Synopsis

Geomarkers *versus* Biomarkers: Paleoenvironmental and Astrobiological Significance

A fundamental problem related to the paleoenvironmental study of early Earth rocks and minerals, and astrobiological exploration of planetary materials (e.g., asteroidal and Mars meteorites, Martian rocks) is not only recognizing and quantifying carbon-related compounds that may be present but also differentiating those molecules formed abiotically from those generated by extinct or extant life. Only through the combination of biomarkers and geomarkers will we be able to understand the global framework. Whereas, biological markers or "biomarkers" are molecular fossils (1), there is not a clear and official definition of the term "geomarker," and it has been ambiguously used to refer to different topics, not always following a formal concept. Biomarkers are defined as "complex organic compounds, which originated from formerly living organisms and which are composed of carbon, hydrogen, and other elements. Abiotic organic compounds are not biomarkers per se because they do not originate from biosynthesis" (1).

Biomarkers occur in many different types of materials and geological settings (sediments, rocks, crude oils, etc.) (2–10) and normally display negligible or no structural changes from their parent organic molecules in living organisms. Three principal characteristics permit biomarkers to be distinguished from many other organic compounds (11): "a) biomarkers have structures composed of repeating subunits, indicating that their precursors were components in living organisms; b) each parent biomarker is common in certain organisms; and c) these organisms can be abundant and widespread." But, our planet and its biosphere evolved together, and the geobiological history of ecosystems is recorded in sedimentary rocks through billions of years (10). Geobiology attempts to rebuild the coevolution of life and environment throughout Earth's history. Thus, to identify potential biomarkers regarding the type of microbes that lived (or still live) at the surface of Mars or other planets, we will need to use the rocks and minerals (and other geological features) as geomarkers to understand the geological and environmental contexts (12). In accordance with Farmer (13), in defining a site-selection strategy to explore for a Martian fossil record, a key concept is contemporaneous chemical precipitation or mineralization. On Earth, geological environments where microorganisms are often preserved in this way include, among others: *i)* mineralizing systems (subaerial, subaqueous, and shallow subsurface hydrothermal systems (Fig. 1); and cold springs of alkaline lakes); *ii)* saline/alkaline environments of arid marine shorelines (sabkhas), or terminal (evaporative) lake basins; *iii)* duricrusts and subsoil hardpan environments formed by the selective leaching and reprecipitation of minerals within soil profiles; and *iv)* periglacial environments ground ice or permafrost (frozen soils) captured and cryopreserved microorganisms and associated organic materials.

A significant handicap in establishing the bio-geo link is the differential development and, in many cases, conceptual and epistemological gaps between the studies regarding biomarkers and geomarkers. But, although biomarkers are perfectly defined, what are geomarkers? A references search in the principal scientific database (ISI—Web of Science) shows nearly 14 000 references, including the term biomarker(s), but there are only 5 publications in which the term geomarker(s) occur(s) explicitly. There is not a clear and official definition of the term, and it has been ambiguously used to refer to different topics, not always following a formal concept. The specific works in which the term geomarker are particularly quoted deal with: *i)* the use of benzohopanes as geomarkers of sediments and petroleums (14); *ii)* the characterization of oil shales, using the alkane geomarkers as indicators of the immature character of sediments and the nature and environmental features of the source (15); *iii)* the utilization of spectroscopic techniques (Raman spectroscopy) for planetary exploration in the near future to search for extinct or extant life signals (16); *iv)* the use of some minerals (graphite) to carry out paleogeographic reconstructions (17, 18); and *v)* the use of mineralogical textures, crystal-chemical features and isotopic values as geomarkers in methanogenic and hydrothermal chimneys (19, 20). When regarding the specific relationship with life, it is important to note that the term "geosignature" has been proposed (21, 22). This review must be taken with caution, because the nonuse of the term geomarker does not necessarily mean that the geological aspects and indicators regarding the history and evolution of a specific geological environment have not been tackled, but it shows a spasmodic development that we want to stress in the present paper. A definition of the term geomarker is necessary, and we propose that geomarkers can be defined as any geological (i.e., mineralogical, geochemical, metallogenetic, sedimentological, petrological, tectonic) feature or set of features, which can be used as proxy indicators of the physical, chemical, and/or biological characteristics of the environment in which they occur, and/or of the process that formed them.

As demonstrated by the NASA–Mars Exploration Rover and ESA–Mars Express missions, geology, and, in particular, mineralogy, provides one the most robust means for discovering ancient aqueous environments and comprises an essential step in selecting the sites that have the best chance for having captured and preserved a record of ancient life or prebiotic chemistry. A sophisticated spectrometer can accurately identify a specific water-related mineral (e.g., jarosite, gypsum, kieserite) on Mars; but, what does it mean? We know that the same mineral can be formed in different terrestrial environments; the same sulfate that we can find in a dessert can also be the product of a hydrothermal system (12, 23). Thus, as previously defined, a previous step to detect possible Martian biomarkers is the utilization of minerals as geomarkers to understand the global (geological and environmental) context (24). This implies that, if it is essential to determine what minerals and rocks are significant for the search of life on Mars, then the appropriate selection and detailed study of the

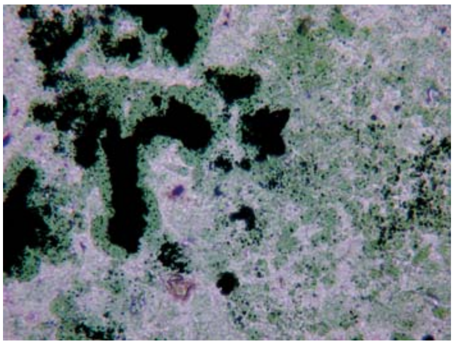

Figure 1. Accumulation of Fe-microspheres (sphere size, ~1 μm) growing on celadonite minerals (green). The clearest part between celadonite is constituted by opaline phases. This mineralogical association has been interpreted (24) as an example of possible biomineralization process under low-temperature hydrothermal conditions.

different geological and mineralogenetic terrestrial settings (Mars analogs) in which such minerals occur and evolve are also of a great interest. In an astrobiology scenario, we can report some examples where microorganisms show their mark while influencing the extracellular magnetite crystallization (25) or affecting the isotopic fractionation of iron during microbial iron reduction (26). In addition, there are other two significant aspects that link mineralogy-petrology and biomarkers-astrobiology: *i)* the capability of some minerals (e.g., sulfates) to trap organic material that is present in their parent solution as they precipitate (27). This preservation is important, because an ideal biomarker would essentially be stable against decay or diagenesis for periods of several thousand million years (28), and *ii)* the shielding effect of some minerals and rocks (e.g., jarosite, basalt) against extreme external conditions (i.e., ultraviolet radiation) (12, 29, 30).

Here, a first definition of the term geomarker is given but only through the combination of both types of markers (biomarkers and geomarkers) will we have a complete scientific panorama, which will not only contribute to the understanding of ancient environments and their associated life but will also help us in the astrobiological recognition and exploration of new potential extinct or extant extraterrestrial ecosystems (31).

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Synopsis

Wastewater Management through Biomass of *Azolla pinnata*: An Eco-sustainable Approach

INTRODUCTION

The green revolution increased productivity in its initial phase, but excessive application of modern extensive agriculture, e.g., use of fertilizers and pesticides, poses a serious threat to the environment and sustainable agriculture. The effects of the green revolution have shifted concern from increasing productivity to sustainability and resource conservation. Since global water distribution comprises a very small percentage of freshwater, its proper conservation and management is a prerequisite for sustainable use. Due to acute scarcity of freshwater resources and ever increasing volumes of wastewater, it has become imperative for both developed and developing nations to conserve water and address problems of water scarcity and wastewater disposal. The three R's of wastewater management are reduce, recycle, and reuse. The best way to conserve water is to recycle it. Use of treated wastewater for irrigation and other nonresidential purposes is being encouraged. These wastewaters, when used for irrigation, increase productivity because they supply mineral ingredients also (1). But depending on the origin, wastewaters may contain toxic heavy metals, which accumulate in soil and biological systems and prove hazardous. However, wastewaters can be biologically treated to lower the load of harmful pollutants and safely reused. Biological treatment of wastewaters is a field of intense interest for developing and developed countries, and success of these treatment processes depends on the usefulness of the biomass produced and easy disposal (2, 3). Many aquatic plants and algae have been used