MANGANESE, METALLOGENIUM, AND MARTIAN MICROFOSSILS. L.Y. Stein and K.H. Nealson, Jet Propulsion Laboratory, 4800 Oak Grove Drive, MS 183-301, Pasadena, CA 91109, steinl@gps.caltech.edu.

Manganese could easily be considered an abundant element in the Martian regolith, assuming that the composition of martian meteorites reflects the composition of the planet. Mineralogical analyses of 5 SNC meteorites have revealed an average manganese oxide concentration of 0.48%, relative to the 0.1% concentration of manganese found in the Earth's crust [1]. On the Earth, the accumulation of manganese oxides in oceans, soils, rocks, sedimentary ores, fresh water systems, and hydrothermal vents can be largely attributed to microbial activity. Manganese is also a required trace nutrient for most life forms and participates in many critical enzymatic reactions such as photosynthesis. The widespread process of bacterial manganese cycling on Earth suggests that manganese is an important element to both geology and biology. Furthermore, there is evidence that bacteria can be fossilized within manganese ores, implying that manganese beds may be good repositories for preserved biomarkers.

A particular genus of bacteria, known historically as *Metallogenium*, can form star-shaped manganese oxide minerals (called metallogenium) through the action of manganese oxide precipitation along its surface (Fig. 1A). Fossilized structures that resemble metallogenium have been found in Precambrian sedimentary formations and in Cretaceous-Paleogene cherts (Fig. 1B; [2]). The Cretaceous-Paleogene formations are highly enriched in manganese and have concentrations of trace elements (Fe, Zn, Cu, and Co) similar to modern-day manganese oxide deposits in marine environments [2]. The appearance of metallogenium-like fossils associated with manganese deposits suggests that bacteria may be preserved within the minerals that they form.

Fig 1A. Metallogenium mineral from Horse Tooth Reservoir in Fort Collins, Colorado. ESEM Photograph taken by Suzanne Douglas at the Jet Propulsion Laboratory.

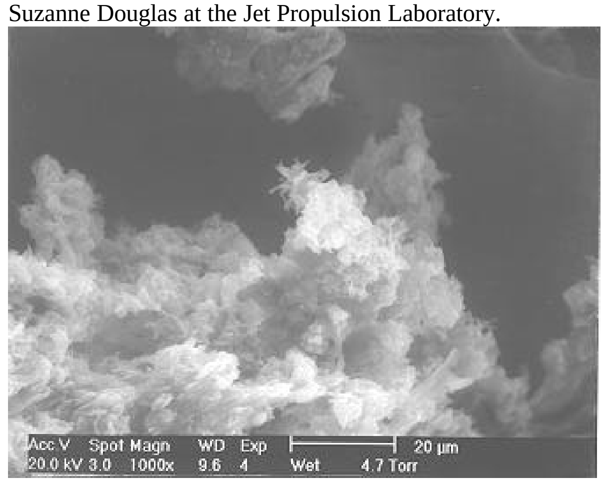

Fig 1B. Duplicated from [2], p. 291

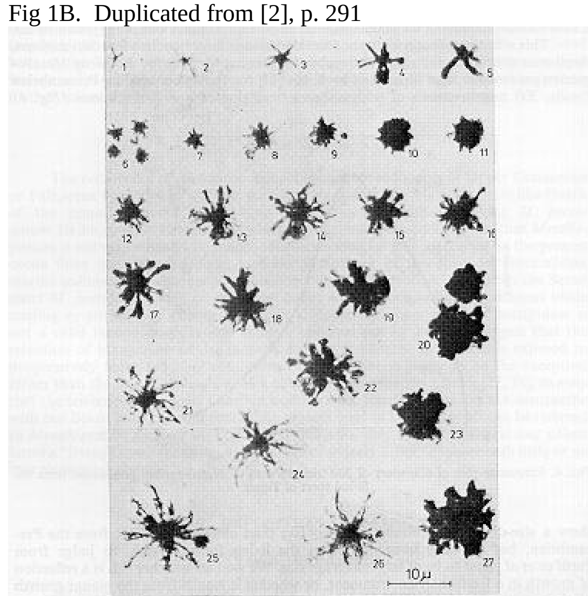

FIG. 3. *Metallogenium personatum* from the Cretaceous-Paleogene Seical chert, Timor; photomicrographs, arranged from top toward bottom in progression of size and number of filaments, and from left to right in progression of mineralization. 1 may not be a *Metallogenium* (possibly a decalcified *Discoaster* of minute size?). 2—5 are paucirayed trichospheres, lacking subdivision of rays, in increasing order of mineralization; 4 includes a subsidiary multirayed trichosphere of very small size and stronger mineralization. This is probably associated by accident, but may represent a new trichosphere budded form the terminal cell of one of the branches of the paucirayed specimen. 6—11 represent a series of small multirayed forms in increasing order of mineralization, up to the lump stage; in 8 the segmented character of the rays is well displayed. 12—20 and 23 is a similar progression of trichospheres of intermediate size. 21, 22, 24, 25 and 26 are large multirayed forms with slight mineralization; 22 displays the expanded terminal cells of the rays, and in 25 such a terminal cell appears to have given rise to a small multirayed daughter trichosphere. 27 is a large and heavily mineralized specimen

Although the identification, physiology, and life-cycle of *Metallogenium personatum* was documented in the 1930's, several reports have been published over the last 60 years showing that metallogenium minerals can be made by several different types of bacteria and also by fungi. We have been investigating a fresh water reservoir in Colorado where metallogenium forms during late summer to early fall. Metallogenium particles were collected on a screen covering an outflow pipe which supplies drinking water to the city of Fort Collins. Bacteria were isolated from the minerals using a growth medium designed for the isolation of manganese oxidizers. The dominant types of bacterial isolates belong to the genera *Pseudomonas*, *Comomonas*, *Cytophaga*, *Flexibacter*, *Arthrobacter*, *Corynebacterium*, and *Rhodococcus*. Many of these genera have known members that oxidize Mn(II), and some our isolates appear to produce metallogenium-like particles in laboratory cultures. So far, we have found no organisms corresponding to the original description of *Metallogenium personatum*, suggesting that in this lake, the metallogenium mineral is formed by other types of bacteria. Our cursory analysis of metallogenium formation rates by our isolates show that many species within the same bacterial genus oxidize Mn(II) at different rates depending upon the stage of growth, the concentration of cells, and the availability of nutrients such as organic carbon and iron. These data suggest that manganese oxidation by the bacterial population in this lake is both a very common process and is physiologically and phylogenetically diverse.

In a separate experiment, some of the metallogenium mineral was dissolved with 1M ascorbate in TE buffer and total DNA was extracted. Eventually, the molecular marker genes corresponding to individual bacterial species associated with metallogenium will be uncovered using molecular techniques. The total diversity compared to the culturable population will be examined to find cultured organisms that are abundant within the metallogenium particles. The formation rates of metallogenium and the physiology of these isolates will be compared to better understand when and how metallogenium forms in the lake. The results of this study will help us to better understand the biological component of manganese oxide formation and enrichment in a sedimentary environment. These processes may contribute to the preservation of bacterial fossils in manganese oxide deposits.

Although there is no definitive proof that the metallogenium-like fossils in the sedimentary record correspond to ancient life, a combination of morphological similarity to extant organisms and the identification of associated biomarkers (eg. isotopic signatures, organic materials, or concentration of certain elements) can strengthen the connection. Thus, to find fossilized bacterial life on Mars, manganese-enriched mineral deposits could be a reasonable place to look. The immense manganese nodule beds on the ocean floor and within lake sediments argue that ancient water basins on Mars would be favorable sites for finding manganese deposits. With this in mind, we recommend the exploration of ancient lake or sea beds on Mars for consideration in the sample return missions.

[1] Longhi, J., E. Knittle, J. R. Holloway, and H. Wanke. (1992). *In* H. H. Kieffer, B. M. Jakosky, C. W. Snyder, and M. S. Matthews (ed.), Mars., 184-208.
[2] Crerar, D. A., A. G. Fischer, and C. L. Plaza. (1980). *In* I. M. Varentsov and G. Grasselly (ed.), Geology and Geochemistry of Manganese, vol. 3., 285-304.