The search for life on Mars

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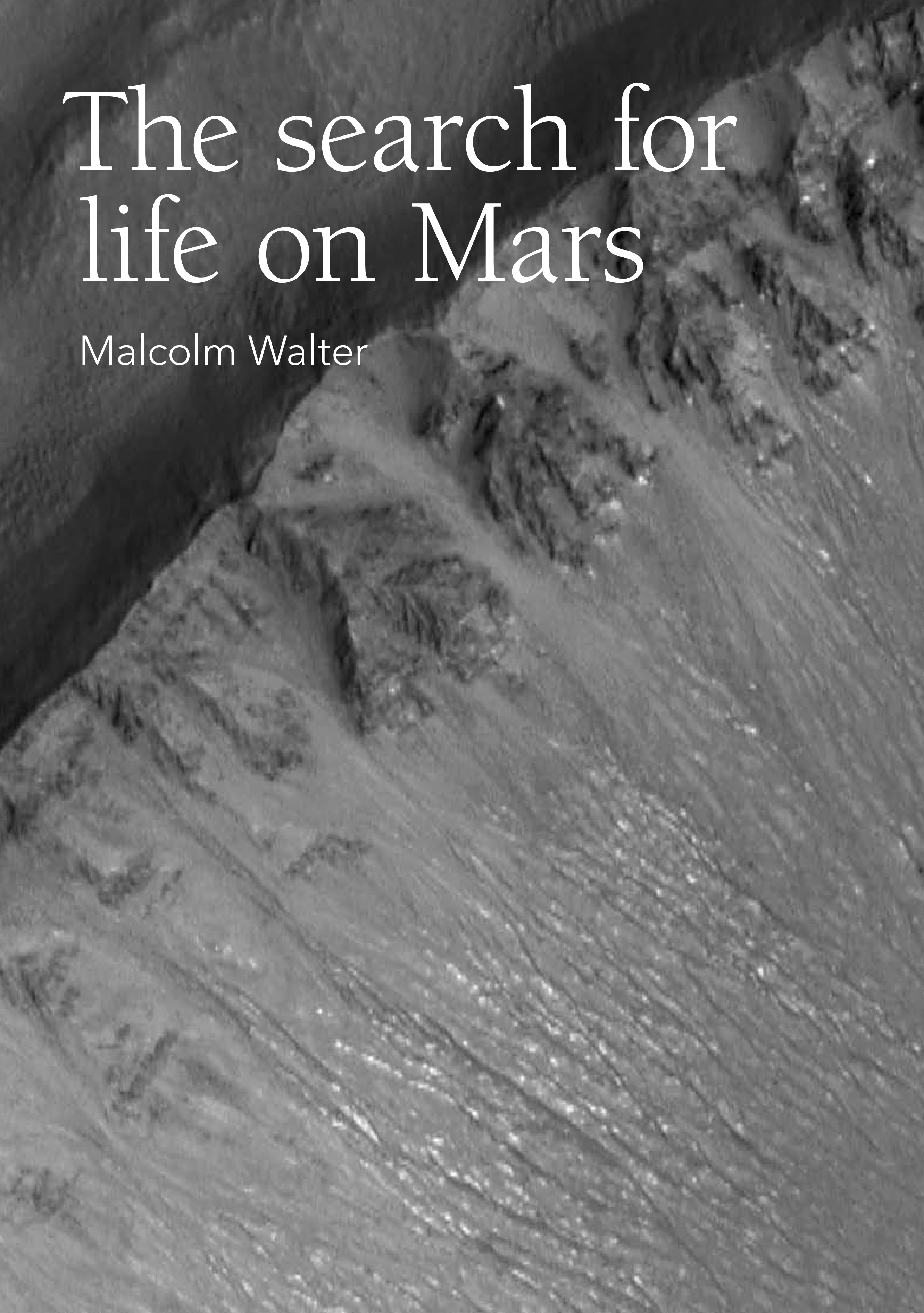

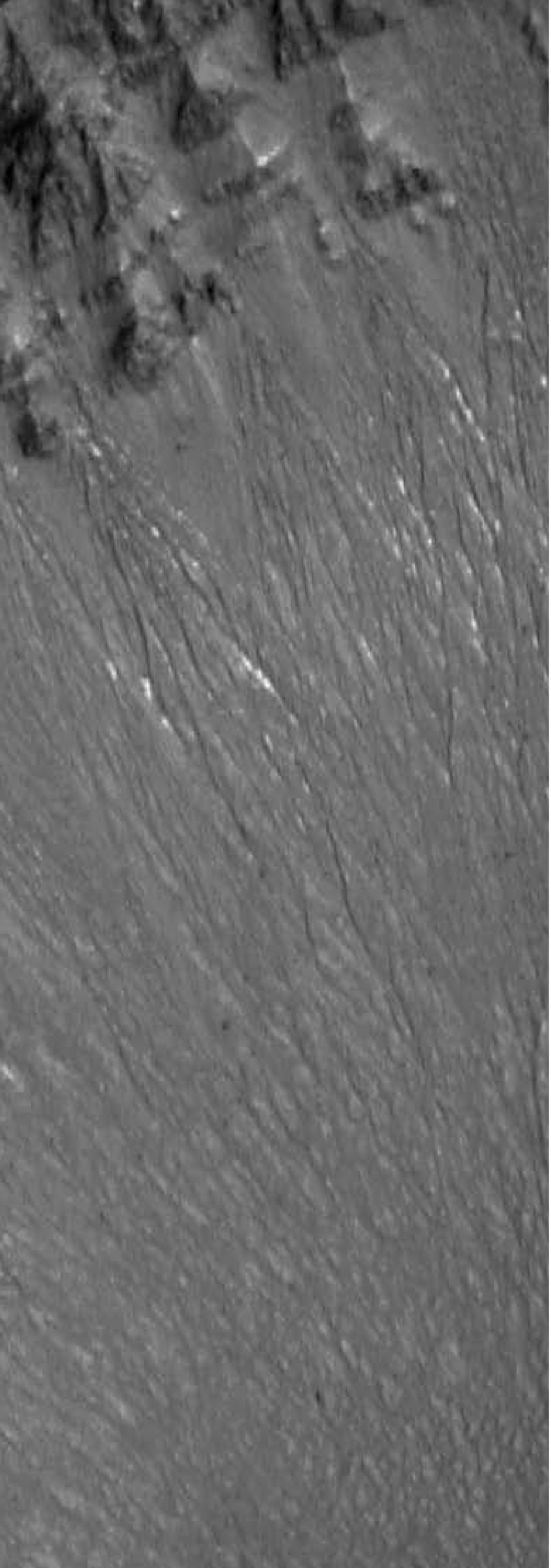

It has long been thought that there might be life on Mars. A century ago some astronomers thought that they could see canals on Mars and imagined a dying civilisation on a drying planet struggling to survive. In the 1950's astronomers noticed that patches of colour on Mars change with the seasons and thought that this might be due to seasonal changes in vegetation. In the 1960's and 70's some enthusiasts saw in the first fuzzy pictures from Mars pyramids and a giant face.

All were deceived. Modern high resolution images show that there are no canals, pyramids or faces. And the colour changes result from seasonal dust storms.

Why focus on Mars?

Over the last decade more than 350 "extra-solar" planets have been discovered and our own solar system has been explored in ever increasing detail. There could be life on many planets and moons, though none has yet been found, but Mars is special. That is because we

Figure 1: An image of Mars showing the northern polar cap. The white patches are water-ice clouds.

Image courtesy of NASA/nasaimages.org

have discovered that early in its history it was warm and wet, like the Earth, although now it is a frozen desert (Fig. 1).

All life on Earth requires liquid water, and so the assumption is made that that will also be true of life elsewhere. Similarly, all life on Earth is constructed from compounds of carbon, and this too is assumed to be true of life elsewhere. This is just a normal conservative scientific approach, of making predictions on the basis of current knowledge. It does not rule out other possibilities, but indicates where the focus should lie.

The Ages of features on Mars

As yet no samples have been collected on Mars and returned for analysis, so we have no direct dates for the features we observe. However, there is an indirect way of determining approximate ages. Like all the rocky planets Mars accreted from the infall of asteroids, meteorites, comets and dust. The rate of infall, "bombardment", was very high early in the life of the solar system and diminished to the current very low rate about 3.9 billion years ago. We know a little about rates of bombardment because samples of the Moon collected during the Apollo missions have been dated here on Earth, and those dates can be directly related to the cratering of the Moon. It is assumed that the rates would have been similar on Mars.

So for Mars we can count the number of craters in a particular region and on that basis determine the approximate age of the landscape. This is how we know that the "warm and wet" period was more than three billion years ago.

Water on Mars

It has been known since the NASA Mariner missions in the 1960s that something liquid flowed on the surface of Mars early in its history. That is demonstrated by an abundance of now-dry river valleys (Fig. 2). Liquid water now is not stable on the surface of Mars because of very low temperatures combined with low atmospheric pressures (Fig. 3). As a result, water ice sublimes directly to vapour without passing through a liquid phase. Even at the current very low temperatures there is still an active "hydrological cycle". One of the Viking landers in 1976 observed water frost on rocks and the Phoenix lander in 2008 observed snow falling.

A range of observations have demonstrated that the polar caps of Mars are a mixture of carbon dioxide ice and water ice. Recent studies using

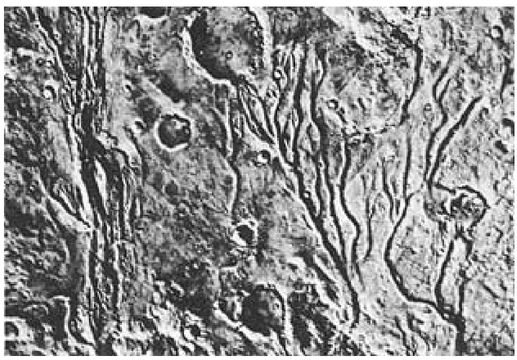

Figure 2: Dry river valleys and meteorite craters, imaged by Mariner 9. The imaged area is several hundred kilometres wide.

Image courtesy of NASA/nasaimages.org

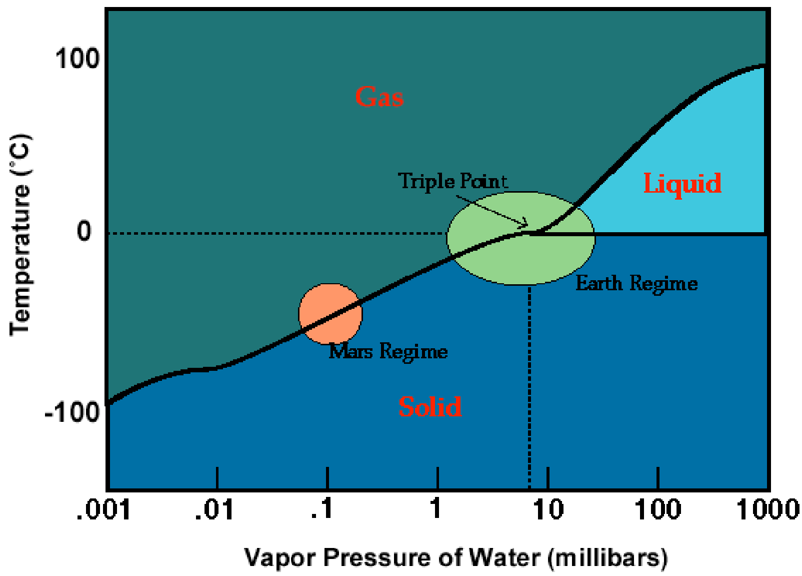

Figure 3: A phase diagram comparing the surface environments on Earth and Mars, showing why pure liquid water can not exist on the surface on Mars.

Image courtesy of NASA/nasaimages.org

gamma ray spectroscopy and ground penetrating radar observations from satellites have shown that water ice is very widespread on the planet, but most is covered by sediment. There is evidence of glaciers.

So there is no shortage of water. There will be liquid water at depth in the crust of Mars because the interior of the planet is hot. That is known because there are volcanoes that have been active in the last few million years. Olympus Mons is an example (Fig. 4).

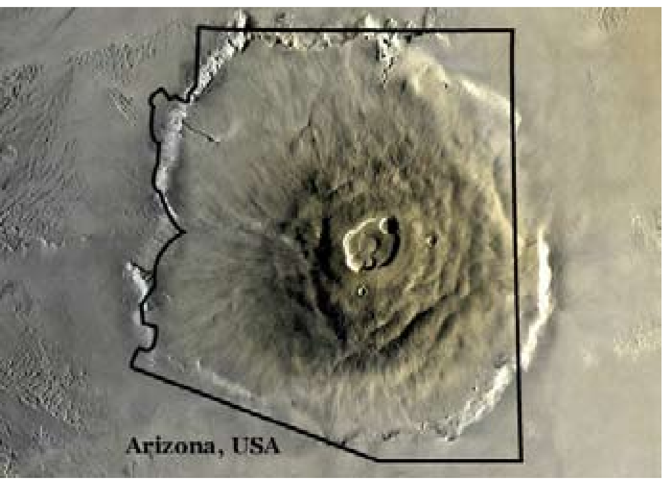

Figure 4: The largest known volcano in the solar system, Olympus Mons on Mars. It is 500 km in diameter and 27 km high. I

Image courtesy of NASA/nasaimages.org

At the equator in Summer, water could be liquid within a hundred metres of the ground surface. There is evidence that even now occasionally water comes to the surface, perhaps after an earthquake or a meteorite strike. NASA's orbiter Mars Global Surveyor discovered large numbers of small gullies on the walls of meteorite craters (Frontis piece). The gullies are fresh and have not been eroded by the wind, and new ones appeared over the lifetime of the mission (Fig. 5). Although it is not known with certainty, the most plausible explanation is that the gullies were eroded by brief outflows of liquid water from underground aquifers. More recently, possible droplets of water were photographed on the legs of the Phoenix lander in 2008 (Fig. 6).

Meteorites from Mars

In 1996 NASA held a press conference in Washington DC to announce the possible discovery of life on Mars. Naturally enough this generated a huge amount of attention worldwide.

The discovery involved meteorite ALH84001 (Fig. 7). This meteorite was discovered in the

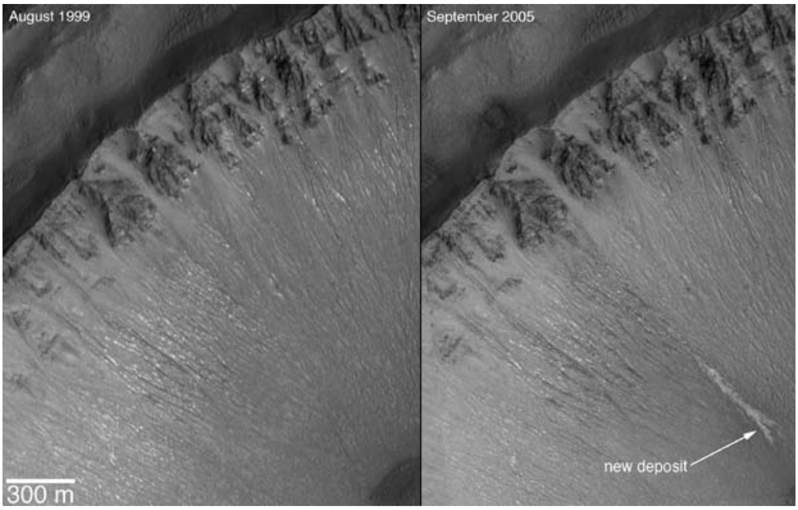

Figure 5: Recently formed gullies on the rim of an impact crater. These are considered to be evidence that occasionally liquid water from underground aquifers reaches the surface and flows for long enough to erode these features.

Image courtesy of NASA/ nasaimages.org

Allen Hills in Antarctica in 1984 and was the first to be catalogued that year, hence the name. Amongst the thousands of meteorites that have been found, 34 are known to have come from Mars. We know that because they have a distinctive chemical and mineralogical composition different from any other rocks found on the Earth or the Moon, and different from all other meteorites. Trapped within tiny bubbles in one of these meteorites are gases that match the composition of the atmosphere of Mars.

It happened like this: an asteroid hit Mars and blasted surface rocks off at such a high velocity that they could escape the gravity of Mars. The force of the blast melted parts of the rocks and as they flew up through the atmosphere gases were trapped in the melt. The rocks cooled in space, permanently trapping the gases.

Back on Earth, in a laboratory in Houston, the rock was broken open and examined with an electron microscope. Structures resembling fossil microbes were found on the broken surfaces (Fig. 8). That discovery led to more detailed analyses to determine whether the meteorite contained any other evidence of life. Organic compounds called polycyclic aromatic

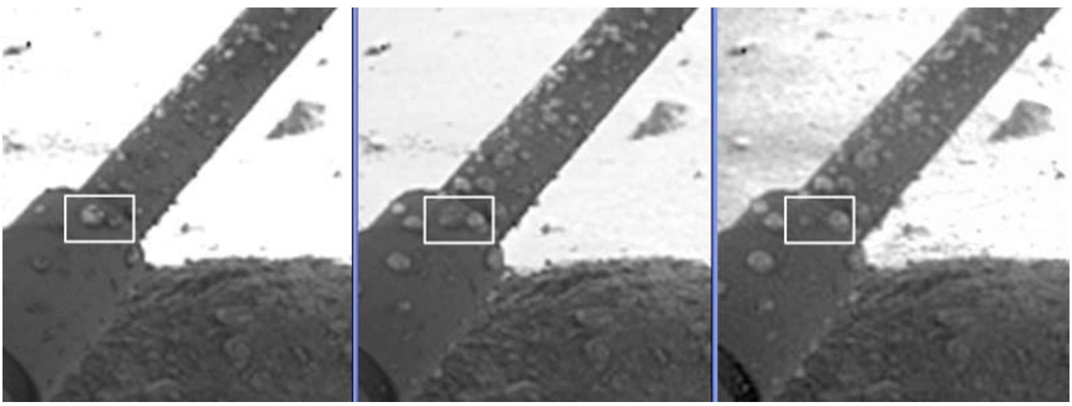

Figure 6: The globules shown boxed on a leg of the Phoenix lander in 2008 are interpreted by some scientists as water that can remain liquid because it is extremely salty.

Image courtesy of NASA/nasaimages.org

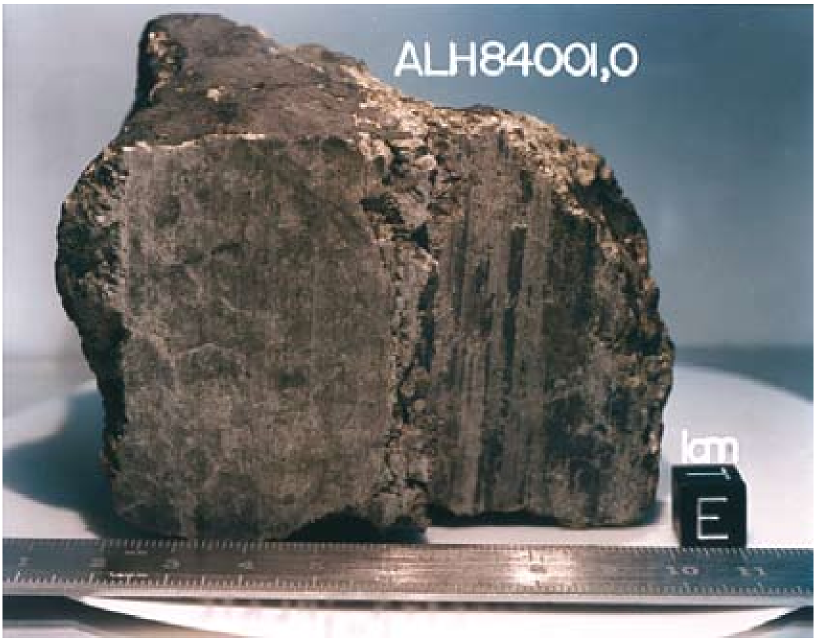

Figure 7: Meteorite ALH84001 which was once considered to contain evidence of life on Mars.

Image courtesy of NASA/nasaimages.org

hydrocarbons ("PAH's") were found, along with distinctive patterns of carbon isotopes. This and other evidence formed the basis for the claim that the meteorite contained evidence of the former presence of life on Mars.

Since 1996 many scientists have studied ALH84001 using a wide range of sophisticated techniques. The conclusion is that all of the observed features can be explained by non-biological chemical processes, and none is evidence for life. This is typical of how science works: hypotheses are offered and then many are refuted.

Methane in the Martian atmosphere

Telescopes on Earth can be used to analyse the atmosphere of Mars because different gases have characteristic infrared spectra. In 2003, patches of atmosphere rich in methane were discovered. Three large patches, or "plumes", are now known. This is significant because methane is unstable on Mars and would break down rapidly. So there must be active sources spewing the methane out of the crust. This also happens on Earth where there are two types of sources: volcanoes and microbes.

This demonstrates that Mars is still an active planet. It is not possible at present to determine whether the methane is biological or geological in origin. On Earth that distinction is made by measuring the carbon isotopic composition of the methane. Biological processes strongly select the lighter isotope, ^{12}C, whereas geological processes do not. It is not yet possible to measure the isotopic composition on Mars but there are plans to do so on a forthcoming mission.

Exploration to date

There have been more than 40 attempted missions to Mars, the first in 1960. In the early years there were many failures but the success rate now is very high. Only two successful missions have had the specific goal of searching for life, NASA's Viking 1 & 2 in 1976. Both were stationary landers with onboard laboratories to analyse for organic compounds and to test for gases produced by living organisms. One experiment gave ambiguous results but it is now accepted that no life was detected. In retrospect that result is not surprising. It is now known that the surface of Mars is highly oxidising, so any organic compounds that might have been present would have been destroyed. In addition, Mars lacks both a substantial

Figure 8: An electron micrograph of a broken surface on meteorite ALH84001. The numerous spheroidal structures are 20-50 nanometres wide. These and the worm-like structure were at first interpreted as fossil microbes.
Image courtesy of NASA/nasaimages.org

magnetosphere and an ozone shield, so both cosmic and ultraviolet radiation reach the surface and would kill any organisms present.

So is there life on Mars?

We have learned over the last 50 years that the conditions essential for life as we know it existed widely on Mars early in its history, and still exist in subterranean environments and occasionally on the surface. But so far the only hint that there is life is the presence of methane in the atmosphere.

Within 20 years we will have much more information from robotic vehicles and we may be able to gather enough information to suggest the presence of life. A final demonstration may require the return of samples, and such a mission is being planned for 2020. That mission will be both enormously complex and enormously expensive.

I think it is very likely that there was microbial life on Mars and probably still is. But I think we will have to wait until astronauts go to Mars later this century to finally determine whether or not there is or was life there.

And the obvious question is, why bother? The answer is that the question of whether we are alone in the universe is one of the most profound questions we face. If there are microbes on Mars, and if we can demonstrate that they had a separate origin from life on Earth, then we will be able to predict that life is abundant throughout the universe. Somewhere out there will be other industrial societies, probably far more advanced than ours.