



# The long term carbon cycle on Mars

Eric Chassefière, François Leblanc

## ► To cite this version:

Eric Chassefière, François Leblanc. The long term carbon cycle on Mars. EPSC-DPS Joint Meeting 2011, Oct 2011, Nantes, France. hal-00610344

**HAL Id: hal-00610344**

**<https://hal.science/hal-00610344>**

Submitted on 16 May 2019

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

## The long-term carbon cycle on Mars

E. Chassefière (1,2) and F. Leblanc (3)

(1) Univ Paris-Sud, Laboratoire IDES, UMR8148, Université Paris-Sud, Bât. 504, Orsay, F-91405, France, (2) CNRS, Orsay, F-91405, France, (3) Laboratoire ATmosphères Milieux Observations Spatiales/IPSL, CNRS-UVSQ, Université Pierre et Marie Curie, Boite 102, 4 Place Jussieu, 75005, Paris, France (eric.chassefiere@u-psud.fr / Fax: + 33 1 69 15 49 11)

### Abstract

It has been recently shown that several valley networks, like Naktong Vallis [1], have been formed during the Hesperian, 3.6-3.7 Gyr ago. According to the same authors, liquid water could have flowed at the surface of Mars until the early Amazonian, 3.1-3.2 Gyr ago. To explain such a residual hydrological activity, a minimum CO<sub>2</sub> pressure of 0.6 bar seems to be required. At this pressure level, the scattering of infrared radiation by CO<sub>2</sub> clouds could have maintained a global temperature above 0°C [2]. It is generally assumed that a CO<sub>2</sub> pressure of at least 1-2 bar is required to maintain water liquid at the surface of Mars during the formation of valley networks.

If 1-2 bar of CO<sub>2</sub> have been present in the Martian atmosphere until the early Amazonian, 3 Gyr ago, where did this CO<sub>2</sub> go? It may not have escaped mainly because during this period non-thermal escape processes were no more efficient [3]. To explain the persistence of a dense CO<sub>2</sub> atmosphere during the whole Noachian, when water was liquid at the surface of Mars and should have formed massive carbonate layers, it has been suggested that carbonates were recycled to the atmosphere due to thermal decomposition of carbonate rocks induced directly and indirectly (through burial) by intense, global scale volcanism [4]. The quantity of CO<sub>2</sub> released by volcanism since the middle-Noachian has been estimated to correspond to a CO<sub>2</sub> global pressure of 400 mbar [5], which one third (150 mbar) would have been emitted during the Amazonian. Whatever is the origin of this CO<sub>2</sub> (crustal carbonates, mantle), it has been necessarily lost to the crust, since escape is unable to have removed more than a few mbar.

The recent discovery of methane in the Martian atmosphere [6,7], with a significant estimated release rate, suggests that the carbon inventory of the atmosphere could double in a few tens million years [8]. Thus methane could be an important source of atmospheric CO<sub>2</sub> over time and adding to the amounts thought to have been released by surface

volcanism [5]. If this methane is the result of serpentinization in crustal hydrothermal systems, the carbon in the released methane could originate from subsurface carbonates that were decomposed by hydrothermal fluids.

We provide an estimate of the integrated flux of methane to the atmosphere since the late Noachian and show that it could be substantial, of the same order as the volcanic flux of carbon (a few hundred millibars). For this purpose, we assume that the hydrothermal activity has remained proportional to the extrusion rate of volcanic lava, estimated from existing geomorphological analysis of the Martian surface [5]. Because CO<sub>2</sub> is more than 100 times less abundant in the present atmosphere than if volcanic and hydrothermal carbon would have accumulated since the late Noachian, we suggest that atmospheric carbon is recycled to the crust through subsurface hydrological activity. In this way, the production of CO<sub>2</sub> through CH<sub>4</sub> release, and the removal of CO<sub>2</sub> from the atmosphere, could have a common origin and be two facets of a currently, although progressively damping with time, active hydrological system.

We propose a typical scenario for the CO<sub>2</sub> pressure evolution since the late Noachian (Fig. 1) assuming a progressive sequestration of carbon, cycled to the crust, then transported by crustal liquid water and deposited under the form of carbonates within the crust (Fig. 2). These carbonates may be decomposed from time to time due to episodic magmatic activity and recycled to the atmosphere under the form of CO<sub>2</sub> by volcanism and/or CH<sub>4</sub> through the reaction of CO<sub>2</sub> with H<sub>2</sub> formed by serpentinization in deep hydrothermal systems. From geochemical modelling, it has been suggested that an extensive reservoir of carbonate minerals, equivalent to an atmospheric pressure of carbon dioxide of at least one bar, could have been sequestered beneath the surface by widespread hydrothermal activity in the Martian past [9]. The present work reinforces this idea, and provides a CO<sub>2</sub> evolutionary path accounting for both (modest) escape to space and storing in carbonates.

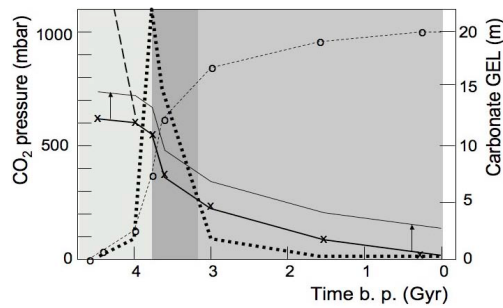


Figure 1 : (i) Evolution with time of the atmospheric CO<sub>2</sub> pressure, assuming the amount of CO<sub>2</sub> adsorbed in the regolith today is negligible (crosses, solid line), with an indication of the effect of impact erosion before 4 Gyr b.p. (dashed segment), (ii) same by adding the equivalent of 140 mbar adsorbed in the present regolith (thin solid line), (iii) evolution of the carbonate content of the crust, in units of a global equivalent layer of carbonate (right vertical scale) (dotted line with circle). The thick dotted line represents the hydrothermal flux of H<sub>2</sub>, as scaled on volcanic extrusion rates, in arbitrary units. The period in light grey (Noachian), with low hydrothermal activity, is dominated by CO<sub>2</sub> escape. The major sink during the period in dark grey (Hesperian) becomes carbonate formation, by contrast with the Noachian. The transition from the period in dark grey to the period in middle grey ( $\approx 3.2$  Gyr b. p.) corresponds to the very end of Hesperian valley network formation [1].

Our hypothesis that large amounts of carbon released by volcanism and hydrothermalism are sequestered in the crust under the form of carbonates is self-consistent. First, it provides a general CO<sub>2</sub> pressure evolution curve (Fig. 1) in good agreement with our view of Mars evolution, with the disappearance of liquid water at the end of the Hesperian or even early Amazonian,  $\sim 3$  Gyr ago. Second, it allows to explain that most of the carbon released to the atmosphere has been converted back to crustal carbonates (Fig. 2). Third, carbonates are a plausible source of the carbon involved in the formation of CH<sub>4</sub>, which seems more likely than a mantellic source, which cannot be excluded, but should be less effective because serpentinization may occur at relatively low temperatures, more representative of the global thermal state of the

Martian crust. Contrary to the steady state carbon cycle at work on Earth, a progressive damping of the carbon cycle has occurred on Mars due to the absence of plate tectonics and the progressive cooling of the planet.

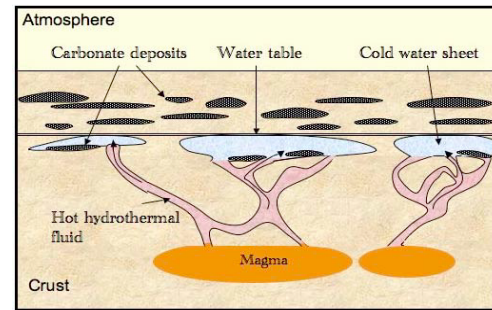


Figure 2 : Schematic view of carbonate precipitation through mixing of hot hydrothermal fluids and cold water in subsurface water sheets in the course of the shrinking of the water table.

## References

- [1] Bouley, S., Ansan, V., Mangold, N., Masson, Ph., Neukum, G., 2009. Fluvial morphology of Naktong Vallis, Mars: A late activity with multiple processes, *Planet. Space Sci.* 57, 8-9, 982-999.
- [2] Forget, F., Pierrehumbert, R.T. 1997. Warming early Mars with carbon dioxide clouds that scatter infrared radiation. *Science* 278, 1273-1276.
- [3] Chassefière E., Leblanc, F. 2010b. Methane release and the carbon cycle on Mars, *Planet. Space Sci.* 59, 207-217.
- [4] Pollack, J.B., Kasting, J.F., Richardson, F.M., Poliakoff, K., 1987. The Case for a Wet, Warm Climate on Early Earth, *Icarus* 71, 203-224.
- [5] Craddock, R.A., Greeley, R., 2009. Minimum estimates of the amount and timing of gases released into the Martian atmosphere from volcanic eruptions, *Icarus*, 204, 512-526.
- [6] Formisano, V., Atreya, S., Encrenaz, T., Ignatiev, N., Giuranna, M., 2004. Detection of methane in the atmosphere of Mars, *Science* 306, 1758-1761.
- [7] Mumma, M. J., Villanueva, G. L., Novak, R. E., Hewagama, T., Bonev, B. P., DiSanti, M. A., Mandell, A. M., Smith, D. M., 2009. Strong Release of Methane on Mars in Northern Summer 2003, *Science* 323, 1041-1045.
- [8] Chassefière, E., 2009. Metastable methane clathrate particles as a source of methane to the Martian atmosphere, *Icarus* 204, 137-144.
- [9] Griffith, L.L., Shock, E.L., 1995. A geochemical model for the formation of hydrothermal carbonates on Mars, *Nature* 377, 406-408.