Seeking the oldest evidence of life on Earth

Introduction

The search for the oldest evidence of terrestrial life is a search for answers to some of mankind's oldest questions. But do we really have a chance of finding unequivocal fossils of the simple, soft bodied microorganisms that were the first inhabitants of this planet if we consider their lack of hard parts, their concealment from the naked eye, their simple morphologies, the timeframes and planetary processes since their formation (perhaps more than 3 billion years ago), and the rarity of suitable ancient rocks?

Despite these challenges, it appears that a biological record may exist in the oldest sedimentary rocks (c. 3.5 billion years) in the Pilbara region of Western Australia. Since the first report of putative fossils in the Pilbara[1,2], the area has become widely regarded as the prime natural laboratory for the study of early life on Earth and, more recently, as an analogue for primitive biospheres that may be preserved in the rocks of other planets such as Mars. However, the interpretation of fossils in Pilbara rocks is contentious, owing to the difficulty of distinguishing between true fossils and abiological artefacts[3].

From studies of younger analogues, however, we now know that there are also non-fossil lines of evidence that can be used in the search for life, as microbes can leave traces of their passing in many different ways. These are not fossils, but ghosts and shadows, chemical and physical signatures that, when combined with contextual information and detailed mapping, can help us identify and understand the record of Earth's earliest biosphere. In 2003, scientists at the Australian Centre for Astrobiology (ACA) commenced a new palaeobiological investigation in the Pilbara to study the ghosts and shadows of the oldest organisms.

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New field research in the Pilbara region

The ACA Pilbara research project is based upon a unique mix of ground based and remote geological and geophysical techniques to acquire contextual information and create detailed maps. The multidisciplinary study is centred upon the Strelley Pool Chert, a remarkably well preserved and palaeobiologically significant 3.45 billion year old sedimentary rock formation that crops out over tens of kilometres in the Pilbara (Figure 1). The Strelley Pool Chert contains unique structures that have been interpreted as stromatolites (a type of sedimentary structure formed by microorganisms – Figure 2).

Three main questions of palaeobiological significance are being investigated in the Strelley Pool Chert:

- Was there life on Earth 3.5 billion years ago?
- If so, what type of environment did it flourish in?
- What were the interrelationships between biological communities and the environment?

The novel combination of ground based geology and remote sensing (airborne and handheld infrared spectral) techniques, incorporating data at regional to microscopic scales, will hopefully answer these questions and help to build a new, more robust model of Earth's early biosphere.

Preservation of ancient signs of life

As Carl Sagan once remarked, *"extra-ordinary claims require extraordinary proof"*, and claiming the oldest evidence for life on Earth is no exception. Palaeobiologists have questioned whether stromatolites in the Strelley Pool Chert were indeed formed by microorganisms, or whether they were formed abiotically[4].

A detailed morphological study of these putative stromatolites commenced in 2003, and has yielded important observations that support a biogenic origin. Distinct and, in many instances, complex morphology, suggests that microbes played a fundamental role in the deposition of sediments. Studies of modern microbial sediments reveal how organisms commonly leave characteristic features in the sediments being deposited around them. Thus, biological activity is often documented in the geological record in the form of chemical signatures and unusual rock formations, including stromatolites, even when the microorganisms themselves are not fossilised. Laboratory and field investigations have suggested that some structures with simple stromatolite-like morphology might also be reproduced by abiologic mechanisms such as structural deformation, current or wave action or chemical precipitation.

Nevertheless, research conducted at the ACA suggests that there are no examples in the geologic record where the range of stromatolite characteristics observed in the Strelley Pool Chert are clearly produced by abiogenic mechanisms, although biogenic examples are documented. Thus, a biologic input seems most probable.

Hydrothermal activity?

During field mapping in 2003, probable traces of hydrothermal activity during deposition of the Strelley Pool Chert were investigated in an area called the Trendall Locality. ACA scientists have discovered unique geological features in the area that are interpreted as probable signs of past hydrothermal activity. An investigation of the interrelationship between possible hydrothermal signatures and the stromatolites is presently underway.

On the one hand, current data indicate that the hydrothermal features are restricted to layers above and below the stromatolites, suggesting that stromatolite-building microorganisms might have flourished between times of hydrothermal activity (i.e. during inactivity or quiescence, suggesting microbes favoured a non-hydrothermal environment).

On the other hand, stromatolites in the vicinity of the interpreted hydrothermal features do show greater morphological complexity compared to those elsewhere in the Strelley Pool Chert, suggesting a relationship between development of possible microbial communities and hydrothermal activity. Investigation of these relationships will provide an excellent opportunity to determine the governing factors that gave rise to early life on Earth.

Short Wave Infrared Reflectance (SWIR) spectral mapping of the Pilbara

Scientists at the ACA are using a Portable Infrared Mineral Analyser (PIMA), an Australian built instrument, to examine the mineralogy of ancient rocks of the Strelley Pool Chert and assist in the recognition and interpretation of sites of past hydrothermal activity. The PIMA instrument uses Short Ware Infrared Reflectance (SWIR) spectroscopy, which is a simple and effective tool for analysing the mineralogy of rocks. Some minerals absorb light at selected wavelengths in the infrared band, owing to the vibration of bonds within their structure [5]. By examining the spectral patterns of light reflected from samples (Figure 3), scientists can determine the minerals present.

The PIMA instrument is being used in the Pilbara to identify hydrothermally altered rocks, which are recognisable by the presence of minerals created by reaction between rocks and hydrothermal fluids. Such minerals (e.g. amphibolites, clays and micas, which are the hydrothermal alteration products of common rock-forming minerals such as feldspar) tend to assimilate hydroxyl (OH^-) groups within their structure. The hydroxyl bond produces a distinctive infrared absorption band at 2200nm that is easily recognisable in PIMA spectra. Thus, the passage of hydrothermal fluids through ancient rocks can be swiftly recognised in the field using the PIMA instrument.

In 2003, PIMA was used to seek evidence of hydrothermal activity in the Strelley Pool Chert. The spectra of black cherts in

Figure 1. The Pilbara study area. The Strelley Pool Chert was originally deposited as a horizontal layer, but has since been tilted around 90° so that it now dips vertically and stands high as a ridge (at right, curving back and in toward the rear centre of the picture). A person walking along the ridge can see unusual conical structures – interpreted as stromatolites – along most of the ridge length. The abundance and excellent preservation of the stromatolitic (?) outcrop provides exceptional opportunities to study what may be the oldest evidence of life on Earth.

Figure 2. A stromatolite in the 3.5 billion year old rocks of the Strelley Pool Chert. Note the conical shape and branched feature on the upper right flank. Those features are best explained by microbial influence during deposition of the fine sedimentary laminations.

the Strelley Pool Chert are relatively featureless, but show indications of water included in the mineral structure. Certain minerals, such as chlorite and muscovite, were identified in upper parts of the formation and in the overlying rocks, and may have resulted from reaction with hydrothermal fluids. The spectral pattern of carbonates associated with the putative stromatolitic layers indicate the presence of dolomite, which can be traced through to more silicified areas of the formation.

The PIMA dataset is also being used to provide ground-truth for mineralogical interpretations of regional airborne infrared maps. By integration with contextual geological information, this information is being used to map and interpret the environments in which the putative organisms flourished 3.5 billion years ago.

Microbes on Mars?

Current studies in the Pilbara are providing important practical information

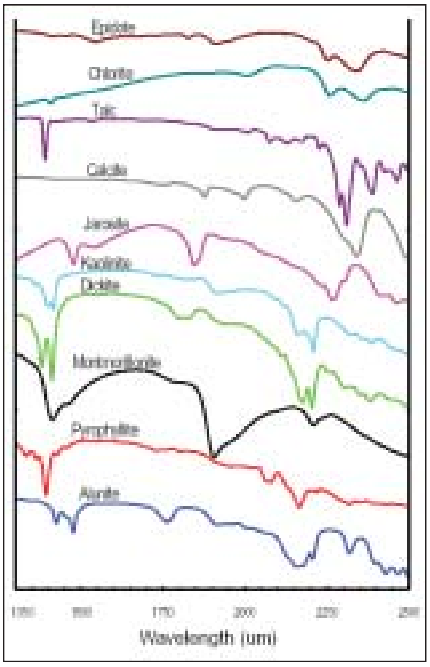

Figure 3. A selection of infrared spectra from minerals – note differing absorptions over the SWIR wave-length band from 1300-2500nm *(courtesy Integrated Spectronics, www.intspec.com).*

and scientific analogues that will assist in the exploration for life on Mars. In particular, the field use for remote sensing instruments such as PIMA simulates the use of rover-mounted instruments to study Martian surface geology and search for signs of life.

The use of PIMA in the Pilbara provides a unique opportunity to model and compare the data acquired by a rover-type instrument with the more detailed suite of geological data available to a scientist in the field. A further, important analogue lies in the comparison of ground based geological and spectral data with airborne spectral maps of the Pilbara, which mimics the relationship between Martian surface geology and data acquired by an orbiting instrument.

NASA and the European Space Agency (ESA) are currently engaged in programmes exploring the surface of the red planet in search of signs of past or present life. Mars exploration began with NASA's Viking mission in the late 1970s, which failed to find evidence for life on the inhospitable surface of Mars [6]. However, the range of conditions in which life can exist is continually being expanded as we discover microbial organisms in extreme environments on Earth, such as the frozen wastes of Antarctica, deep in the Earth's crust and hot seafloor vents [7].

This knowledge provides more reason to believe that microbes might find a niche somewhere on Mars, but we simply haven't looked in the right place yet; or at the right time! Indeed, we now suspect that the surface of Mars may not always have been so inhospitable to life and, at least in the early stages of its history, Mars may have offered environments for life that were similar to those on early Earth [8].

Thus, many scientists believe that our best chance of finding evidence for life on Mars is to target areas comparable to those that bear evidence of early life on Earth, such as the fossilised putative hydrothermal deposits found in the Pilbara. If such environments nurtured the earliest life on Earth, the same could be the case on Mars. It follows that a thorough understanding of the Early Archaean biosphere on our own planet and its preservation in the geological record will better equip humans to search for life on Mars.

Studying the ancient biosignatures in the Pilbara and their relationships to the environments of the early Earth will provide scientists with valuable information for the search for signs of life on a planet other than our own. By combining the Pilbara studies with Earth-based mapping of the Martian surface and studies of organisms in extreme environments on Earth, described elsewhere in this issue, Australian scientists are helping to answer some of mankind's oldest questions... "Where did we come from?" and "Are we alone?"

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