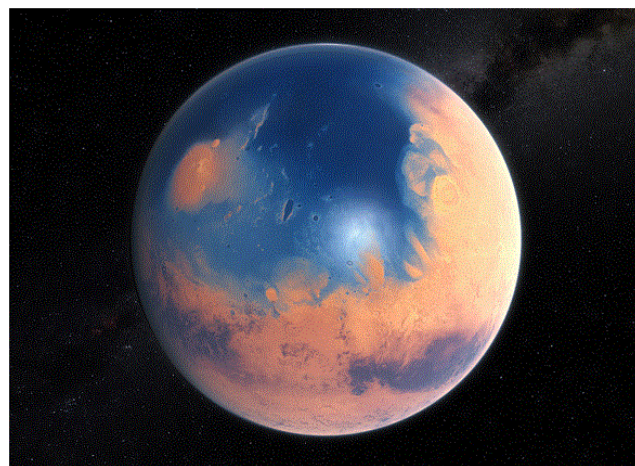


Figure 5: Artistic impression of the distribution of water over the surface of ancient Mars.

Curiosity’s observations have confirmed this in several ways, some of them as simple (though not less consistent than any other) as the presence of rounded stones, already observed by earlier probes; a rock only can be shaped spherically within a constant flow of water, provided the reckoned and very likely conditions of ancient Mars. CheMin (Chemistry and Mineralogy), a Curiosity’s instrument designed to identify minerals, has found some of them which could be formed only in the presence of water (i.e. hematite), and the scientific cameras of the rover have imaged sedimentary structures that, again, are known to be typical of a long process of deposition on the bottom of a bulk of water.

As for the present, the existence of liquid water on Mars is considered a factor of the major importance in order to accomplish successfully the goal of assessing the habitability Mars could offers. In this sense, the aforementioned study concludes that, on the surface, neither the strong UV, nor the ionizing radiation received, nor the low temperatures would allow the viability (understood as survival, metabolism and reproduction) of presently known terrestrial-like organisms. Even within the upper 15 centimetres below the surface,

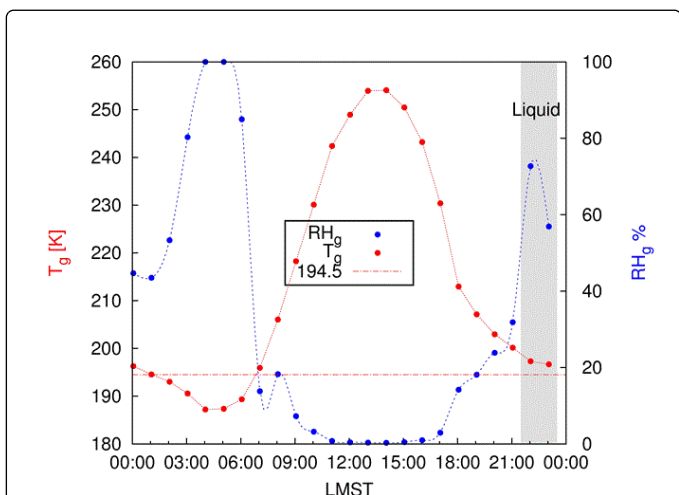


Figure 3: Daily evolution of the ground temperature (T_g) and ground relative humidity (Rh_g) as observed by REMS at Gale crater.

The nighttime surface temperatures are so low that the humidity at the surface can even reach saturation (100%). At these conditions frost may form at the surface for a few hours a day. The frost point temperatures are indicated in Figure 4.

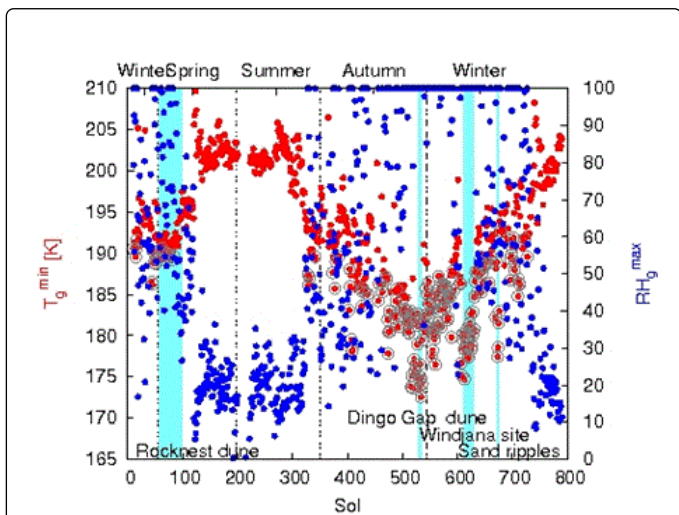


Figure 4: Seasonal evolution of relative humidity and temperature of the ground.

The range of temperatures and RH values when perchlorate brines are transiently stable takes place at intermediate RH values and slightly warmer temperatures: for calcium perchlorate above the eutectic temperature of $T_e=194.5$ K and the eutectic a.w. of 0.52 (52% RH). Of course, the results described in ref. [13] are those inferred for the

where radiation cannot penetrate, the temperatures at which transient liquid water can be found are below the minimum tolerated by the most cold-resistant microbes. Nevertheless, it is necessary to add that, according to recent studies based on analysis performed by Sample Analysis at Mars (SAM) instrument suite, Martian ground contains indigenous organic compounds, both aromatic and aliphatic [15], as well as fixed forms of nitrogen, probably as a component of nitrates, that are biochemically useful [16]. These compounds have been detected in drilled samples of the upper most 5 cm of the Martian regolith. So, together with the transient presence of liquid water and from a chemical point of view life, as we know it, may have access to the elements it needs for its maintenance. Despite the fact that physical properties of the environment would constrain the survival of any organism, the presence of liquid water imposes the caution to redefine the so-called Special Regions on Mars to avoid any sort of biological contamination with terrestrial organism that unavoidably will travel there in the future [17].

Whereas it is highly likely that Mars was very similar to the Earth at the times when life arose in our planet and therefore as habitable as it was, the matter of the present habitability has just started to be discerned and the question of whether life arose there as well or not, or even if it is present right now, is impossible to answer conclusively at this point of the exploration. A recent commentary in *Nature Geoscience* [18] argues that Earth life has most likely already been transferred naturally to Mars. Life has been present on Earth for at least 3.8 billion years, and the authors postulate that there has been plenty of time for the transfer process to occur naturally through impact events. Starting from the premise that Earth life must have been transferred naturally to Mars before, it may have survived on Mars during earlier, wetter times.

Furthermore, one of the most intriguing of Curiosity's analysis somehow related to the habitability has been the detection of methane in the atmosphere or, to be more precise, the unexpected and mysterious behaviour of the methane found. Methane had been detected, not without controversy, several times before by ground based telescopes and orbiters, and its behaviour was already similar to that registered by Curiosity by means of the Tunable Laser Spectrometer (TLS, one of SAM's components) in this case. After measuring increases in its atmospheric concentration, it disappeared leaving no trace. It was precisely this sudden disappearance that cast doubt upon the earlier measurements given that, according to our current understanding of photochemistry and dynamics of the martian atmosphere, methane, once in the atmosphere, should stay there for an average period of 300 years, spreading homogeneously during that time [19].

Since more than 90 % of the methane in the atmosphere on Earth has a biological origin, it is problematic to explain where the amount of Martian methane come from, and it is even a bigger conundrum to identify the sink processes by which it disappears in weeks or months instead of in hundreds of years.

Implications

Besides the central matter of the habitability assessment, the presence of transient liquid water on Mars suggests an explanation for a phenomenon that was not satisfactorily explained, namely the Recurrent Slope Lineae (RSL). These are the effects of loose materials landslides widely registered on several topographic structures. They use to be attributed to the sublimation of CO₂ ice within those materials, which would lose support falling downslope. But the

freezing of CO₂ is not possible near the equator, so at least the RSL's observed all around the equatorial latitudes are probably due to phase state changes of salts through brine state. As it has been explained above, the in-situ observations provided by MSL show that surface covered by sand or loose fine grained material are subject to larger RH/T variation and thus are prone to cross several phase state changes of salts. These changes may easily trigger downslope drainages of fine-grained loose material [20], (Figure 6).

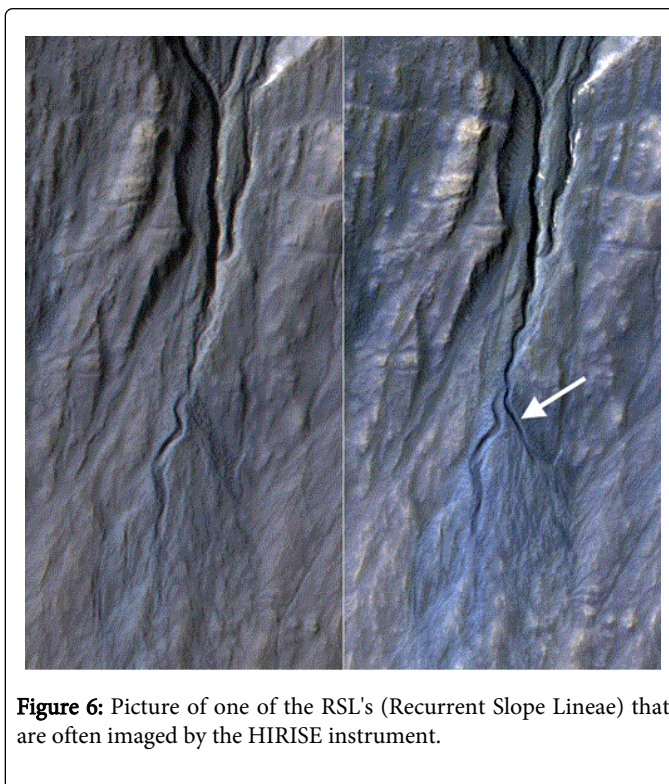


Figure 6: Picture of one of the RSL's (Recurrent Slope Lineae) that are often imaged by the HIRISE instrument.

These lineal features appear on slopes, and grow with seasonal dependency. Those observed at equatorial latitudes could be caused by phase state changes of brines within the regolith.

Another phenomenon that can be explained through the formation of perchlorate brines (and that, at the same time can be a clue to support their daily presence at crater Gale) is the severe damage suffered by Curiosity's wheels [13]. Soon after its landing, disturbing cracks started to appear on some of them, what was surprising for more, given that the design was similar to that of the Mars Exploration Rovers (MER's, Spirit and Opportunity), which never showed such a wear and tear when standing the same mean pressure (i.e. platform weight over wheel area in contact with a flat terrain). It has been pointed out that, maybe the daily contact of the wheels with the corrosive perchlorate solutions during every night have weakened the scratched surface of the anodized aluminium, making much easier its further damage against sharp rocks, (Figure 7).

For all the aforementioned, the "discovery" of liquid water on Mars surface will have to be studied carefully in the immediate future with the implementation of specific research. It is important to remark that what has been monitored is not the formation of brines themselves, but the conditions in which the formation of brines should take place. Brine formation should be detected by measuring changes in the conductivity (or resistivity) of the regolith. This method has been very

recently used to discover the unexpected existence of subsurface brines in the Antarctic dry valleys (an Earth analogue for Mars) [21].

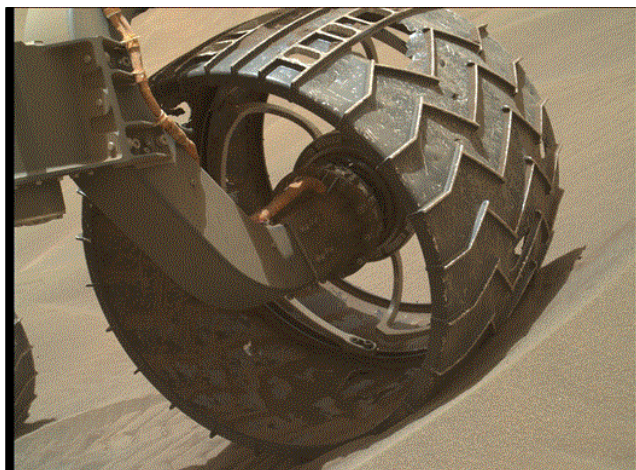


Figure 7: Curiosity's wheels showing signs of severe damage after almost 10 km of traverse.

Besides the fact that the accurate characterization of this feature of the Mars environment will lead to a better knowledge of the Red Planet dynamics, it will be mandatory to count on the possibility of “*In Situ* Resources Utilization” (ISRU) for the foreseen manned mission to Mars in the mid-term, so it is extremely important to go into depth in the phenomenon, since the availability of water could be useful to obtain a reliable supply of indispensable substances (water itself, oxygen, fuel...). Hopefully, some of the next missions to Mars yet scheduled will carry an instrument designed to make measurements that will allow ascertaining conclusively the process as well as to obtain accurate values of the relevant parameters involved.

Habitability will keep on being a main research line with no doubt, and maybe from the evidence of liquid water eventually confirmed, the direct search for past and present life on Mars will be addressed. However, when these new missions are sent, it is likely that Curiosity will be yet climbing Mount Sharp in the middle of crater Gale driven by its Radioisotope Thermoelectric Generator (RTG), the power source that feeds all its instruments and engines, which will be working during some 50 years more.

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