MORPHOLOGICAL INVESTIGATIONS OF MARTIAN SPHERULES, COMPARISONS TO COLLECTED TERRESTRIAL COUNTERPARTS.

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Introduction: On the basis of the microscope camera imaging of Opportunity we studied the morphology of the "blueberries", the Martian spherules [1,2]. Such hematite spherules occur in several terrestrial environments: 1) spherules found by Chan et al. in Utah State [3] are considered to be terrestrial counterparts, and 2) spherules collected by T. Pócs in Venezuela and West Australian deserts are possible analogues with the Martian spherules.

OPPORTUNITY'S MARTIAN SPHERULES: For Martian spherule studies we used the MER camera images (Fig. 1.). Our morphology studies focused on their occurrence, embedding into the surface rocks, their shape, especially their systematic difference from the spherical one, their size, distribution and environment. We compared the characteristics of the spherules with their similar terrestrial counterpart candidates (i.e. desert spherules, pisolites, morphological characteristics of living organisms of similar size on the Earth).

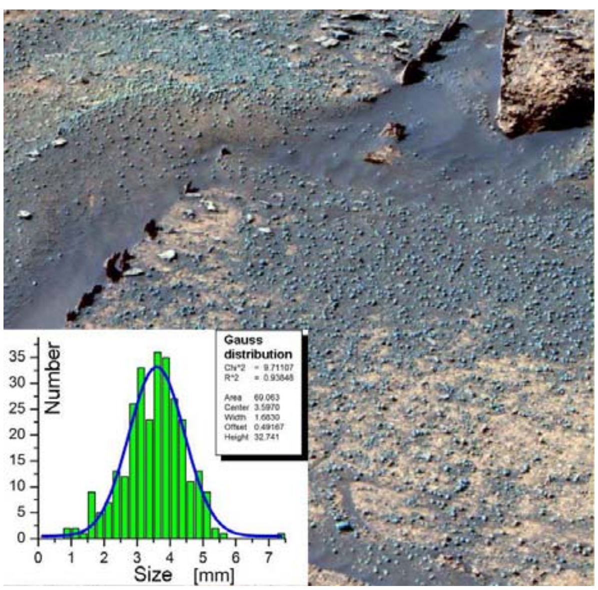

Fig. 1. ***Martian spherules and their size distribution***

Observation of the characteristics of spherules:

1.) Opportunity found multiple number of spherules along its way in the Meridiani landing site. Spherules occur on the surface of the soil or rocks and also they are embedded inside rocks. Their occurrence density on the surface has been estimated to reach some hundreds per square meter, (althoughugh it may be even greater in some regions).

2.) A large part of the spherules was found embedded in the rocks. Embedding is well visible both in field imaging observations and in soil surfaces from drillings made by Opportunity (Fig. 2c.).

3.) The great majority of spherules have almost regular spheroidal shape, although many broken spherules can be observed, too. The spheroidal spherules are the non eroded ones. Variations from the regular spheroid cannot be considered consequences of random or erosional effects (non-uniform spherules).

4.) No platform on the spherules was found. Platform would be the trace of spherule formation on a surface, it could witness the connection between the surface and the spherule (like as in the case of pisolites in karst waters).

5.) *"Twin-spherules"*. A number of spherule pairs were found fusing into each other, somewhat reminiscent of forms of biological reproduction [4]. These spherule forms, however, are similar neither to simple bacterial nor yeast proliferation morphology (Fig. 2a.).

6.) *"Lengthwise pit"*. In some cases lengthwise pits run half around the surface of the spherule, very similar to those surface pit found on apricot or cherry fruit crops. There were cases when this lengthwise pit consists of more sections.

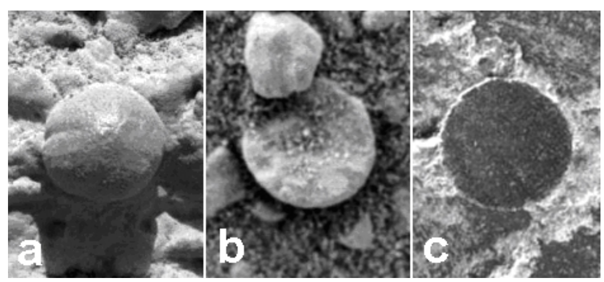

Fig. 2. Twin (a), broken (b) and scraped (c) surface spherules

7.) *Missing inner structure.* Several spherules on the images were broken half (among natural conditions) (Fig. 2b.), but some were cut or chiselled by the drilling of Opportunity while it remained embedded in the host rock (Fig. 2c.). In all these spherules no inner structure can be seen.

However, in some cases some striping is visible on the broken or refined surfaces. In terrestrial cases - when the grains are produced by detaching from a wall - the products have some lamination and in the case of spheroidal forms these layers form spheroidal shell layers. This way the pisolites and the pisolite-like formations, the stalagmites, the natural pearls all exhibit layered structure. This refers to the fact that Martian spherules did not form by such processes, i.e. they did not grow on the surface.

8.) The size of the Martian spherules covers a rather narrow size range, most of them are between 1.5 and 5 mm. Their size distribution fits a Gauss-distribution (Fig. 1.).

9.) On the basis of the Mössbauer spectrum made by Opportunity the material of the spherules mainly or its overwhelming majority is hematite [1,2].

10.) Shiny spherules. There are spherules with shiny surfaces. Probably the Martian winds polished their surface. These shiny spherules are more comparable to the terrestrial analogues.

Fig. 3. ***Spherules from the West Australian desert near Lake Barlee***

OBSERVATIONS ON TERRESTRIAL ANALOGUES: Spherules of similar size and appearance have been collected in Southwest Australia (which at present has Mediterranean climatic conditions), in the West-Australian Desert (Fig. 3.) of subtropical desert climate near Lake Barlee and from the Venezuelan Guiana, in the Gran Sabana of seasonal tropical climate. The spherules from the West Australian Desert are shiny and black, bluish-black or blackish-brown, the others are of a lighter brown to orange red colour and opaque. All of them, as shown by electron microprobe analysis contain a high amount of iron, alumina and some titanium.

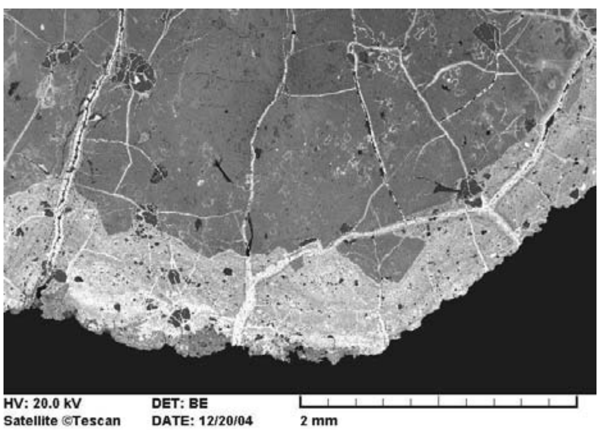

Fig. 4. ***Cross section image (BEI) of a terrestrial spherule from Australia: dark-grey is alumina, light-grey is Fe_2O_3***

The mineralogical investigation has shown, that all spherules are composed of limonite, goethite, haematite, very fine-grained clay minerals, and some quartz grains, the Venezuelan ones in addition also contain magnetite. In some spherules all these minerals are arranged in alternating, concentric layers. On the backscattered electron image (Fig. 4.) the internal layers are rich in alumina (70-80 wt %), and the surface layer is enriched in iron (Fe_2O_3, 85-90 wt %). Concerning their origin, these iron-rich concretions developed in sedimentary layers (mostly sandstone), when their site had been inundated by shallow sea water. In Western Australia the shperule containing sandstone is called "ironstone" and is very widespread, the "free" spherules are the result of the weathering of these ironstones, the binding material being much softer than the iron concretions.

Comparisons: The shape, surface and size of the Utah spherules found by Chan et al. [3] are more variable than respective features of the Martian ones. Twin-forms can also be found among them. Their formation is interpreted as posterior hematite dissolved in the soil, which does not exclude biological effects.

The Australian and Venezuelan spherules of T. Pócs are also similar to Martians in many aspects. They are more irregular in shape and more variable in size, than the Martian ones, probably due to the shorter time of exposure. The reason why they are shiny and blackish in the desert, and brown or reddish and opaque in other climatic conditions, can be the result of the smoothing and shining effect of windblown sand and the exposure to the very strong irradiation. Their scattered position on the deserty grounds, both on Mars and Earth, can be simply the result of the bedrock waethering, or maybe the distribution by water during a time of waterlogging. In any case, their development in both places are bound to the previous presence of abundant water and maybe that of bacteria.

Conclusions: From the facts that 1) Opportunity found many spherules at its landing site, and 2) Spirit did not find any, it is concluded, that the formation of the spherules is the consequence of local rather then global Martian conditions. The facts that 3) many spherules are embedded in the rocks, shows that the spherules were formed simultaneously with the sediments, or that they were present during the formation of the evaporites. Both cases suggest that the spherules originate from the wet period of Mars [5], however, 4) the images suggest that spherules were embedded during the sedimentation of the rocks, 5) regular spheroid shape, lack of platform-like formations suggest that spherules were formed in a dynamic process: "levitating" in a liquid or in continuous movement (i.e. cave pearls: new layers settle to the surface from the continuously moving pearls of the water).

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