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General palaeontology (Taphonomy and fossilisation)

Microfossils

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Abstract

Defining biosignatures, i.e. features that are indicative of past or present life, has been one of the major strategies developed over the last few years for the search of life on the early Earth and in the solar system. Current knowledge about microscopic remnants of fossil organisms, namely microfossils are reviewed, focusing on: (i) studies of recent environments used as analogues for the early Earth or extraterrestrial environments; (ii) examination of Precambrian rocks; and (iii) laboratory experiments simulating biotic and abiotic processes and resulting in the formation of genuine or pseudomicrofossils. Fossils' preservation depends on environment and chemical composition of the primary structure, although they might undergo taphonomic processes that alter their morphology and/or composition. Altogether, these examples illustrate what can be potentially preserved during the very first stages of fossilization and what can be left in the geological record after diagenesis and metamorphism. Finally, this provides a rationale to tentatively define diagnosis criteria for microfossils or ways to look for life on Earth or in extraterrestrial environments. ***To cite this article: E.J. Javaux, K. Benzerara, C. R. Palevol 8 (2009).***

Résumé

Les microfossiles. La recherche de vie primitive sur Terre et dans les environnements extraterrestres requiert la caractérisation de biosignatures ou d'indices de vie. Cet article résume les avancées récentes de la communauté géobiologique sur les traces morphologiques microscopiques de vie : les microfossiles. En principe, les organismes appartenant aux trois grands domaines de la vie sont susceptibles d'être préservés sous forme de microfossiles. Cependant, suivant les conditions environnementales de préservation et les propriétés biologiques originelles, certaines formes de vie peuvent ne pas être fossilisées et d'autres voient leur morphologie et/ou composition chimique altérée(s), ou même détruite(s) par les processus taphonomiques. Les difficultés inhérentes à l'identification de microfossiles sont présentées, en s'appuyant, en outre, sur une série d'exemples de recherches géobiologiques menées sur des environnements actuels analogues aux conditions de la terre primitive ou d'autres corps du système solaire, sur des roches précambriennes et enfin dans le cadre d'expériences en laboratoire explorant les processus biotiques et abiotiques. Les

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éléments de diagnose nécessaires pour identifier des microfossiles dans des roches, utiles pour la micropaléontologie terrestre et l'exopaléontologie sont discutés. ***Pour citer cet article : E.J. Javaux, K. Benzerara, C. R. Palevol 8 (2009).***

Keywords: Microfossils; Geobiology; Taphonomy; Biogenicity; Endogenicity; Syngeneity

Mots clés : Microfossiles ; Géobiologie ; Taphonomie ; Biogénicité ; Endogénicité ; Syngéneité

1. Introduction

The search for life on early Earth and beyond Earth in the solar system requires the characterisation of biosignatures (traces or indices of past or present life). Biosignatures have traditionally included chemical, isotopic and morphological proxies that have been interpreted as remnants of life-preserved in rocks [10]. Morphological signatures can be macroscopic such as macrofossils, or sedimentary structures built by microorganisms, such as stromatolites. However, this article focuses more specifically on the microscopic morphological signatures of life which are generally called microfossils. Microorganisms can produce biominerals that might have a particular chemistry, crystallography, and/or texture, but these are more specifically discussed by Benzerara and Menguy (*Looking for traces of life in minerals* [this issue]). They can also alter rocks or minerals and leave microchannels such as those formed by endolithic cyanobacteria in carbonates, e.g. [29], or in basalts [25] but these "ichnofossils" or traces of biological activity are not microfossils themselves.

On Earth, the only reference planet inhabited by life that we know, one common feature of life, is the cell (with the exception of viruses). The three domains of life include cells with diverse biochemical properties that are important for their preservation potential in the fossil record. When looking for traces of early life in terrestrial rocks, we have to consider three important issues [10]:

- *the preservation environment*: under what conditions are cells with varying biochemical properties preserved?
- *the taphonomy*: how do processes of degradation and preservation retain, alter or erase original biological properties?
- *the criteria of biogenicity*: how can we tell biological from non-biological when observing purported microfossils in rocks?

Here we shortly review a series of examples from geobiological investigations that were carried out: (1) modern environments considered as analogues of some environments of the early Earth or other planets; (2) Precambrian rocks; and (3) laboratory systems that simulate biotic and abiotic processes forming microfossils. These examples will help in defining microfossils, as well as understanding the mechanisms of fossilisation, including the processes that potentially erase biosignatures. From there, it will be possible to discuss criteria of biogenicity that may be applicable to Earth systems but also will be useful for exopaleontology.

2. What is a microfossil?

2.1. Definition

Microfossils are the microscopic remains of organisms. The organisms may be prokaryotic cells of the Bacteria or Archaea domains, unicellular eukaryotes (protists), whole multicellular eukaryotes, or parts of multicellular microscopic or macroscopic eukaryotes. Virus can be included, although so far only very few reports suggesting their presence in the fossil record exist e.g. [46]. The size of a microfossil ranges from the smallest living cell (250 ± 50 nm constitutes a reasonable lower size limit for life as we know it, [39]) to larger sizes that are not visible with the naked eye.

2.2. Composition

Microfossils can have a variety of morphology and chemical composition, depending on their original properties and the conditions in which they are preserved (Fig. 1).

2.2.1. Carbonaceous composition

The organic sheaths of cyanobacteria and the walls of microscopic unicellular and multicellular algae, fungi, diverse protists like dinoflagellates, thecamoebians, and plant spores or animal eggs can be preserved as carbonaceous objects in fine-grained sediments. Because of the compaction of enclosing sediments, these micro remains are usually flattened and their walls show wrinkling, folding, or breaks resulting from mechanical stresses. Such taphonomic features modify the original size and morphology of the organisms, but they can