DID MARTIAN ORGANIC DEPOSITS FORM THROUGH CATALYTIC REACTIONS IN A HYDROTHERMAL ENVIRONMENT THAT WAS SUBJECTED TO AN INTENSE METEORITE FLUX?

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Introduction: The exploration of Mars keeps providing surprises that reaffirm the astrobiological interest of studying the red planet, and the need of future manned exploration. Recent evidence of organic matter preserved in 3 Gyr-old mudstones at Gale crater raises new questions about the chemistry at work in a very different early Martian environment [1].

Given the importance of this discovery of organic deposits, we want to put it in context of three important processes at work in early Mars. First of all, there is growing evidence for an Archaean heavy bombardment produced by destabilization of the asteroid belt, and producing a remarkable increase in the flux of chondritic materials to the terrestrial planets [2-4]. The relevance of the LHB at the red planet has been also confirmed from the study of Martian craters [5]. These authors found about one hundred craters larger than 150 km in the ancient southern highlands that are early to mid-Noachian in age. They cover 40-50% of Mars and give an idea of the magnitude of the projectile flux for large objects, but they could be not more than the tip of the iceberg if we consider much smaller projectiles.

Secondly, there is a very significant body of evidence for a dense Martian atmosphere during the Noachian period [5]. Third, there is growing evidence for the extensive presence of water in Mars' surface and subsurface at different epochs. For example, clear evidence for Amazonian acidic liquid water on Mars surface has been found, producing aqueous alteration minerals [6].

And finally, it is important to realize that a dense atmosphere associated with volcanic outgassing during the Noachian period could have promoted significant deceleration, but also disruption of fragile chondritic asteroids. In such circunstances the arrival of meteorite powders could be also a way to promote catalytic reactions at Mars' surface. In other words, Mars during the Noachian was probably subjected to a continuous rain of chondritic materials that arrived at a time in which significant hydrothermal activity was at work. Under these circumnstances we have heat, water and probably N-bearing species that could be promoting the catalytic reactions found to increase chemical complexity [7-8].

The parent bodies of chondrites were highly porous and retained significant amounts of water, organics and volatile compounds, available in the outer disk formation regions. Small asteroids and comets are formed by these primordial materials, and at the very beginning were subjected to planetary perturbations and fragmentations during close approaches to planets so probably were easily disrupted [8-9]. We have estimated that the early Earth was subjected to a meteoritic flux that could have well been at least 5-6 orders of magnitude the at present [4]. If that hypothesis is correct, huge amounts of chondritic materials could have reached the surfaces of the Earth and the rest of the terrestrial planets at an annual rate of thousands of billions of metric tons [4]. Consequently, the amount of volatiles delivered under such high-flux circumstances are also very significant, and probably playing a key role in fertilizing the Earth's surface [4,7,8]. Then, we think that the reactive minerals forming undifferentiated meteorites could have rained over the surface of Mars and the other terrestrial planets [8]. These minerals being exposed to a warm, and water-rich environment could have promoted catalytic reactions promoting subsequent organic complexity, then producing over time the first steps towards the origin of life on Earth and Mars (Fig. 1) [6-7].

Figure 1. A hydrothermal environment with presence of water and heat, under the continuous arrival of chondritic materials in early Earth and Mars, could have promoted catalytic reactions increasing organic complexity in both planetary surfaces. From a J. Trigo Campoy watercolor.

Discussion: We have considered a simplified scenario that could explain the origin of organic deposits found in Mars' surface [1]. The real scenario could be more complex and probably had a key contribution of volcanic activity in the specific atmospheric and sur-face environment during the Noachian, Hesperian and even Amazonian periods [2,11]. It has been modelled that the surface waters of Mars maintained acidity because of a drop in temperature, and it favored the dissolution of atmospheric CO and a subsequent at-mospheric pressure decrease [2]. There is additional evidence that the Martian elemental C/N/^{36}Ar ratios, and the volatile elements retained may be consequence of the arrival of undifferentiated bodies towards the end of the Noachian era [see e.g. 12].

Our early-Mars wet scenario probably also provides an explanation for the evidence of aqueous fluids and precipitation of carbonates in the subsurface of Mars, and could explain the different precipitation stages found in ALH84001 carbonates [13].

Now that an international team of scientists is involved in the MSR Science Planning Group (MSPG), they need to plan requirements for the handling and return of Martian samples because our planet deserves all our efforts to guarantee planetary protection (PP) from potential Martian living organisms. In such a con-text the possible appearance of life forms should be contemplated.

Conclusions: The discovery, and further study of organic deposits in ancient Mars terrains could provide clues to several important processes at work in early Mars. In particular, the Archaean heavy bombardment period marked by the destabilization of the asteroid belt, could have produced a remarkable increase in the flux of chondritic materials over ancient Mars. At that point we envision a Mars surface at least partially cov-ered by water, with possible hydrothermal environ-ments at work. In such circumstances, and given the catalytic reactions discovered to be promoted by the minerals forming the chondritic meteorites [7,8], we predict a significant increase in chemical complexity. If we are correct, the chain of complex organic reactions occurred in early Mars could have only be truncated by a more unstable climatic environment, probably subjected to massive volcanic outgassing [2], in the red planet. On the contrary, a major stability in Earth could have provided a niche for the evolution of life [14].

In view of all this new evidence, we beleive that a sample-return mission could provide extremely valuable samples from some of these preserved Noachian/Hesperian regions. And obviously, future manned exploration missions could provide a way to study such primordial environments in detail, and put them in context to answer significant questions from an astrobiological point of view. Among these key questions: 1) Was Mars' surface able to catalyze complex organics during long enough periods of time to increase complexity to the level required to allow the appearance of simple life forms? 2) Could Mars' organic deposits be hiding evidence of such primordial life?

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References: [1] Eigenbrode J.L. et al. (2018) *Science* 360, 1096-1101. [2] Bottke W.F. et al. (1998) *Nature* 485:78-81 [3] Bottke W.F. and Norman M.D. (2017) Ann. Rev. Earth Planet. Sci. 45, 619-647. [4] Trigo-Rodríguez J.M., Llorca, J. and Oró, J. (2004) In Life in the Universe: from the Miller experiment to the search for life in other worlds. Seckbach J., Chela-Flores J., Owen T. y Raulin F. (eds), Kluwer Publishers, Dordrecht, Holland, pp. 201-204. [5] Bottke W.F. et al. (2017) 48th LPSC, LPI Contrib. No. 1964, id.2572. [6] Fernández-Remolar D.C. et al. (2011) MAPS 46, 1447-1469. [7] Rotelli L. et al. (2016) Scientif. Rep. 6, doi:10.1038/srep38888. [8] Trigo-Rodríguez J.M. (2017) 48th LPSC, LPI Contribution No. 1964, id.1161. [9] Trigo-Rodríguez J.M. (2015) In Planetary Mineralogy, EMU Notes in Mineralogy 15 pp. 67-87. [10] Trigo-Rodríguez J.M. and J. Blum (2009) Planet. Space Sci. 57, 243-249. [11] González-Fairén A. et al. (2009) Planet. Space Sci. 57, 276-287. [12] Marty B. et al. (2016) Earth and Planet. Sci. Lett. 441, 91-102. [13] Moyano-Cambero C.E. et al., (2017) MAPS 52, 1030-1047. [14] Schulze-Makuch D. and L.N. Irwin (2008) Life in the Universe. Springer-Verlag Berlin, Heidelberg, 251 pp.