Exobiology: Martian environmental conditions.

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ABSTRACT

In view of the renewed speculation on a past or even contemporary life on Mars, the present Martian atmospheric research programme, represented by the SPICAM atmospheric sounder on Mars express, can be used to study the different aspects of the Martian environment and their compatibility with life, this interest having been prompted by a Belgian participation in a controversial observation of Martian formaldehyde by the PHOBOS spacecraft in 1989. The analysis shown here confirms that the surface Martian conditions can be compared to in sterilising properties to the best medical cleansing procedures known today. However, the UV filtering properties of deposited dust could create a subsurface favourable environment if enough humidity and energy were present. This occurrence is now less improbable after the discovery of recent water spills on the Martian surface.

KEYWORDS

Mars, life, exobiology, surface UV, extremophiles.

INTRODUCTION

The study of the atmosphere and conditions of the Martian environment began at the opposition of 1877 when Asaph Hall, the discoverer of Phobos and Deimos, put in evidence seasonal changes in albedo, rapidly interpreted by the best observers of the time as a dense orographic network irrigating the planet from the poles to the equator. Stellar occultations would soon show to be compatible with a surface pressure of 85 hPa. These conditions, accompanied by water and oxygen would have allowed Martian desert life. A more correct view of Mars was derived when the 1965 Mariner 4 radio-occultation experiment together with the telescopic CO_2 observation of Kuiper in 1947 showed a low surface pressure of around 10 hPa of pure CO_2 without any detectable traces of other gases. The images of Mariner 6 and 7 in 1969 confirmed this impression: Mars was a cold and dry world and the observed changes in albedo were related to patterns in dust depositions associated with seasonal storms, the dust level explained the previous error in the estimation of surface pressure. In 1976, the Viking landers put into evidence life-like oxido-reduction behaviours of the Martian soil but with temperature dependences incompatible with any known living organism, the influence of the hydroxyl radical was put into evidence and the overwhelming majority of the scientists at the time concluded that the Martian surface and atmosphere constituted a sterile environment.

Belgian involvement: the PHOBOS formaldehyde observation.

IASB-BIRA involvement in this question began in 1989 when the PHOBOS mission in orbit around the planet Mars observed a few limb infrared occultation spectra before spacecraft failure. The instrument was the infrared Russian channel of the Franco-Russian AUGUSTE limb sounder and extensive contacts had been taken since 1987 between IASB-BIRA and the Russian Institute for Space Research IKI the design and interpretation of this channel. The 3.7 μm spectral interval used had been chosen for the detection of HDO in the lower Martian atmosphere and surprisingly showed two peaks which until now can only be identified as formaldehyde. A 1969 telescopic spectrum obtained by JPL was also then interpreted as containing a formaldehyde structure. This result was published (Korablev et al, 1993).

Modelling and context evolution in the post PHOBOS period

Modelling efforts were made for an explanation: the simplest one being that methane produced in the soil by microorganisms would oxidise to formaldehyde accumulating in the atmosphere in the absence of rain. This mechanism had to be rejected due to the lack of methane observations and the consensus on the absence of life. An extensive study of organic chemistry was then performed using the IASB-BIRA MARS-2D photochemical model (e.g. Moreau et al., 1991, Moreau 1995, Moreau and Fonteyn, 1999). This model treats interactively radiative, dynamical and chemical processes in two dimensions. Domain of application of the model extends from South Pole to North Pole and from the ground to 120-km altitude, with a horizontal resolution of 5 degrees and a vertical resolution of 1 km. The present chemical code has been developed to study a CO_2—H_2O—N_2—SO_x—Cl_x atmosphere. It includes the calculation of the meridional distributions of 36 chemical species pertaining to 6 chemical families: O_x, HO_x, NO_x, SO_x, Cl_x, C_x.

Solving for each of them a continuity/transport equation derives the distribution of all species (e.g. CO_2, CO, O_2, H_2, and N_2O). The model succeeds in producing formaldehyde through purely chemical processes but never in quantities sufficient to reproduce the observation. Extensive efforts performed to repeat this observation by telescopic techniques as well as modelling attempts are reviewed in Moreau et al (1995). The search was extended to exceptional events as global dust storms and cometary impacts (Moreau and Muller, 1997). IASB-BIRA introduced an ISO "Target of opportunity" proposal which was accepted by ESA but never executed due to the absence of global dust-storm, even during their nominal season, demonstrating the rarity of the phenomena (Muller and Moreau, 1998). The problem has become even more complicated when the Martian Global Surveyor studies of the magnetic field showed the disappearance of the internal dynamo and thus a very weak internal energy source eliminating for the time being the hypothesises requiring volcanic and geothermic processes. The question of this still unconfirmed and unexplained observation remains thus open.

An even more spectacular announcement was made in 1996 when NASA reported the discovery of fragments of microfossil cavities in a Martian meteorite as well as organic traces of biological origin. This discovery is still contested and new arguments for and against the identification of these formations as an early Martian life appear every year since. The 1996 presentation had been made possible by advances in microbiology as new microbes are discovered in various hostile environments. These extremophiles thrive under conditions that, from the human vantage, are clearly extreme. Some of them are smaller in size than the 2μm size of the smallest previously known microbes and could make the 200 nm size of the Martian fossils realistic. In 2000, the analysis of the Mars Global Surveyor images revealed traces of water spills undisturbed by eolian erosion, leading to suspect both the presence of subterranean water and of contemporary geothermal activity and thus, pointing to an unexpected habitat for a Martian life. Later in 2000, the discovery of sedimentary layers proving that the planet was covered by permanent oceans and lakes in its early history confirmed that Mars could have known the same life evolution process as early earth, leading to even more speculation.

Radiative studies related to the SPICAM project and a proposed UV sensor.

The expertise of IASB-BIRA being in the observation and modelling of the chemical and radiative aspects of the Martian atmosphere, it was decided to use these resources for the determination of the physical conditions at the surface and near the surface in order to determine the survival possibilities of any known organisms. Three ways are proposed: the use of the results of the SPICAM light (Mars express) aeronomy instrument, the design of a specific UV sensor for a lander and finally the modelling of the radiation field and chemical composition constrained by the results of these studies. A description of the Mars-Express ESA mission is given in http://sci.esa.int/home/marsexpress/.
The SPICAM light UV channel covers the entire range of UV radiation described as UV-B between 280 and 320 nm as well as UV-C between 110 and 280 nm. These wavelength ranges correspond to the action spectrum of damaging radiation on living organisms, so beside its main role as an ozone and minor constituents monitor, the analysis of the signal will constrain the levels of a biotic radiation received at the

surface. In particular, a signal simulation has revealed that the iron oxides contained in Martian dust could make it quite easily opaque and that a very thin dust deposit (less than 100 µm) would already be sufficient to protect surface microorganisms (Muller et al, 2000, Moreau and Muller, 2000). The measurements of gaseous composition will also allow constraining the levels of H_2O_2 and OH in order to eliminate the organisms that are incompatible with their Martian level. An example of simulation is given on figure 1; it indicates that the combination of dust and ozone present in high latitude dust storms could provide a UV screen.

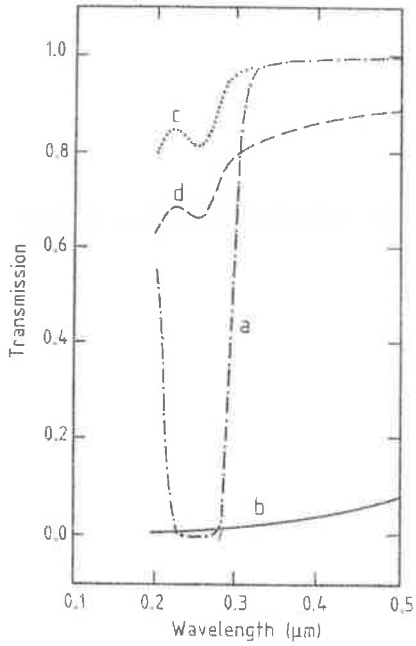

Figure 1: transmission of the solar spectrum at the surface. Case (a) represents an ozone value 100 times higher than the equatorial minimum, case (c) represents a clear atmosphere with equatorial ozone conditions. Case (b) is a case of extreme dust absorption, the visible optical depth being 0.1 for a path of 1 km; it corresponds to a dust storm and while 20 % of the visible radiation at 550 nm is transmitted, the UV is entirely absorbed. Case (d) corresponds to a total optical depth for dust of 0.2 at 550 nm for a 60° zenith angle; case (b) corresponds to an optical depth of 1.6 in the same conditions. Case (d) represents the clean Martian condition outside of local dust storm events and does not provide an adequate UV shield. (Muller et al, 2000).

The UV sensor on a lander is a project accepted by ESA in cooperation with Pr. G.Horneck of the Institute of Space Medicine of the DLR, Cologne. It intends to determine the UV level reaching the surface during the mission. This instrument intends to cover the entire range of abiotic UV from the CO_2 absorption around 195 nm to 320 nm, the complex organisms have their maximal sensibility at 280 nm while more primitive organisms without protective pigments do not have any protection at the lower wavelengths. The observations would yield the global, direct and diffuse irradiances received in order to determine the Martian UV radiative climate over at least one Martian year.
The modelling effort will consist in the integration of the obtained results in the existing Martian 2D model and in future models inspired by the developments in progress in the frame of the IASB-BIRA earth observation programme.

CONCLUSION

The consensus, drawn after the Viking mission, of a sterile Mars cannot be accepted anymore without verification and all efforts must be done to characterize the Martian environment and a possible surviving life before Mars is contaminated massively by human missions. The knowledge of the Martian conditions can help us also understand the nature of the early terrestrial marine and surface lives.

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