Why Biologists should support the exploration of Mars

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Summary
Physicists, chemists and geologists in the USA and Europe propose that the search for extraterrestrial life is an important justification for the exploration of Mars. Biologists, however, much more excited by the advent of the postgenome sequencing era, in general display little enthusiasm for planetary exploration. We argue that the search for traces of life on Mars represents a major thought-provoking challenge for the life sciences that should be taken up by the biological community. BioEssays 23:1–3, 2001. © 2001 John Wiley & Sons, Inc.

The search for life on Mars, past, dormant or extant, is one of the most thought-provoking challenges for biology. It supported by evidence that liquid water and potential sources of energy, the key ingredients for the development of living organisms (as we know them), were present on ancient Mars and may still be there not far below the planet’s surface. Analysis of samples from Mars should be of fundamental interest to all biologists and especially those working on the definition and origin of life, on the evolution and adaptation of molecular mechanisms in living cells, or on the development of organisms within ecosystems.

If a Martian were to write a paper on Earth biology based on the science pages of influential newspapers and policy publications of research institutes, she or he would not hesitate to conclude that the basic principles of biology are now known and that we have entered a stage of systematic studies to develop applications in medicine and agriculture, i.e. that biology is no longer a science. The most important and fundamental question in biology persists, however: “what is the nature and origin of life?” Looking for traces of life on Mars is within our reach and a challenging way to focus on this question. Life on Earth has adapted to the most extreme environments but all known living organisms have the following properties in common. (1) They are based on cells, (2) both water and salt are essential and cell membranes contain pumps to exclude NaCl and include KCl in the cytoplasm, and (3) although genetic information flows in the direction DNA to RNA to protein, protein is required in all steps, showing that the process is an end result of evolution and does not represent a progression or macromolecular hierarchy. This means that all living organisms, even the ones that we consider as most ancient or primitive, are well along the path of evolution and that we know nothing about what preceded them. The quest for the apparition of life elsewhere in the solar system should start now in the way that we approach biological problems in our laboratories. It will colour our understanding of the most fundamental biological processes, from the molecular mechanisms within the living cell to biodiversity and the development of organisms within ecosystems, their adaptation to external conditions and their evolution. In this framework, biochemical and molecular biology approaches are being developed to identify potential molecular signatures of life. In addition to work on RNA, DNA, proteins, their precursors and other metabolic products, these approaches also include studies of novel analogues of information encoding molecules, such as chemically modified nucleosides, for example.(1,2)

Biochemistry in the 19th century and molecular biology in the 20th century were born from fundamental scientific discoveries made by chemists and physicists who were interested in the processes of life. Biologists, although at first understandably reticent about what they saw as absurd reductionism, eventually admitted the usefulness of these approaches and they have become the bases of modern biology. Nevertheless biology as a science still contains concepts that cannot be reduced to physics and chemistry. The most fundamental hypothesis in biology refers to the structure—function relation: if a macromolecule “exists” in a biological context, it is because it has been selected by evolution, by virtue of its function. A physicist or chemist may say that their catalytic properties are useful functions of naturally occurring zeolites; but such materials did not appear spontaneously in nature because they display these properties. Cells are often discussed as wonderfully synchronised machines but the more insight that we gain into their molecular mechanisms, the more we realise that this “harmony” is based on waste by selective elimination and generally cumbersome

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BioEssays 23.00 1
strategies. This is because the organising power of nature apparently does not occur from rational design, but has been built up in time through evolutionary processes. The very existence of a cell, its place in an organism, and the reactions that take place within it, can only be understood if its history is understood. The understanding of the origins of life on Earth, on Mars or elsewhere intimately involves the complex conceptual framework unique to biology, and will not be obtained on the basis of physics and chemistry alone, although these disciplines will continue to provide indispensable ways and means to approach the problems. (3) Despite this, many biologists remain reticent about supporting “large science” projects. Even facilities such as synchrotrons do not enjoy their full approval, while they are quite happy to acknowledge the importance of protein structures for their studies. The “how many pipettes for one synchrotron” argument is now extended to “how many beam-lines for one trip to Mars”.

The surface of Mars today is cold and dry—conditions, which, although generally inhospitable to supporting life, are extremely favourable for the preservation of its traces. It is a reasonable bet that if biological cellular structures or macromolecules were trapped in salt crystals when the Martian seas evaporated, for example, they would be very well conserved for our observation and analysis. (4) With our present knowledge, it is not likely that traces of life on Mars would include those of large plants or animals (forests or cows, as once suggested by Carl Sagan...) as these would have been detected from orbit. Traces are likely to be microscopic or even molecular, which means that there is no alternative to bringing samples back to Earth for analysis. (5) Even though it is true that a sample from just about anywhere on the Earth’s surface contains traces of micro-organisms, we may not be so lucky with Mars and it is essential that biologists should be actively involved in the choice of sampling sites. A scheduled trip to Mars to bring back samples puts our backs to the wall with an important question: apart from the obvious precautions and quarantine to avoid cross-contamination, do we have the knowledge and tools to deal with the sample return? We believe that a good deal of preliminary work in biology is necessary, with special emphasis on developing new concepts. A large effort is now made towards developing special instrumentation for sample analysis, but new, radical ideas in biology are also required. Non-destructive methods will be required to deal with dynamical biochemical systems. These methods, which should extend beyond the analytical approach, must be able to deal with studies of reactivity, adaptability and kinetics involved in characteristic biological events, such as metabolic pathways or information transfer. As is clear from examples below, such work will also provide important results for Earthly applications so perhaps it will not be too difficult to obtain serious support for it, and funding.

Macromolecules are the smallest signatures of life. They encode information and are catalytically active with great specificity. Not enough is known about how they behave in a cell-free environment. How are their structures, stability, dynamics and interactions affected? (6) The modern concern with the safety of genetically modified organisms and the fate of “free” DNA would also be addressed by such studies. Organisms such as the ones belonging to the evolutionary domain of the Archaea, and macromolecules adapted to extreme Earth environments are currently being studied under the cover of potential biotechnological applications. (7) An understanding of the reactivity of biological structures that leads from macromolecular to cellular adaptation to an extreme environment, however, is absolutely fundamental. In this context, the term reactivity must be accepted in its broadest sense to include all the properties of a system that contributes to its biological function. These studies will require an approach of tightly linked biochemical and biophysical methods. Results from the Viking mission indicated that the surface of Mars is highly oxidised, making the presence of organic material unlikely. The chances of detecting traces of life would be higher in buried sediments. How do biological cells or macromolecules behave on various mineral surfaces? How are they affected by the physical and chemical nature of the surface, by the presence of bound water or salt? These questions should be tackled through studies of model systems and simulations. As examples, the in vitro selection of RNA molecules with specific molecular affinity (aptamers), and non-genomic peptide synthesis, can be used to study interactions between an information-containing molecules and various supporting surfaces. (6) Current very imaginative studies of the nature and origin of life should also be strongly encouraged. These include, for example, the exploration of new macromolecular combinations that allow the coupling of information content and reactivity.

Planning a trip to Mars to bring back samples for analysis is too important a biological venture to be left to physicists, chemists and geologists (or even areologists) alone...!

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