MERIDIANI PLANUM HEMATITE DEPOSIT: POTENTIAL FOR PRESERVATION OF MICROFOSSILS.
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Introduction: Christensen et al. [1], using data from the Mars Global Surveyor Thermal Emission Spectrometer (TES), have identified gray crystalline hematite in a 350 km by 750 km region near Meridiani Planum. The deposit corresponds closely to the low-albedo highlands unit "sm", mapped as a wind-eroded, ancient, subaqueous sedimentary deposit [2]. Christensen et al. [3] interpreted the Meridiani Planum deposit to be "an in-place, rock-stratigraphic sedimentary unit characterized by smooth, friable layers composed primarily of basaltic sediments with approximately 10 to 15% crystalline gray hematite."

The Meridiani Planum hematite deposit has recently been designated as the prime landing site for one of the two Mars Exploration Rover (MER) spacecraft. The MER landings are scheduled for January, 2004.

Christensen et al. [1] discussed five possible mechanisms for the formation of this deposit: direct precipitation from standing, oxygenated, Fe-rich water; precipitation from Fe-rich hydrothermal fluids; low-temperature dissolution and precipitation through mobile groundwater leaching; surface weathering and coatings; thermal oxidation of magnetite-rich lavas. Four of these mechanisms involve the interactions of rock with water, and thus have implications in the search for evidence of microbial life.

Direct precipitation from standing, oxygenated, Fe-rich water. Iron formations are "chemical sediments, typically thinly-bedded or laminated, whose principal chemical characteristic is an anomalously high content of iron, commonly but not necessarily containing layers of chert." [4]. Iron formations are among the most common chemical sedimentary deposits of the Precambrian. The iron occurs as oxides, principally hematite and magnetite.

Precipitation from Fe-rich hydrothermal fluids. Hematite is one of several iron minerals that can form when large volumes of hydrothermal fluids move through rocks. The mineralogy of a hydrothermal zone is typically complex, reflecting local changes in temperature, pH, fluid composition and other variables [5]. For example, detailed studies of two silica-depositing hot springs [48 to 55° C] determined that iron was partitioned among hematite, goethite, ferrihydrite, siderite and the iron smectite nontronite [6].

Low-temperature dissolution and precipitation through mobile groundwater leaching. Iron-rich laterites and ferricretes are formed on Earth when acidic groundwaters extensively leach soil and rock. Mafic minerals are unstable in acidic reducing environments and form colloidal iron oxides and hydroxides. These can be transported by water and redeposited if Eh and pH rise [5].

Surface weathering and coatings: Rock varnish, a complex combination of clays with Fe- and Mn-oxides and hydroxides, coats the surfaces of exposed rocks in many arid environments [7]. Hematite, maghemite and magnetite have been identified in rock varnish [8]. The coatings are derived from airborne dust and other sources external to the rock, apparently deposited in the presence of thin films of water [9].

Hematite Deposits and Microbial Life: Several of the mechanisms proposed for hematite formation include microbial mediation, and microbial fossils are sometimes preserved. We are documenting such preservation by iron oxides, including hematite.

Iron Formations. Many iron formations contain fossil evidence of microbial life. In fact, the very existence of terrestrial iron formations has been interpreted as evidence of photosynthesizing organisms which significantly increased the percentage of oxygen in Earth's atmosphere and oceans [10].

Numerous microfossils are preserved in specimens of the ~2 Ga banded iron deposits of the Gunflint Formation, Canada [11]. While most of these microfossils are preserved in chert, scanning and analytical electron microscopy reveals that some of the micrometer-scale rods, spheres and filaments are associated with iron oxides [12; Fig. 1]. Transmission electron microscope analysis of some filamentary microfossils in

Gunflint samples demonstrate that they are in fact mineralized by hematite [13].

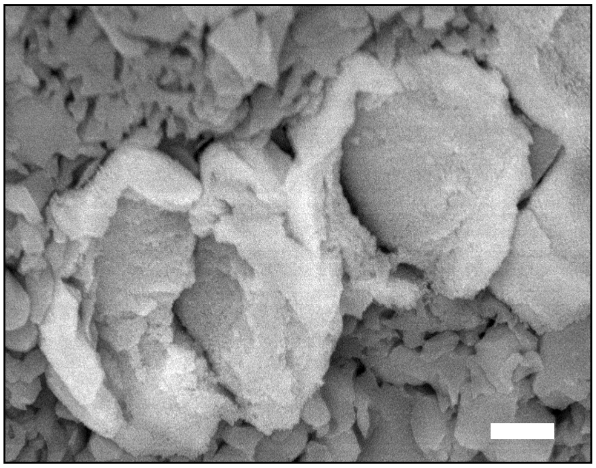

Fig. 1. Spherical microorganisms mineralized by iron oxide – Gunflint, Canada; SEM, scale bar = 1 µm

Hydrothermal Systems. Iron oxides precipitate with silicon dioxide or calcium carbonate in many hydrothermal systems. Wade et al. [6] noted the remains of rod-shaped bacteria and dehydrated biofilm in a silica-dominated iron hot spring, along with hematite and other minerals.

Chafetz et al. [14] reported recognizable bacterial remains in Fe- and Mn-oxide deposits within hot spring travertines in Morocco. These microfossils were found in centimeter-scale black "shrubs". Filamentous and coccoidal bacteria were observed densely packed within the shrubs, but no microfossils were found within the enclosing aragonite and calcite laminae.

Iron-Rich Laterite and Ferricrete Soils. Microbes are ubiquitous in terrestrial soils. Bioloads of 10^6 to 10^9 bacteria per gram are typical, with organic-rich surface soils generally containing more organisms than deeper mineral soils [15]. Many microbes can derive energy from the reactions of iron and oxygen in soils. Specialized bacteria oxidize iron from Fe^{2+} to insoluble Fe^{3+} in acidic environments such as mine tailings.

Filamentous microfossils of several generations, as well as abundant extracellular polysaccharide (EPS), have been preserved by iron oxides in a ferricrete sample from the soil surface near Shark Bay, Western Australia [16]. The general state of degradation of these microbial filaments indicates that they were mineralized after cell death and lysis.

Rock Varnish. Natural rock varnish may be a product of microbial activity [17]. Initial studies demonstrated the presence of bacteria known to cause precipitation of manganese oxides [18]. Bacteria, isolated from natural varnish samples and cultured, produced varnish similar to natural material.

Bacteria, EPS and microcolonial fungi have been found in varnish deposits coating granitic rocks from Sonoran Desert sites in Arizona, as well as in varnish samples from Hoover Dam, Nevada and the Pilbara region of Western Australia [19, 20]. In each case the varnish consists of a complex mixture of clay minerals with Fe- and Mn-oxides. Some of the bacteria and many of the fungal bodies are apparently recent, but the varnish layers also contain evidence showing Fe- and Mn-oxide mineralization of a subset of these microorganisms (Fig. 2).

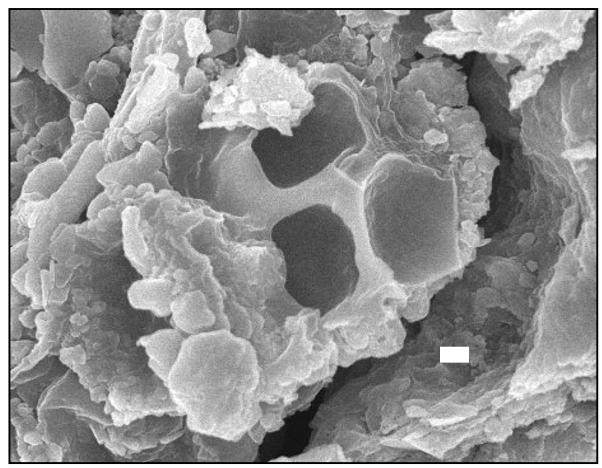

Fig. 2. Microcolonial fungi mineralized by Fe- and Mn-oxides – Pilbara, Australia; SEM, scale bar = 1 µm

Discussion: On Earth, diverse microbiota have been identified in each of the four “wet” environments discussed by Christensen et al. [1] for hematite deposition. Our research and the work of other colleagues has demonstrated that a subset of the microorganisms are preserved by hematite and related iron oxides in each of these environments.

The hematite deposits in Meridiani Planum and other smaller hematite sites are the only places on Mars at which a specific mineral has been identified and correlated with mappable geologic units. These deposits may be the only large-scale mineralogical evidence for water-rock interactions early in the planet’s history.

If the Meridiani Planum hematite deposit does carry a record of fossil martian microbes, suggestive macroscopic indications may be detected by the Mars

Exploration Rover. The characteristic banding of many iron formations, metal-rich "shrubs" in hydrothermal minerals, Fe-rich soils or dark rock coatings should be recognizable with the MER instrument suite. The spacecraft's combined capabilities of elemental and mineralogical analyses along with microscopic imaging may well allow the source of the hematite to be determined.

If the martian hematite deposit does carry a record of ancient microbial life, however, that record will probably not be revealed by the MER instruments. The spacecraft's spectrometer suite provides analyses at a scale of centimeters or larger. Most microfossils, though, are significantly smaller than even the 30 μm resolution limit of the MER Microscopic Imager.

Thus, confirmation of martian microbial life by direct fossil evidence will require the return of samples to terrestrial laboratories. A key function of the next generation of Mars landers may be to discover and certify prime sites for future Mars sample return missions. The Meridiani Planum hematite deposit may well be among those prime sites.

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