A SEARCH FOR ANCIENT LIFE ON MARS: THE ROLE OF SMALL MISSIONS

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Detection and characterisation of signatures of possible extinct life on Mars are best performed by a logical sequence of missions, starting with orbital spacecraft and progressing to landers, with rover capability, and sample return. Because each mission tends to be highly focused, and to follow or precede certain other missions, each one can employ a relatively small, inexpensive spacecraft.

Although the present martian surface is extremely inhospitable to life, there are good grounds for believing that 3.5 to 4 Gyr ago, when life was emerging on Earth, conditions on Mars were much more salubrious and Earth-like, suggesting that life may well have emerged there as well [1]. Consequently, despite a common perception that the Viking mission resolved (negatively) the question of possible life on Mars, the fact that it searched only for the presence of organic matter and current metabolic activity in the upper regolith leaves unresolved the possible presence of cryptic life and does not address the potential presence of a fossil record of ancient life. Furthermore, although the example of Viking creates an impression that the search for extraterrestrial life demands large, expensive missions, we believe that a search for extinct life can be carried out using a carefully planned sequence of relatively small, inexpensive missions.

The scientific basis of a strategy for the detection of extinct life on Mars is outlined elsewhere [2]. Here we describe briefly the sequence of measurement objectives that would satisfy that strategy, and the instrumentation and missions that would perform those measurements. This sequence is best visualised as a progressive zeroing in on the biosignatures which a putative extinct lifeform would have left on Mars. Several of the earlier measurements in the sequence would meet the objectives of other planetary-science disciplines, besides those of exobiology, and will be performed by currently planned or proposed missions, though not necessarily in the order proposed here, which is deliberately optimised to meet exobiological objectives.

The key to any search for biosignatures, be they chemical biomarkers or morphological fossils, is an understanding of the conditions both in which the ancestral organisms could have existed and in which their signatures could have been preserved. A basic constituent of all known life and a necessary agent in the process of fossilisation is liquid water, so the initial focus of the search for ancient life is on the distribution of water on Mars, both today and in the past. The former is pursued by global mapping of near-surface water using gamma-ray/neutron spectrometry from orbit, and of subsurface water using long-wave radar from orbit and EM sounding from either balloons or landers/rovers.

The record of ancient liquid water on Mars is recovered from topography and geomorphology carried out by laser altimetry/gravity-field measurements and high-resolution imagery from orbit, respectively. This record can be amplified by mapping the global distribution of minerals characteristic of aqueous activity. This is also the crucial first step in determining the location of those lithologies capable of preserving biosignatures, and is best performed by means of near-to-mid-IR spectroscopy from orbit. Ultimately, the planning of landed-science missions will demand local mapping of these lithologies at a spatial resolution of better than 100m/pixel, but because of the data-intensive nature of these spectral measurements, such resolution is impractical on a global scale. Consequently, IR spectral mapping will require a sequence of at least two missions, with the first providing global coverage at a resolution of a few km, as planned for Mars Global Surveyor, followed by a high-resolution version of the same instrument that will focus on selected sites with about 100 times better resolution.

High-resolution visual imagery from orbit will also permit reconstruction of the relative chronology of interesting lithologies. Other orbital objectives would include acquisition of molecular and isotopic data on atmospheric species to permit definition of the volatile reservoirs on Mars and their long-term evolution. But the ultimate objective of the orbital phase is the identification of promising sites for the pursuit of landed science.

Experiments on the martian surface will have two broad objectives: the detection and analysis of organic matter, and the identification of lithologies potentially capable of hosting either chemical biomarkers or morphological fossils. A necessary precondition for the former is determination of the nature and distribution of the martian surface oxidants. Following identification of oxidant-free "oases", either at depth in the regolith, at areas of recent aolian erosion, or within protective lithologies, those environments will be analysed first for total organic carbon, and then in increasingly fine detail for the elemental, molecular and isotopic composition of the biogenic elements, C, H, O, N and S.

Meanwhile, lithologies in the neighborhood of the lander will be surveyed using visual imagery and IR spectroscopy at high resolution in a search for aqueously altered minerals that would be good candidates for preserving biosignatures. Such minerals would include carbonates, silica and phosphates. Visual imagery would also search for macroscopic evidence of extinct life, such as stromatolites. Definitive mineral identifications would probably require follow-up analysis by means of a technique such as x-ray diffraction, which would be usefully coupled with elemental analysis using x-ray fluorescence. Such analyses would require a capability for movement over the martian surface, using a rover with a range of at least a few tens of meters but preferably much greater. Also, accurate analysis of minerals comprising a martian rock would require an ability to remove the weathered layer probably present on such a rock.

Both organic and mineralogical analyses therefore place a premium on acquisition of material from environments protected from martian surface processes. This translates into a requirement for techniques capable of penetrating into martian regolith and into sedimentary rocks.

Identification of a promising lithology would lead to analysis for the presence of organic matter, which, if positive, would be followed by progressively detailed elemental, molecular and isotopic analyses. These would employ a variety of techniques, mainly chromatographic and mass-spectrometric.

Positive identification of chemical biomarkers, or other organic molecules that could plausibly be associated with martian biology, would constitute a strong case for a search for metabolic activity, not considered further here, or morphological fossils. Robotic identification of a (possibly microscopic) fossil may be feasible some years in the future. However, a positive identification by a robotic mission would certainly demand confirmation in a terrestrial laboratory, leading to a requirement for sample return at this stage in the study.

This necessarily brief account has omitted several lines of inquiry that are peripheral to the main thrust of biosignature detection and characterisation but which would be important components of the exobiological exploration of Mars, such as delineation of the course of prebiotic chemical evolution. Other examples include definition of the volatile inventory on Mars and its development through time, and precise chronometry of the martian surface.

Two factors should be noted in connection with this study. First, many of its scientific objectives, particularly in the early phases, are shared with other planetary-science disciplines. Exobiology and traditional planetary science will be collaborators, not competitors, in the future exploration of Mars. Second, the need for most observations/measurements to be performed in sequence mandates a series of spacecraft, each of which can be relatively small and inexpensive. Even a small-scale sample return mission may not be infeasible [3].

[1] McKay C.P. & Stoker C.R. (1989) Rev.Geophys. 27, 189. [2] DesMarais D.J. *et al.* (1995) This volume. [3] Kaplan D.I. (1995) This volume.