Microbial fossils from terrestrial subsurface hydrothermal environments:Examples and implications for Mars. Beda A. Hofmann, Natural History Museum Bern, Bernastr.15, CH-3005 Bern, Switzerland, hofmann@nmbe.unibe.ch. Jack D. Farmer, NASA Ames Research Center, MS 239-4, Moffet Field CA 94035-1000, U.S.A. jfarmer@mail.arc.nasa.gov

The recognition of biological signatures in ancient epithermal deposits has special relevance for studies of early biosphere evolution and in exploring for past life on Mars (1–3). Recently, proposals for the existence of an extensive subsurface biosphere on Earth, dominated by chemoautotrophic microbial life, has gained prominence (4,5). However, reports of fossilized microbial remains or biosedimentary structures (e.g. stromatolites) from the deposits of ancient subsurface systems are rare. Microbial preservation is favoured where high population densities co-exist with rapid mineral precipitation (2,6). Near-surface epithermal systems with strong gradients in temperature and redox are good candidates for the abundant growth and fossilization of micro-organisms, and are also favorable environments for the precipitation of ore minerals. Therefore, we might expect microbial remains to be particularly well preserved in various kinds of hydrothermal and diagenetic mineral precipitates that formed below the upper temperature limit for life (~120°C).

Under rapid precipitation, fossilization is known to occur by the coating of external organic surfaces by various kinds of metalliferous precipitates. The glycoproteins of bacterial cell walls are known to bind metal ions (7,8). This type of passive mediation has been documented in modern hydrothermal systems which exhibit very high precipitation rates, including the vent areas of subaerial springs (9) and black smokers of the deep sea (10). However, elements such as Fe, Mn, Ni, and V are also known to be important components of metalloenzymes in many heterotrophic microorganisms, being required co-factors for cell growth (11). In these groups, the precipitation of Fe- and Mn-oxides is directly mediated by physiological processes, with fine-grained metal oxides forming either intracellularly (e.g. in magnetotactic bacteria, 12), or accumulating within exopolymer matrices (13, 14).

Examples of well-preserved fossil microbiotas from subsurface environments have previously been published only from Warstein, Germany (15). Other occurrences containing possible microbial remains include salt dome caprocks from the Texas Gulf area (16) and epithermal U-bearing veins at Menzenschwand, Germany (17). Here we present a number of newly recognized occurrences of well-preserved subsurface microbiotas, all enclosed in opal, chalcedony or megaquartz, from localities in California, Oregon, Texas, Brazil, Germany, the Czech Republic, the Faeroer Islands, India, the Kerguelen Islands,

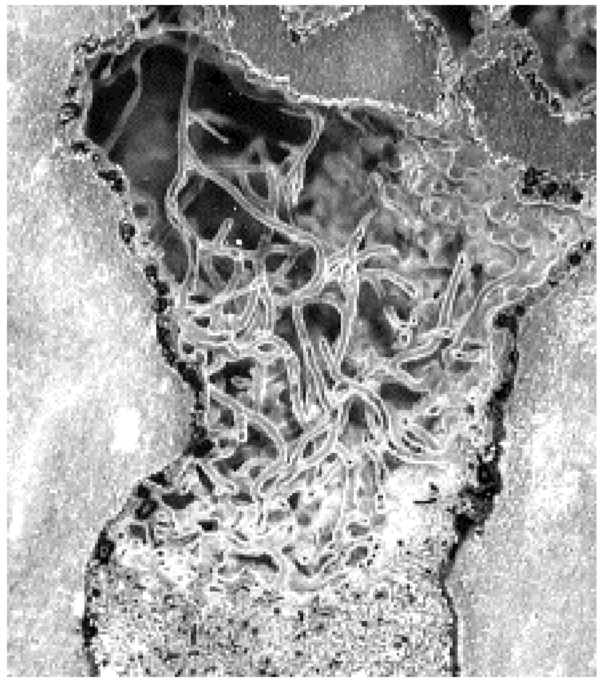

Fig. 1: Mineralized microbial filaments in rhyolite amygdule, Central Oregon. Open space is filled with chalcedony. Arnoth collection. Field of view 3 mm.

New Zealand and Mongolia (Hofmann and Farmer in preparation). Many of these occurrences are within amygdules in basaltic to acid volcanic rocks or in vein-type epithermal mineralizations. Subsurface microfossils from these localities are remarkably well preserved, commonly as heavily encrusted branched filament molds with a primary internal diameter of 2 to 10 μm. The encrusted filaments typically have an outer diameter of 50 to 200 μm. In the examples studied, microbial filaments (cell walls and/or sheaths) were apparently coated and/or replaced by very fine-grained goethite, iron-silicate minerals and/or chalcedony and subsequently embedded in chalcedony or megaquartz. In some large amygdules, mineralized filamentous structures reach dimensions of up to 10 cm length. In the absence of filamentous morphologies, a biological

Microbial fossils: Examples and implications from Mars. B. A. Hoffman, J. D. Farmer.

origin for structures from Menzenschwand and some other sites include finely-banded stromatolitic fabrics with lamina shapes resembling the surfaces of some microbial mats, homogeneous fine grain size, and isolated patches of reduced minerals (reduction spots) in an oxidized host rock (18,19,20).

Many of the subsurface microbiotas so far identified are from volcanic environments, commonly amygdules. Similar environments are very likely to be found on Mars. Our findings suggest that vesicular textures, along with late stage aqueous minerals deposited within fractures of a variety of host rocks should be considered important potential targets for a fossil record of subsurface microbial life on Mars.

References: [1] Walter, M.R. and Des Marais, D.J. 1993. Preserva-tion of biological information in thermal spring deposits: Developing a strategy for the search for a fossil record on Mars. Icarus 101: 129–143. [2] Farmer, J.D. and Des Marais, D.J. 1994. Exopaleontology and the search for a fossil record on Mars. Lunar Planetary Science 25, 367–368. [3] McKay, D.S., Gibson, E.K, Thomas-Keprta, K.L., Vali, H., Romanek, C.S., Clemett, S.J., Chillier, X.D.F., Maechling, C.R. and Zare, R.N. 1996. Search for past life on Mars: Possible relic biogenic activity in Martian meteorite ALH84001. Science 273, 924–930. [4] Stevens, T.O and McKinley, J.P. 1996. Lithoautotrophic microbial ecosystems in deep basalt aquifers. Science 270, 450–454. [5] Pedersen, K. 1993. The deep subterranean biosphere. Earth Science Reviews. 34(4), 243–260. [6] Farmer, J.D., Cady, S. and Des Marais, D.J. 1995. Fossilization processes in thermal springs. Geological Society of America, Abstracts With Programs, 27(6), 305. [7] Ehrlich, H.L. 1996. Geomicrobiology. (Second Edition). Marcel Dekker Inc., New York. [8] Ferris, F.†G., Fyfe, W. S. and Beveridge, T.J. 1988. Metallic ion binding by Bacillus subtilis: Implications for the fossilization of microorganisms. Geology 16, 149–152. [9] Farmer, J. D. and Des Marais, D. J. 1994. Biological versus inorganic processes in stromatolite morphogenesis: Observations from mineralizing systems. pp. 61–68. In L.J. Stal and P. Caumette (eds.). Microbial Mats: Structure, Development and Environmental Significance. NATO ASI Series in Ecological Sciences, Springer Verlag. [10] Zierenberg, R.A. and Schiffman, P. 1990. Microbial control of silver mineralization at a sea-floor hydrothermal site on the northern Gorda Ridge. Nature 348, 155–157. [11] Beveridge, T. and Doyle (eds). 1989. Metal Ions and Bacteria. Wiley, New York. [12] Frankel, R.B., Papaefthymiou, G.C., Blakemore, R.P., and O'Brien, W. 1983. Fe3O4 precipitation in magnetotactic bacteria. Biochim. Biophys. Acta 763, 147–159. [13] Ghiorse, W.C. 1980. Biology of iron and manganese depositing bacteria. Annual Rev. Microbiol. 38, 515–550. [14] Ghiorse, W.C. and Hirsch, P. 1979. An ultrastructural study iron and manganeses deposition associated with extracellular polymers of Pedomicrobium-like budding bacteria. Arch. Microbiol. 123, 213–226. [15] Kretzschmar, M. 1982. Fossile Pilze in Eisen-Stromatolithen von Warstein (Rheinisches Schiefergebirge). Facies 7, 237–260. [16] Sassen, R., McCabe, C., Kyle, J.R., and Chinn, E.W. 1988. Deposition of magnetic pyrrhotite during alteration of crude oil and reduction of sulfate. Org. Geochem. 14, 381-392. [17] Hofmann, B. 1989. Genese, Alteration und rezentes Fliess-System der Uranlagerstätte Krunkelbach (Menzenschwand, Südschwarzwald). Nagra (Swiss Natl. Cooperative for the Storage of Radioactive Waste) Technical Report 88-30, Baden, Switzerland. [18] Hofmann, B. 1990. Possible microbiological origin of reduction spots in red beds: Proc. First. Int. Symp. Microbiology of the Deep subsurface, Orlando 1990. [19] Hofmann, B. 1990. Reduction spheroids from northern Switzerland: Mineralogy, geochemistry and genetic models. Chem. Geol., 81, p. 55–81. [20] Hofmann, B. 1991. Mineralogy and geochemistry of reduction spheroids in red beds. Mineralogy and Petrology 44, 107–124.