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Atomic force microscopy of ancient terrestrial microfossils : implications for the search for extraterrestrial microfossils

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On Earth, despite the growing power of analytical techniques, the identification of microfossils in the oldest sedimentary rocks still gives rise to significant controversy. Their resolution is absolutely mandatory if we want to identify with confidence microscopic cellular remains in both very ancient terrestrial and, especially, extraterrestrial rocks. Our investigations of ancient microfossils using atomic force microscopy (AFM) demonstrate the excellent potential of this instrument in better characterising ancient microfossils and, thus, aiding their interpretation. These studies pave the way for investigations of extraterrestrial material.

We made an AFM study of well-known microfossils embedded in the 800 My conglomerate from Draken formation (Spitsbergen) and the 1.9 Ga cherts from the Gunflint Formation (Canada) with an AFM (Nanoscope III, D3100 Digital Instruments). We were able to make *in situ* 3D- morphological measurements of very small microfossils down to 1.5 μm in size, preserved in different ways: (1) as well-defined organic walls embedded in a silica matrix, (2) as poorly-defined organic walls (previously calcified) subsequently silicified, and (3) permineralised by FeS. Three physical modes of the atomic force microscope, sensitive to differences in local mechanical or adhesive properties of the sample, have also proven useful. AFM in force volume mode (FV) documented a very strong correlation between the topographical image of a microfossil wall and the adhesion map, permitting the study of the distribution of kerogen. Permineralized iron-sulfur cells can also be recognized with lateral force imaging (LFM), because of the difference in friction between the quartz matrix and the pyritic cells. Finally, phase imaging (PI) is also an essential mode to highlight the

submicrometer particles inside the wall of the Draken microfossils.

The procedures necessary for this type of investigation are very delicate and complicated and there are a number of problems such as tip contamination that pose serious constraints on correct observation ($i.e.$ elimination of artifacts). However, this non-destructive observational tool method has many advantages, $e.g.$ high resolution, minimal sample treatment, and acquisition of supplementary physical information. Although the constraints limit the use of AFM for *in-situ* robotic studies in the search for life on Mars, its potentiality in chemical force mode and also as a nano-dissecting tool may provide valuable information that can help to distinguish real microfossils from mimetic artifacts with sub-micron resolution, on terrestrial and extraterrestrial samples, such as those provided by a sample return mission.