THE QUEST FOR A SECOND ORIGIN OF LIFE

Malcolm R. Walter*

It is difficult to imagine any greater goal for science than searching for life beyond Earth. Everything we know about life is based on a sample of one: life on Earth. We can only imagine the consequences of discovering life elsewhere, provided it had a separate origin. That, ultimately, is why we are exploring Mars. However, in the process, we are learning about the origin and evolution of the Solar System. Mars preserves a very ancient history that has largely been destroyed on Earth by tectonic recycling processes.

The Mars Science Laboratory (MSL) rover, Curiosity, is one of the latest in a long series of missions to Mars that started in 1960 with launches by the former Soviet Union and later the USA. The first successful mission was NASA's Mariner 4, which was launched on 28 November 1964, half a century ago. More recently, the European Space Agency launched very successful missions, followed by an Indian Space Agency mission, and the Japanese have also joined the quest. There have been more than 40 attempted missions, of which about half were successful at least to some extent. MSL is perhaps the most amazing mission of all. Who can forget the "seven minutes of terror" that constituted the landing sequence?

NASA's two Viking missions in the 1970s were the first, and still the only (apart from the failed Beagle2), missions with the explicit goal of searching for life on Mars. For some the results were equivocal, but most consider that no evidence for life was found. Maybe that was because the landing sites were frigid deserts, or maybe the instruments were not sensitive enough, but in any event the consensus is that there were no positive detections.

As recently as the 1950s, it was thought by serious scientists that there could be advanced forms of life on Mars – not little green people but ferns and other vegetation. That was because seasonally changing patterns of colour had been observed from Earth-based telescopes. We now know that these result from seasonal dust storms. And, of course, modern imagery has revealed that there are no canals, pyramids, or faces. So now the search for life on Mars focuses on microbes (Walter 1999).

From these numerous missions we have learned that early in its history Mars was warm and wet, like the Earth at the same time, more than three billion years ago. We have a record of life on Earth at that time, and it was microbial. If life arose here, why not there?

Thus the question is, with a whole planet to explore, how can we possibly expect to find anything microscopic? This seems like the ultimate needle in a haystack problem. Well, we can find the needles, for many reasons. Studies of Earth's biology, geology, and palaeontology over more than a century have taught us a lot. We know how to define precise exploration targets, and more and more we have highly effective instruments with which to equip our spacecraft and rovers. The early results from measurements by some of these instruments on Curiosity are described in the articles in this issue.

From the beginning of the exploration for life on Mars, we have used techniques first developed for comparable searches on Earth. This approach is known as the use of "Earth analogues." These can be places where there are living microbes or places where their fossilized remains can be found. Two such places – Shark Bay and the Pilbara – I know well because I and my colleagues and students have studied them for decades.

Shark Bay is on the coast of Western Australia (Playford et al. 2013). This is a vast area with several large embayments. One of these is Hamelin Pool, which is a misnomer because the "pool" is 55 km north–south by up to 25 km east–west. It is now part of a marine national park and a World Heritage Site. The high salinity of the area keeps out many metazoans, so it has become a haven for microbes that otherwise would be grazed upon. The result is an ecosystem that resembles that of early Earth.

Visually, the ecosystem is dominated by cyanobacteria, the organisms responsible for oxygenating the Earth as a result of their photosynthesis. They are responsible for much of the architecture of stromatolites (Fig. 1), sedimentary structures that can be found in abundance in rocks as old as 3.49 billion years. However, when this ecosystem is analysed by modern genomic techniques, it turns out to be extremely complex (Goh et al. 2009; Fig. 2), with many different kinds of microbes. If there were ever life on Mars, this is the sort of community we could expect, possibly without oxygenic photosynthesisers but still with some organisms that reacted to light (this seems to be an important component of stromatolite-building communities).

Figure 1 Subtidal stromatolites offshore from Carbla Point, Hamelin Pool, Shark Bay, Western Australia. The complexity of the microbial communities that inhabit and construct these and other stromatolites in this area is shown in Figure 2. Photo: David Flannery

The Pilbara region is also in Western Australia. Here we find some of the oldest well-preserved rocks in the world; they are up to 3.5 billion years old (Van Kranendonk et al. 2007). Such rocks are extremely rare because of subsequent tectonic reworking. The only other comparable area known is in the Barberton Mountainland of northeastern South Africa.

The Pilbara preserves the oldest convincing evidence of life on Earth (Fig. 3). That does not mean it is the oldest life, just that it is the oldest preserved in the rock record (e.g. Allwood et al. 2006; Van Kranendonk et al. 2008). Older rocks in Greenland are considered to preserve evidence of life, but in my opinion it is not convincing. In the context of

* Founding Director, Australian Centre for Astrobiology
University of New South Wales, Sydney, Australia

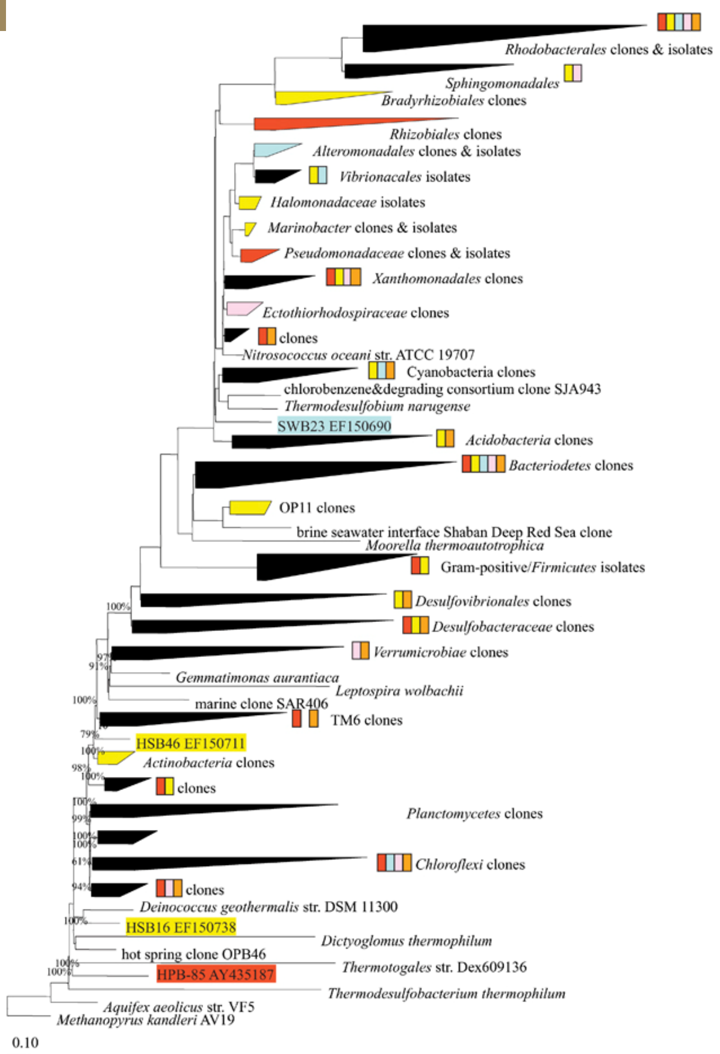

FIGURE 2 Phylogenetic relationships of total bacteria genomically sequenced from Shark Bay intertidal stromatolites. In addition to bacteria there are diverse archaea and eukaryotes, not included here. The scale bar represents 0.1 nucleotide changes per nucleotide position (this is a measure of the genetic disparity between related organisms). The colours represent different studies summarized here. Details are in Goh et al. (2009), from which this figure is reproduced with permission.

FIGURE 3 Martin Van Kranendonk discussing 3.43-billion-year-old stromatolites in the Strelley Pool Formation, "Trendall locality," Shaw River, Pilbara Craton, Western Australia. PHOTO: CAROL OLIVER

FIGURE 4 A thermal spring in Sentinal Meadow, Yellowstone National Park, USA. Even the boiling, 96 °C water contains living "extremophilic" microbes. Some of the colours on the white SiO_2 sinter are due to differing microbial communities distributed according to their temperature tolerances. PHOTO: GEOFFREY BRUCE

searching for past life on Mars, the Pilbara is particularly significant. The fossils are within the age range when Mars was warm and wet, and they are our best model for what may have lived on Mars.

There are many other areas that are informative as Earth analogues. One of the most significant is Yellowstone National Park in Wyoming, USA. It was there that research first revealed the high temperature tolerance of some microbes (FIG. 4). Scientific work there goes back to the 19th century (Weed 1889), and modern work on the microbiology of the hot springs was pioneered by Dick Castenholz and Tom Brock (e.g. Brock 1978). Any credible exploration model for life elsewhere must factor in the environmental limits of life on Earth, something we have yet to fully define. The research in Yellowstone has perhaps been eclipsed by that on the "black and white smoker" hot springs on our ocean floors, but it remains critical for our understanding of "extremophiles." Such environments must have existed on Mars (Walter and Des Marais 1993): the combination of volcanism and water make that inevitable, and some candidate sites have been identified (e.g. Brown et al. 2010).

MSL has confirmed that early in its history, Mars was warm and wet, with evidence for the former presence of lakes, rivers, and deltas. The layered structure of Mt. Sharp provides an excellent opportunity to read part of the history of Mars as the rover climbs the slopes – up in geological time – just as would a geologist on Earth. MSL is not designed to search for life, but it will continue to provide a wealth of new data on the past habitability of Mars.

REFERENCES

Allwood AC, Walter MR, Kamber BS, Marshall CP, Burch IW (2006) Stromatolite reef from the early Archaean era of Australia. Nature 441: 714-718

Brock TD (1978) Thermophilic Microorganisms and Life at High Temperatures. Springer-Verlag, New York, 465 pp

Brown AJ and 8 coauthors (2010) Hydrothermal formation of clay-carbonate alteration assemblages in the Nili Fossae region of Mars. Earth and Planetary Science Letters 297: 174-182

Goh FI and 6 coauthors (2009) Determining the specific microbial populations and their spatial distribution within the stromatolite ecosystem of Shark Bay. International Society for Microbial Ecology Journal 3: 383-396

Playford and 5 coauthors (2013) The Geology of Shark Bay. Geological Survey of Western Australia, Bulletin 146, 281 pp

Van Kranendonk MJ, Smithies RH, Hickman AH, Champion DC (2007) Review: secular tectonic evolution of Archaean continental crust: interplay between horizontal and vertical processes in the formation of the Pilbara Craton, Australia. Terra Nova 19: 1-38

Van Kranendonk MJ, Philippot P, Lepot K, Bodorkos S, Pirajno F (2008) Geological setting of Earth's oldest fossils in the c. 3.5 Ga Dresser Formation, Pilbara Craton, Western Australia. Precambrian Research 167: 93-124

Walter MR (1999) The Search for Life on Mars. Perseus Books (US), Allen & Unwin (Australia), 170 pp

Walter MR, Des Marais D (1993) Preservation of biological information in thermal spring deposits: Developing a strategy for the search for fossil life on Mars. Icarus 101: 129-143

Weed WH (1889) Formation of travertine and siliceous sinter by vegetation of hot springs. US Geological Survey 9th Annual Report 1887-1888, p 613-676