BIOLOGICAL ROLE OF MARTIAN AIRBORNE AND DEPOSITED DUST

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ABSTRACT

The radiative and chemical conditions at the surface in different Martian possible habitats are computed at various seasons combining a 2D photochemical model and radiation simulations. In most situations, the solar UV B and C radiations reach the surface however, a thin layer of deposited dust can constitute an effective UV shield, the protection presented by the atmosphere and airborne particles will also be characterized. This life favorable hypothesis is discussed for several Martian analogues.

INTRODUCTION

The Martian atmosphere consists mainly of carbon dioxide *(95.32 %)* with trace quantities of N_2 *(2.7 %)*, *Ar (1.5 %)*, O_2 *(0.13 %)*, CO *(0.07 %)* and less abundant species. The thinness of the CO_2 Martian atmosphere, partially transparent to the solar ultraviolet radiation, results in an intense photochemical activity, possibly including photocatalytic processes at surface level or on the aerosols. Understanding the Martian atmospheric chemistry is of fundamental interest to characterize the history of Mars (escape of species to space, atmosphere/surface interactions like oxidation), as well as for a purpose of comparison with Earth (chemistry/dynamics coupling, possible role of heterogeneous chemistry, extreme aeronomical effects of CO_2, development of biological processes during planetary history).

Twenty years ago, the Viking Mission's life detection experiments proved that the Martian soil is extraordinarily oxidizing. The evolution of CO_2 from Labeled Release experiment is consistent with the presence of a thermally labile oxidant. Detection and characterization of the chemical and physical nature of this powerful oxidant is therefore of great interest not only in the exobiology point of view but also to understand exchanges between the atmosphere and the regolith on Mars. In the thin cold Martian atmosphere, photochemical reactions occurring between traces of water and the ultraviolet radiation from the Sun lead to the production of H_2O_2 which in turn can condense onto soil grain and airborne dust. Hydrogen peroxide is a key chemical component in the lower atmosphere oxygen-hydrogen chemistry. In the classical photochemical scheme, hydrogen peroxide is almost entirely produced by HO_2 "self reaction" and destroyed during the day through photolysis. An other significant sink of atmospheric H_2O_2 is its condensation in the cold regions of the atmosphere. This condensation process is naturally crucial in the Martian lower atmosphere since it restrains the quantity of atmospheric odd hydrogen by playing the role of reservoir and, therefore, it controls the oxidation capacity of the atmosphere. This molecule, in fact, is be the key constituent for the chemical regulation of H_2, O_2 and CO in the today Martian atmosphere Additional trace species are also important in understanding the behavior of atmospheric and surface oxidants. One of these trace gases is ozone. Ozone is a good indicator for the water vapor abundance (Barth *et al.*, 1973). It is photochemicaly produced by the third body reaction of atomic oxygen, molecular oxygen and carbon dioxide and destroyed by photolysis and reaction with odd hydrogen species (H, OH, HO_2). Between Viking and the present period happened 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 between IASB-BIRA and the Russian Institute for Space Research IKI since 1987 on 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 (fig.1) was published (Korablev et al, 1993). Since, the Martian photochemical study of Mars at IASB-BIRA has been oriented to the search for a mechanism explaining a possible accumulation of formaldehyde in the lower atmosphere.

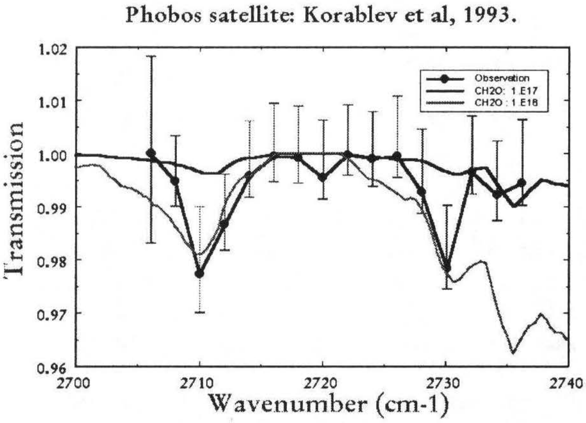

Fig.1: Observation of formaldehyde from the PHOBOS mission in 1989, the error bars correspond to several limb occultation observation around a grazing altitude of 20 km. (Korablev et al, 1993). In the absence of rain, formaldehyde would accumulate in large quantities in the earth's atmosphere but its presence in the Martian atmosphere without the sure detection of a methane source is still unexplained. The unfortunate failures of Mars Observer and Mars 96 did not allow to verify this observation up to now.

IASB-BIRA 2D MARS MODEL

The IASB-BIRA MARS-2D photochemical model (e.g. Moreau *et al.*, 1991, Moreau and Fonteyn, 1998) is a model treating interactively radiative, dynamical and chemical processes in two dimensions. The 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). Model used the total column of water derived from MAWD/Viking data (Farmer *et al.*, 1977) and for vertical distribution a scale height of 7 kilometers. In the model, the surface temperature is calculated by resolving a simple energy balance equation applied to the surface The model has been already been applied to the inverse detection of life possibilities on Mars by the Mars-Express SPICAM instrument (Muller et al, 2001). A surprising consequence of the computations is that beside reproducing the Barth (1973) daytime observations of the ozone variation with latitude, it gives sufficient ozone columns to produce an ozone UV shield but unfortunately in the darkest polar night. The specific chemistry and dynamics associated with the global dust storms has yet to be modeled, it is not excluded that the heterogeneous ozone production in the dust associated with rhe UV filter properties of the dust together with a warmer and wetter environment could be favorable to life .

UV SHIELD CHARACTER OF THE MARTIAN DUST.

For spectral simulation purposes, we used the MODTRAN 3.7 model modified for the Martian atmosphere and representing multiple scattering by an eight streams DISORT routine. The model possesses built in representations of multiple scattering and the results are expressed in physical units that can be used as inputs to instrument mathematical models. Specific Martian aerosol models are still to be tested with MODTRAN. MODTRAN has been developed as the successor of LOWTRAN and is continuously maintained by the Air Force Geophysical Laboratory in Hanscom Field (Massachusetts) (Berk et al., 1998).

The MODTRAN desert aerosol model has been chosen for its simplicity, the simulation is made for two optical depths: 0.1/km and 0.01/km at the surface and a visibility increasing with altitude. Its composition of 90% quartz particles and 10% hematite represents an optical lower limit for Martian dust. When the spectral dependence in the U.V. of the actual Mars dust will be known, it will result certainly in much higher optical depths in the U.V. and thus, as dust storms are effective U.V. screens even for the "desert" case, the remaining question is the filter effectiveness of background aerosols in quiet conditions. Figure 2 presents simulations of the transfer of direct solar radiation at the Martian surface for different conditions.

HEMATITE AS A MARTIAN ANALOGUE?

Most of the substances which have been detected on Martian soils have spectra below 300 nm which have absorptions comparable with hematite, itself an important Martian component (Soderblom, 1992, Christensen *et al,* 2000). The granulometry of Martian dust is still to determine as a correct interpretation of the asymmetry parameter g requires the knowledge of the composition. The values of g indicated by Kahn et al (1992) range between 0.55 and 0.8, which are fairly independent of the size parameter. A Mie computation shows these values to be compatible with particles of a minimum size of 0.1 µm radius, an upper limit cannot be put easily in the case of a polydispersion as g stays constant and the high g value would still be compatible with a one µm haze as observed by Smith *et al*, (1997). This Pathfinder value was refined by Markiewicz *et al* (1999) to an average 1.71 µm effective radius. The large 10 µm crystalline hematite surface layer recently discovered by TES (Christensen *et al*, 2000) in the Sinus Meridiani region would fractionate before reaching the airborne phase. The UV properties of the other iron oxides are close in terms of refractive index (Clark *et al.*, 1993) and the conclusions drawn using hematite as an analogue would not differ if magnetite was substituted. A simple Mie computation shows that that a 100 µm layer of optically neutral silicate containing a few hematite or magnetite submicron spheres constitutes an effective screen for UV-B radiation. Montmorillonite and palagonite contain metal traces but would difficultly constitute an effective shield by themselves (fig. 3), metal rich grains will thus always be a necessity to produce effective screens.

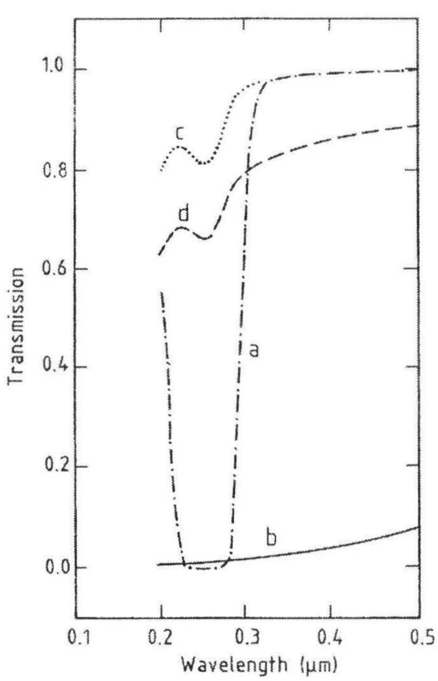

Fig. 2. : transmission of the solar spectrum at the surface. Case (a) represents an ozone value 100 time higher than the equatorial minimum, case (c) represents a clear atmosphere with equatorial ozone conditions. Case (b) is a case of extreme dust absorption, the visible optical depth being 0.1 for a path of 1 km; it corresponds to a dust storm and while 20 percent 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, 2001.

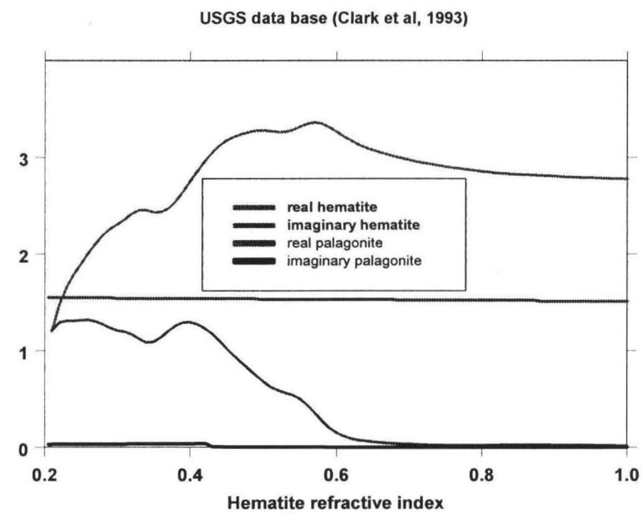

Fig 3.: optical properties of hematite and palagonite for wavelengths ranging between 200 and 1000 nm, palagonite has a zero imaginary index in the entire range and a constant real index, on the contrary, in the UV-B hematite has both an effective imaginary and real index, leading to strong extinction and absorption properties. In the visible and in the red, the imaginary index decreases allowing a thin hematite layer to transmit energy.

CONCLUSION

Knowledge of the ultraviolet flux incident on the Martian surface is important in the photochemical and exobiology point of view. This radiation flux depends on factor such as cloud cover, atmospheric dust loading, season, local time, and altitude. In the current Martian environment, the total integrated UV flux over 200-400 nm is comparable to the Earth's but the shorter wavelengths (UVC and UVB) contribute a greater proportion of this UV flux and, consequently are more biologically damaging. For a clear Martian atmosphere, the dominant attenuation process of the UV flux reaching the surface is CO_2 Raleigh scattering, except for high latitude in winter where ozone absorption may become significant. CO_2 absorption is significant at wavelengths < 204 nm and effectively provides a shield below 190 nm. For a moderate dusty atmosphere, aerosols can be effective if the aerosol

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