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FOSSIL LIFE ON MARS

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Three major problems beset paleontologists searching for morphological evidence of life on early Earth: 1) selecting a prospective site; 2) finding possibly biogenic structures; 3) distinguishing biogenic from abiogenic structures. The same problems arise on Mars. My terrestrial experience suggests that, with the techniques that can be employed remotely, ancient springs, including hot springs, are more prospective than lake deposits.

If, on the other hand, the search is for chemical evidence, the strategy can be very different, and lake deposits are attractive targets. Lakes and springs frequently occur in close proximity, and therefore a strategy that combines the two would seem to maximize the chance of success.

The search for morphological evidence of life on Earth during the Archean and Proterozoic (3.9 Ga–0.57 Ga) has been underway for about a century. Most major discoveries were made in the course of non-paleontological investigations. Each has lead to later systematic and frequently successful searches by paleontologists. There are two reasons why paleontologists have often followed others: we had to learn which rock types preserve remnants of unmineralized organisms and, even in those rock types, fossils usually are rare. Many discoveries have resulted from regional mapping.

For instance, if part of the strategy were to search for stromatolites on Mars, the following observations, although admittedly geocentric, should be considered:

1. The only abundant rock types in which these occur frequently are limestone and dolostone. They also occur in some siliciclastic rocks (sandstones) but they are exceedingly rare. Limestones and dolostones are rare in Archean sedimentary rock sequences.
2. It is rare to find a well-preserved limestone or dolostone with no stromatolites, but it is normal to have to search extensively within any such rock body (and in cherts) before finding possible stromatolites.
3. In most environments where stromatolites occur now (lakes, rivers, marine embayments, open ocean), they occupy only a small fraction of the available area. The reasons for this restriction are very poorly understood and warrant further study.

There is one environment where stromatolites occupy a large fraction of the available area—hot springs. These are associated with volcanism and presumably were abundant on Mars. They are readily recognizable on satellite imagery and aerial photographs because of their more or less circular form within which there is an annular arrangement of sediment types—they are targets in every sense of the word. There are reasons other than ease of recognition and abundance of stromatolites that make springs attractive sites for exploration for life:

1. They are sites of chemical disequilibrium that can be exploited as a source of energy for life;

2. The chemical and thermal gradients associated with springs sort organisms into sharply delineated distinctive and different communities, and so diverse organisms are concentrated into relatively small areas in a predictable and informative fashion;
3. Minerals such as silica and calcium carbonate precipitate from spring waters, so maximizing the chances of preservation of organisms;
4. Chemical sediments in which organisms can be morphologically preserved predominate in spring deposits—clastic sediments are relatively rare, in contrast to the deposits of rivers and lakes.

Once possible stromatolites have been located they must be distinguished from similar but abiogenic deposits. On Earth these are of two main types—splash deposits (stiriolites, that form on shorelines and around geysers) and pedogenic deposits (carbonates, silica and iron and manganese hydroxides that form in soil). Making the distinction can be very difficult or impossible without microscopic and chemical analysis. The following types of observation are required:

1. The distribution and nature of associated sediments (i.e. macroscopic facies relationships).
2. Search for diagnostic mesoscopic features (e.g., evidence of sediment coherence such as is provided by microbial mats—ragged desiccation cracks, overfolded laminae; evidence of possibly abiogenic chemical precipitation *in situ*—fitted pisolites; evidence of movement of microorganisms towards the lightconical laminae with rib-like features).
3. Diagnostic microscopic features (fabrics which indicate the former presence of cells, even if the cells themselves are not preserved). Probably only about 1–10% of stromatolites have such features.
4. Chemical discontinuities such as a carbon isotopic difference between oxidized and reduced mineral species in the stromatolite.
5. In the most favorable cases, preserved microfossils. These are extremely rare in carbonate stromatolites, and occur in perhaps 1–10% of chert stromatolites. Preserved molecules derived from cells (biomarkers) are even more rare.

Even with all of these techniques available on Earth, it is difficult to prove that a stromatolite is biogenic. We generally settle for 90% probability. We could improve on this if we understood more about abiogenic structures that resemble stromatolites, and if we knew more about the processes by which minerals precipitate in and around microorganisms, which might allow us to distinguish biogenic mineral fabrics. We do know, for instance, that stromatolites have a distinctive carbon isotopic composition that is different from that of at least some otherwise comparable structures.

If the site selection strategy were to include spring as well as lake deposits, the chances of finding morphological evidence of life would be significantly enhanced. If in addition it was possible to combine a range of macroscopic, mesoscopic and microscopic observations with isotopic analyses, it would be possible to select probable stromatolites from amongst a larger sample set on the surface of Mars.