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"Biogenic" Dark Dune Spots on Mars and Probable Antarctic Analogues

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Abstract: Dark Dune Spots (DDSs) are remarkable morphological features, which appear during late winter and spring mainly on intra-crater dark sand sheets in the southern polar regions of Mars. We studied the high-resolution MGS MOC images and the morphological dynamics of the spots suggested that the previously suggested frosting-defrosting mechanism cannot explain solely their formation. We proposed that DDSs are signs of life activity and we suggested a lifecycle of putative Martian photosynthetic surface organisms.

Introduction: The images of Mariner 9 revealed that dark-toned „splotches", inside or outside the craters, could be found in the low latitudes of Mars. Using the Viking images it has been suggested that the dark „splotches" are eolian dunes made up of fine-grained sediments of dark blue in color (**1**, **2**, **3**). The dark dunes in both polar areas have colors and albedo similar to that of the dunes at low latitudes, but they are dramatically different from the widespread bright dust dunes on Mars (**4**). The dark dunes are composed of low-albedo, sand-sized eolian sediments, mainly dense basaltic sand (**5**).

On the Mars Orbiter Camera (MOC) images of the Mars Global Surveyor (MGS) made between 1998 and 1999 we studied south polar regional dark dune fields, which are the first surfaces to frost in the fall and defrost during late winter/early spring, (still frost may well persist on them until late spring or even early summer. There DDSs and their clusters were observed during late winter and early spring. In earlier analyses Edgett at al. (**6**) and Malin & Edgett (**7**) concluded that a complex process of CO_2 and H_2O sublimation and re-precipitation occurs as defrosting process. This process is function of the seasonal and local temperature controlled by surface and interior physical properties of the dunes.

Observations: We have analyzed 200 MGS MOC pre-processed images (http://www.msss.com/moc_gallery/) published on the net by the Malin Space Science Systems. From the two polar regions of the Mars (different, **8**), the DDSs of the southern one were chosen for morphological analysis. MOC red wide-angle context images (ë=600-630 nm) helped orientation, MOC narrow-angle images (ë =500-900 nm) covering (1-3)X(20-80) km^2 area, with a high resolution of 1,4-5,5 m.) were used for analysis (**Figs. 1, 2, 3**, & **5**). The narrow-angle images were taken between June 1999 and June 2001 and cover areas between 48°S--8**2°**S latitudes. On all of these images nearly circular DDS and their clusters can be seen. The DDSs frequently have an inner ring-structure (**6, 7**) which can be seen only on the highest resolution images (**Fig. 1**).

Our interesting new observation was the relationship between the fine-scale topography and the circular shape of the individual DDSs on top of the dune sheets. (**Fig 2** illustrates the general situation.) This circular shape of DDSs indicates that spots are formed not (or not only) by sublimation but rather by some radially spreading process (e.g. water leaking into homogeneous sandy soil). If the defrosting process is only sublimation, then the preferential sites for frost sublimation are those surfaces, which receive the highest radiation flux from the Sun. For this reason spots with sublimation origin ought to have diverse, irregular, rather than circular, shapes.

Another observation is that on slopes the spots are elongated downwards. On slopes the circular spots are replaced by DDSs with ellipsoid or fan shape, indicating that gravitational force does affect spot morphogenesis (**Fig. 1** and **3**), too. There are spots from which extensions start to outflow downward. All these observations suggested us that a fluid phase (most likely water) played a fundamental role in spot morphogenesis.

Fig. 3A shows a spectacular example of elongated dark spots in the crater located near 61°S, 5°W. The presence of liquid phase and surface waters flow is supported by **Fig. 3B**. The image shows DDSs that are not only elongated but are arranged in several hundred meter long, winding stripes, which are most probably tracks of water flows. In other environments Malin and Edgett (**9**), Mangold et al. (**10**) have already found recent groundwater seepage and surface runoff gullies on Mars, but Reiss and Jaumann (**11**) found extremely fresh runoff gullies within the last Martian year.

On a plain surface the spots tend to have circular shape, surrounded by a gray ring (**Fig. 1B, C** and **D**). On slopes they develop into an ellipsoid (**Fig. 3C**), elongated in the direction of the gradient, or they form a fan-shaped region at the lower end (**Fig. 3D**). With time the spots grow and coalesce, and by the end of the summer the whole territory turns dark..

Biological interpretation: In order to interpret the shown sequence of changes of the DDSs phenomenon in our model we involve activity of living organisms, called MSOs (Martians Surface Organisms). In the Edgett *at al.* (**5**) and Malin and Edgett (**6**), models DDS phenomenon was interpreted as sinple defrosting process. However, the systematic variations and repeated appearance of DDSs and their patterns cann't be interpreted only by surface relief and physical defrosting reasons.

In our model two fundamental questions are explained: 1) How can liquid water form at temperatures obviously below freezing, and if formed, why does not it freeze immediately? 2) If some mechanism produces liquid water, how on Mars does not it evaporate immediately in the very thin Martian atmosphere? Our answer to these problems were solved by the suggested existence of Martian Surface Organisms (MSOs) which have adapted to an above the ground, below-ice lifestyle (they have some earthly analogues).

The photoautotrophic MSOs must have evolved pigments with high absorbance. We suggest they conduct the following lifecycle. During the winter the soil below the spots is deep-frozen and some form of ice/frost covers them. MSOs must occupy a layer between the soil surface and the ice sheet. Because ice is transparent to light, MSOs intensely absorb the emerging sunlight (which is continuously available in the polar region) and thus warm up at the end of the winter. From a frozen state they pass to a molten one, which also applies to part of the ice around them. Thus MSOs find themselves in a liquid solute, in contact with the underlying soil, enabling them to take up the necessary nutrients. The volume and extension of the liquid region increase with the intensity of the insolation. The ice cover above the forming liquid water provides excellent heat insulation and prevents fast evaporation that otherwise would be inescapable due to the low atmospheric pressure. (The fact that the spots mainly appear in the polar region indicates that a long period of sunlight is a necessary condition for their formation, since it prevents night frosting of water around the MSOs.) Thus the most basic living conditions of the MSOs prevail until there is sunlight and until the ice sheet above them does not evaporate. The proposed mechanism of spot formation is shown in **Fig. 4.**

The MSOs "Martian" type life conditions in Antarctica: It is important that life under similar conditions is known on Earth. Priscu *et al.* have found that the 3-6 m thick ice cover of the lakes in the dry valleys of Antarctica contains wind-blown sediments in the middle region. Photosynthetic organisms on the surface of these sediment grains absorb sunlight and melt the ice around them, thus partly creating their own living conditions (**12**, **13**). A multi species consortium is found on the grains, able to perform continuous photosynthesis, nitrogen fixation and decomposition, forming a small ecosystem with nutrient cycling.

The Martian ice cover would also protect MSOs from intense UV radiation. (Although atmospheric CO_2 filters out UV below 190 nm, the flux of UVB (280-320 nm) and UVC (200-280 nm) radiation is higher on Mars than on present-day Earth, which must constrain life processes, especially photosynthesis, whether of earthly or endemic origin (**14**).) Aggressive chemical reactivity of the Martian soil at the Viking landing sites is likely to be due to super-oxide ions that form under UV irradiation (**15**). Thus shielding from UV irradiation should also reduce the concentration of harmful super-oxide ions in the habitat of the MSOs, in addition to the fact that the color of the dunes indicates a local depletion of iron, necessary for the formation of superoxide. (the present-day UV exposure of the Martian surface is comparable to that of the Archean Earth, **16**, **14**). Martian organisms could easily have adapted to present-day UV conditions through billions of years. Note that even on Earth today one finds organisms such as *Deinococcus radiodurans* (**17**) or *Rubrobacter radiotolerans* (**18**), tolerant of enormous levels of radiation, including UV. *Deinococcus* is able to survive a dose of 1.5 million rads. After cooling and freezing it may survive 3.0 Mrads (**17**). This extreme radio-tolerance may be by-product of extreme desiccation tolerance.

MSO life sequence from late winter: At the end of the winter sunlight start to warm up the MSOs, activate them and melt the bottom of the ice cover above them. (gray spots) With time the ice shield becomes thinner and thinner, until it melts through up to the surface. In the core, immediately a very intense evaporation begins in the unprotected region culminating in the appearance of the dark, underlying soil, featuring as the dark center in the middle of the gray spot (**Fig. 1C, 1D** and **4B**). The evaporation of liquid water in the middle of the spots and the consequent drop in temperature could be ideal for the preservation of viability of MSOs. It is striking that where the black spots appear by late winter, there are lighter, grayish patches on the images of the defrosted, dark soil. It seems obvious that in these cases a different layer covers the Martian regolith. This layer is, following from our mechanism, a layer of dried MSOs, analogous to dried algal mats or lichen-like covers on the Earth. By the end of fall, or the beginning of winter white frost settles in (first just in the dark dune regions) and the whole territory turns white. The long winter (six earthly months) allows the white frost to become dense and to form proper ice at the bottom, sealing the surface from the atmosphere completely. Sunlight appearing by late winter then warms up MSOs and the cycle is ready to start again.

Summary: Our DDSs transformation sequence and many characteristic features of the DDSs were successfully interpreted by our model involving living organisms. Our considerations showed that photoautotrophic organisms could maintain their own living conditions on Mars. One may wonder whether the low atmospheric pressure is compatible with photosynthesis, but this objection is not hard to reject. First, although it is true that total pressure is just 6 mbar, but 95% of the atmosphere is CO_2, thus its *partial pressure* is higher than on Earth. Second, conditions below the ice sheet are expected to be different (in fact, more favorable). The existence of the postulated MSOs should be detectable by orbiting spectroscopic instruments. It is encouraging that Pershin (**19**) has observed a color index value of 763/554, suggestive of photosynthetic pigments, during analysis of the Martian images made by the Hubble Space Telescope..

If one indeed finds life on Mars, the history of its origin becomes very interesting. Given the fact that viable dried organisms or their propagules could travel regularly between Earth and Mars, while preserving their viable state (**20**, **21**), it may be possible that Martian and terrestrial organisms share a common ancestry: phylogenetic sequence analysis should be able to tell whether this holds or not.

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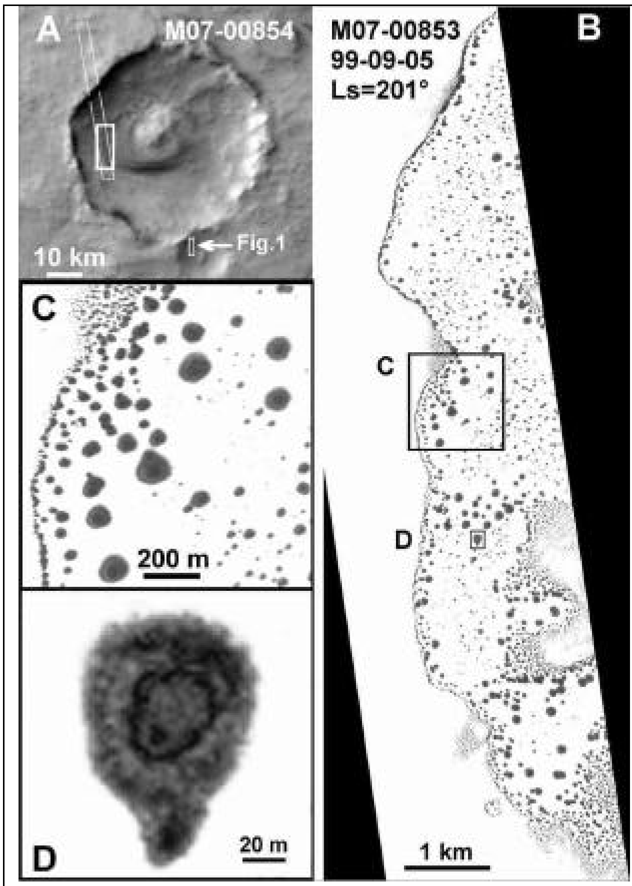

Fig. 1. Characteristic Martian dark dune spots and their clusters. (**A**) A 50-km-wide crater (65°S, 15°W) with intracrater dune field. (**B**) DDSs during early spring along edges and on top of the intracrater dune field, (**C**) Nearly circular DDSs on the flat dune field. (**D**) Inner ring-structure of one of the DDSs.

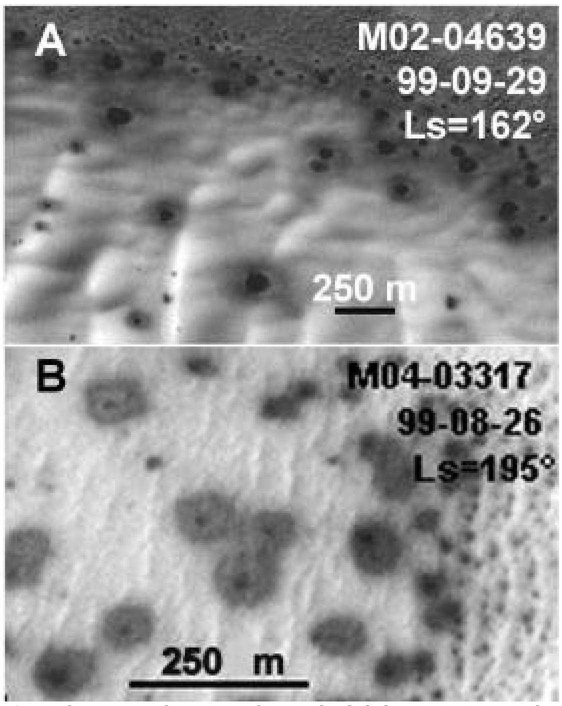

Fig. 2. These images demonstrate that circular dark dune spots overprint the fine-scale topographic variations. (**A**) DDSs in late winter in the Smith Crater. (**B**) DDSs in early spring on the dune field of the Jeans Crater.

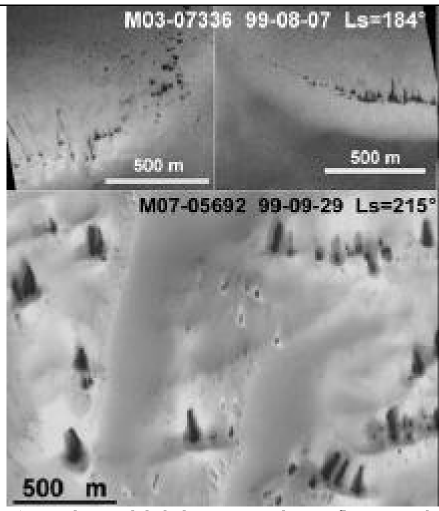

Fig. 3. Elongated dark dune spots and water flowing on the slopes of the dune fields. None of these DDS formations can be explained by a mere defrosting effect, but all of them can be interpreted as showing water seepage and occasional flow. The emergence and continued presence of liquid water are, presumably, due to biological activity.

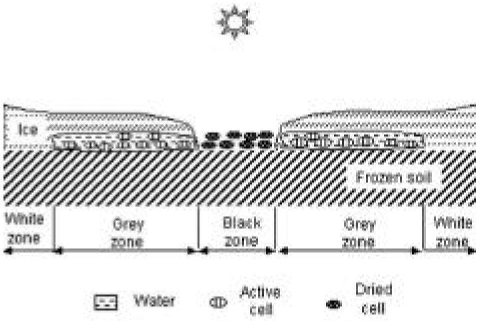

Fig. 4. Dynamics of biogenic spot morphogenesis. (**A**) In the firs phase of spot development organisms on the soil, below the ice warm up by the absorption of sunlight and melt the ice around them. The ice cover provides heat insulation and blocks evaporation. (**B**) The ice cover first disappears in the center, where the melting started. Water evaporates quickly; the organisms desiccate and the dark core of the spots develop.

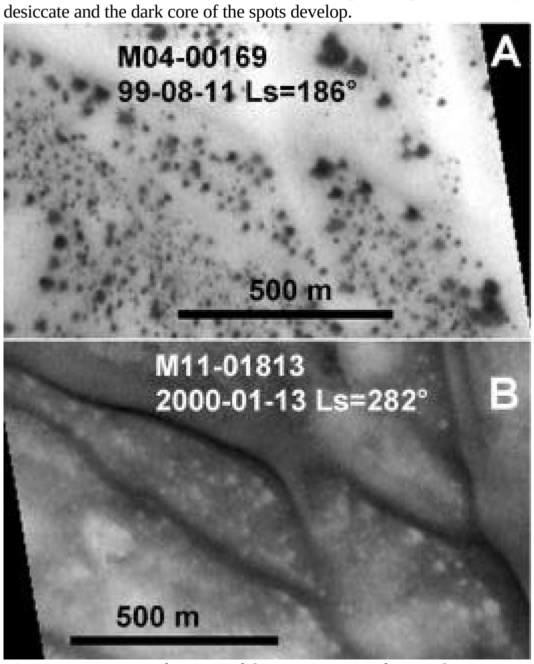

Fig. 5. Comparison of images of the same territory from early spring **A** and from summer **B**, shows that there are lighter gray patches on the dark soil where the dark spots were at the end of the winter. This suggests that a layer with a different albedo covers the dark soil. We interpret this as a layer of desiccated MSOs