Experimental modeling of subsurface gas traps on Mars

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Abstract. Methane seasonal variation observable by MSL mission and possible variations of atmospheric mass on timescale (10⁵-10⁶ years) are among the most intriguing problems in Mars exploration. These variations are connected with hypothetical biosphere activity in the subsurface Martian soil and existence of liquid water on the Martian surface within modern era. Stability of liquid water on surface request higher atmospheric pressure in comparing to modern value. CO₂ can not loss with known mechanisms of atmospheric escape. Therefore, the main part of necessary CO₂ must be buried in upper layers of the Martian soil. Local and seasonal time variable sources and fast methane destruction are needed to explain high seasonal variations of methane concentration in air at the Martian surface. Gas reservoirs, containing biogenic or abiogenic methane could be possible seasonal sources of methane as well. In this work we experimental study stability of the gas reservoirs covered of mixture of regolith and water ice with perchlorates. Thickness of covered regolith layer was about 10mm. In experimental runs we increased a temperature of gas traps and monitored a possible diffusion of gases through the isolated layer with mass spectrometer. The gas traps stay stable at gas pressure up to 1 bar. We did not discover any diffusion process before mechanical destruction of reservoirs at gas pressure over 1 bar. In this work we show that the big subsurface gas reservoirs can exist for a long time before cracking due to slow process of the water ice sublimation by climate and seasonal variation of subsurface temperature.

1. Introduction

The question about life possibility or traces of the existence of life in the past is one of the most discussed questions in Mars exploration. This question connects with atmosphere exploration. On the one hand, liquid water is not stable on the surface of Mars at modern atmospheric pressure. On the other hand, liquid water can exist in shallow subsurface reservoirs in modern Mars. It is known that liquid water probably existed on the surface in the past (billion years and less) [1].

Therefore, the questions about the high-density atmosphere existence in the near past and mechanisms of atmosphere loss are widely discussed today. The atmosphere's composition of terrestrial planet is similar. So the minimal quantity of outgassing CO₂ on Mars is estimated 0.5-1 bar. Martian isotope ratio of ¹²C/¹³C is comparable to Earth, so the loss of CO₂ by atmospheric escape process should be minimal because it leads to strong enrichment of ¹³C/¹²C ratio. Therefore, the main part of the outgassing CO₂ must be buried on the planet.

Carbon dioxide is able to form carbonates at presence of liquid water, but only the small quantity of carbonates were discovered on Mars till now. There is another way to bury a big mass of carbon
dioxide by adsorption into regolith. Adsorption of atmospheric CO$_2$ in high latitude regions is possible during low obliquity periods. The following slow process of water vapor transport to “cold traps” could create the water ice crust covering absorbed CO$_2$ ice. It leads to the formation of gas subsurface reservoirs. Massive CO$_2$ ice deposits were discovered in the South Polar Layered Deposits of Mars at depth more than hundreds of meters [2]. Moreover, they are comparable with the present mass of the Martian atmosphere. However, a temperature at these depths is stable against [3] the seasonal and longtime (about 120 000 years) surface temperature variations. Therefore, gas reservoirs in shallow subsurface layers are more interesting because they are subjected to the longtime and seasonal temperature variation.

Methane concentrations changing in the Martian atmosphere are both at decade timescale [4] and during several months [5, 6]. Local and seasonal time variable sources and fast methane destruction are needed to explain high seasonal variations of methane concentration in air at the Martian surface. 15th and 16th of June 2013 methane spike are registered near Gale Crater with two independent methods [7, 6]. Methane concentration in this region increased to 15 ppbv. Shallow gas reservoirs, containing biogenic or abiogenic methane, could be possible seasonal sources of methane as well.

In this work we experimental study stability of the CH$_4$ and CO$_2$ reservoirs covered of mixture of regolith and water ice with perchlorates. We also estimate regions of gas traps stability and regions where these gas traps could be destructed with seasonal temperature variations. We show that gas traps destruction has a threshold mechanism.

2. Experimental facilities

2.1. Experimental facility for looking for microseepage

Figure 1 shows experimental facility for exploration of gas diffusion through traps. Sample (2) was connected to buffer chamber (3) with pressure sensor and two tubes with valves: one for pumping out, another for studied gas inlet.

At the beginning tube from buffer chamber to sample and tube to gas inlet were locked. Then, the chamber was pumped out. Studied gas through inlet tube was pumped in chamber to necessary pressure. Then all chamber inputs were closed and output to sample was being opened. The sample surface was purged with nitrogen vapours. Its entered to membrane input of mass-spectrometer. In case of gas diffusion through ice regolith signal on mass-spectrometer is more than background. The sample was cooled with dry ice (1). We increase the pressure in experiments run until the mass-spectrometer signal was being appeared.

2.2. Laboratory modeling gas trap formation

Special facility was developed for laboratory modeling of gas trap formations (see figure 2). Brass tube has special radial protrusion. Dry ice cylinder (diameter 10mm and thickness 2mm) was set on this protrusion. Bottom of the tube was cooled by liquid nitrogen. Then model regolith was poured
into the tube. The thermocouple was set into regolith. Then the regolith was filled the perchlorate solution. We terminated the cooling after the solution have been frozen. Then we were waiting until the dry ice completely evaporate. On next step the tube has been inserted into thermostat with dry ice and has been connected to the facility for looking for microseepage.

We used two methods for freezing regolith. In the first method bottom of the tube was opened and dry ice evaporate directly to atmosphere. In the second method bottom of the tube was closed and dry ice evaporate through regolith.

2.3. Mass-spectrometer
In this work for methane detection we used experimental static mass-spectrometer with double focusing development by Ioffe Institute. Its ion optical scheme was described in work [10]. This mass spectrometer has dual membrane inlet system, which was described in work [11]. Ion source of mass-spectrometer use electron ionization [12]. Mass resolution of mass spectrometer is equal to 250, range of measured mass from 12 up to 300 a.m.u.

We measured a calibration line for methane concentration calculation. Air-methane has mix with volume methane fractions: 100 ppm, 1000 ppm, 10000 ppm and 100000 ppm. The methane counts were normalized by argon counts. Figure 3 shows calibration curve.

Error of methane fraction detection was being less than 7%. Methane was been detecting by ion m/z = 15 a.m.u. Limit of methane detection was being 55 ppmv.

2.4. Regolith
We used three types regolith in experimental runs: frozen water solution of NaClO₄, frozen water solution of NaClO₄ with SiO₂ and frozen water solution of NaClO₄ with JPL martian regolith analog (SiO₂, Fe₂O₃, Al₂O₃, CaO, MgO, SO₃, Na₂O, P₂O₅, TiO₂, K₂O, MnO, Cr₂O₃).

In all experiments, we used the saturated water solution of perchlorate (2.09g NaClO₄ on 1g H₂O).

3. Results
On figures 4,5 coevolution of temperature, gas concentration outside the gas trap and excess of atmospheric pressure in gas trap are presented for experimental runs with CH₄ and CO₂.
Figure 4. Time diagram for experiment with 3mm thickness regolith sample (methodic 1). Curve 1 — changes concentration CH\textsubscript{4} over time. Curve 2 — is different between the facility and atmospheric pressures. Curve 3 — is the temperature of the sample model regolith.

Figure 5. Time diagram for experiment with 10mm thickness regolith sample (methodic 2). Curve 1 — changes concentration CO\textsubscript{2} over time. Curve 2 — is different between the facility and atmospheric pressures. Curve 3 — is the temperature of the sample model regolith.

4. Discussions

Figure 4 and 5 shows time diagram for experiments with SiO\textsubscript{2} sample with thickness 3mm and 10mm (created by method 1 and method 2). It's clear that diffusion was not observed till the moment of gas trap destruction.

We see that even slims regolith layers can hold high pressure. Liquid water can exist in these traps.

We measured the sublimation speed of model regolith in depend on temperature for computing the stable of the studied gas traps (see figure 6). According to measured Mars regolith temperature oscillations [3] we computed a map of the gas traps stability with 1 bar overpressure (see figure 7).

Although the liquid water on the Martian surface cannot stable exist nowadays, the pressure in gas traps can be enough for liquid regions existence. Environments in these regions can be comfortable for methanogens existence. In this case, the CO\textsubscript{2} can create the necessary pressure for trap destruction with temperature increases. Then we can see this trap destruction as local methane release.

Figure 6. Loss time 1mm ice from Martian surface in depend of surface temperature for different perchlorate water solutions concentrations.
Figure 7. Lifetime gas traps at a depth 10, 30 and 100 cm on modern Mars for regolith with saturated perchlorate water solution.

5. Conclusion

In this way, we show the possibility of gas traps existences. Their destruction can be a spontaneous source of methane and explain the fast atmospheric methane variations.

We showed the stability of shallow gas traps on a large time scale (more 100000 years).

We also demonstrated the possible existence of the shallow underground environments with high atmospheric pressure and liquid.

References

[1] Boynton W V 2007 Journal of Geophysical Research Planets 112 E12S99
[2] Roger J Phillips 2011 Science 332 838
[3] Michael T Mellon, William C Feldman and Thomas H Prettyman 2004 Icarus 169 324-40
[4] Formisano V, Atreya S, Encrenaz T, Ignatiev N and Giuranna M 2004 Science 306 1758–61
[5] Yuk L Yung 2018 Astrobiology 18 10
[6] Christofer R Webster 2018 Science 360 1093-6
[7] Marco Giuranna 2019 Nature Geoscience 12 326-32
[8] Wilson J T 2018 Icarus 299 148-60
[9] Jakosky B M 2017 Science 355 1408-10
[10] Kogan V T 2015 Technical Physics 60(10) 1549-55
[11] Kogan V T 2013 Technical Physics 56(5) 597-601
[12] Kogan V T 2009 Technical Physics 54(11) 1714-20