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Searching for life in a handful of dust

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30 October 2006
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David L. Chandler

Ripping open a sterile pack, Richard Quinn pulls out a surgical mask and carefully positions it over his nose and mouth. He puts on a fresh pair of latex gloves, unwraps a sterile scoop and crouches down on the dusty, pebble-strewn hillside. Then he scrapes a spoonful of powdery grey dirt into a vial and crimps a sterile metal seal onto it.

As I watch him, the wind quickly coats my shoes and clothing with a film of beige grit, and Quinn's meticulous procedure suddenly seems incongruous. Yet there's good reason for his care. The soil underfoot looks mundane, but this patch of ground in the Yungay region of Chile's Atacama desert is something special: some of its soil is the most lifeless yet discovered on this planet, more sterile than the cleanest operating room. And therein lies its attraction for Quinn and the many other scientists who have studied this region for a decade. They believe, paradoxically, that understanding the behaviour of this lifeless dirt holds the key to finding life elsewhere - not on Earth, but on Mars.

Quinn wants to solve a puzzle thrown up 30 years ago when NASA's two Viking craft landed on Mars. Among the experiments carried out after they touched down was one called the Labelled Release (LR) test, designed to look for telltale signatures of life. Its results looked promising, yet are still mired in controversy. However, when Quinn and others repeated the test on the sterile dust from Yungay they found startlingly similar results. Now the quest is on to understand what it is about the chemistry of the Yungay soil that gives a false positive for the signs of life. If the researchers can crack that, they hope to be able to design a definitive test to send back to Mars to establish once and for all whether life exists on the dusty plains of the Red Planet.

So far this has proved remarkably difficult. "Dirt is complicated, it's really hard to understand," says Chris McKay, who like Quinn is based at NASA's Ames Research Center in California. He has been leading expeditions to the Atacama desert for a decade. In fact McKay has roamed the world in search of extreme environments where living organisms struggle to survive, in the hope of better understanding the potential for life on Mars. He has tested soil everywhere from the dry valleys of Antarctica and the Canadian Arctic, to a Mexican mountain top above the world's highest tree line. So far the Yungay region is proving the deadest of them all.

The sterile characteristics of this soil may be a result of its extreme dryness - with only 2 per cent of the moisture of the Sahara and California's Death Valley. During 10 years of research, only a single rainstorm has been detected around Yungay, when 20 millimetres fell in April 2005. By Atacama standards, McKay says it was "a flood of Biblical proportions".

But lack of water is only part of the story. Soils vary greatly in

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composition from place to place, and even subtle differences in the mineral composition of the grains can have a dramatic influence on how the stuff responds to tests designed to look for life. Even lifeless soil, it now seems, displays complexities in the way it reacts with organic compounds that were not even guessed at when the Viking craft landed back in 1976.

Vital signs

The thinking behind Viking's LR test - one of three experiments aimed at spotting signs of life (see "Seeking the signs of life") - seemed straightforward enough. A pinch of Martian soil was scooped into a sealed container, to which was added a small amount of water containing nutrients that are consumed by virtually every known form of microbial life. The carbon in these nutrients was made up of the rare, radioactive isotope carbon-14, so if microbes devoured the nutrients the carbon dioxide they exhaled would be radioactive. If the experiment's detector picked up signs of radioactive CO_2, it would then heat the soil in the expectation that this would kill the creatures releasing the radioactive gas, and so halt its production.

That is what Viking seemed to find. When the nutrients were added, the soil gave off radioactive gas. Then the soil was heated to 160 °C for three hours and gas production halted. According to criteria agreed by Viking's science team, this counted as a positive: clear evidence that life was present on Mars.

Gilbert Levin, the designer and principal investigator of the LR test, was certainly convinced, and remains so today. However, Viking's other results pointed in a different direction. Another sensor, a combined gas chromatograph and mass spectrometer (GC-MS), failed to find any organic compounds in the soil. That was a double blow to the idea that the LR test had found traces of life. Not only was it at odds with the results of the LR test, it also raised the question of what could have happened to the organic compounds known to be constantly raining down onto Mars inside meteoritic dust. The likely answer, many people reasoned, was that something in the soil was reactive enough to oxidise and destroy the meteoritic organic material - and if that was happening, then these same chemical reactions could also have produced a false positive result in the LR test. Levin, however, has stuck to his guns, arguing that recent tests show the GC-MS was far less sensitive than originally thought and would have failed to pick up traces of organic material even in soil containing thousands of microbes. What's more, no one has yet figured out exactly what oxidisers might account for the results (see "Sterilising the soil").

Then, three years ago, McKay, Quinn and their colleagues gave the story a new twist with their discovery that the lifeless soil from Yungay exhibited a very similar response to that of Martian soil in the LR test. For planetary scientists, finding Mars-like dirt here on Earth was like stumbling on gold. Even if it was not the exact same thing, they figured that Yungay's soil could give them important new clues to explain Viking's data. With the desert soil available in practically limitless amounts, they could carry out a whole battery of tests to try to get to the bottom of whatever was generating the CO_2. It had to be something chemical, as for most samples every biological test came out negative.

Fussy eaters

The team were also able to try the LR test with a subtle but crucial tweak. The molecules of many organic nutrients such as glucose and the amino acid alanine are "chiral": in other words, they are not identical to their mirror image, just as our left hand is not identical to our right. Living creatures digest one form of these nutrients but not the other. So if you repeat the LR test with two separate nutrient solutions - one with biologically desirable nutrients, and one with the mirror-image forms - then if gas production arises from chemistry alone, the amount produced will be identical. If there are significant differences between the two, then metabolic processes typical of living creatures are likely to be at work. Sure enough, when Quinn and his colleagues tried this test on soil from Yungay, they found the reaction to be the same for left and right-handed nutrients, confirming that soil alone can produce CO_2

in the LR test; no life is required.

What causes the reaction - and why it stops after the soil has been heated - both remain a mystery. There are clearly oxidising chemicals in the soil but, as McKay says, it's "hard as heck" to figure out what they are and what they are doing. "It's a humbling lesson," he says. To hunt for clues, Quinn returned to Chile in June this year to collect samples from dozens of spots including along a 600-kilometre transect extending south from Yungay into slightly moister parts of the Atacama where hardy forms of life survive. Testing these samples back at his lab at Ames, he found that the results of the chiral LR test shift gradually from one end of the transect to the other. In the wetter regions, there is a distinct difference between the reactions from left and right-handed nutrients, but the closer the sampling area gets to Yungay, the smaller this difference becomes. On top of that trend there can sometimes also be large differences between sample sites just a few metres apart. Some show no chiral preference at all, while others show differences that suggest there must be microbes in the soil.

In an effort to explain this, Quinn has studied visible differences such as soil type, slope angle, orientation to the sun and the presence of water channels from last year's rare rainstorm, and now hopes to use this data to help tease out the factors that account for the uneven results in the LR test. He has identified at least three things that can generate CO_2: oxidisers in the soil, changes in the acidity of the soil that occur in the presence of moisture, and microbes.

The sterile Yungay soils certainly contain strong oxidants, the kinds of compounds suspected of destroying organic material in Martian soils, though whether they are the same chemicals remains uncertain. What has become clear, however, is that some samples of desert soil collected around Yungay contain both active microbes and oxidants.

This is encouraging news for Levin and others still hoping to find life on the Red Planet. "It demonstrates that an oxidising soil, and a soil with a chemical reactivity level similar to Viking's, does not necessarily preclude the presence of microbes," Quinn says. If anything, Atacama soils appear to be even more oxidising than those on Mars, he says. Nevertheless, Quinn is not betting on there being active microbes on Mars. There are other aspects to the Martian environment - strong ultraviolet light and drier conditions than Yungay - that he thinks probably preclude life, at least near the surface.

Last week, the story took another turn. Researchers led by geochemist Rafael Navarro-González of the Autonomous National University of Mexico suggested that the GC-MS experiment on Mars could have missed organic molecules even if they were there (*Proceedings of the National Academy of Sciences*, DOI: 10.1073/pnas.0604210103). Their tests on Mars-like soils measured the organic matter present and found trace amounts. But this was non-volatile and so would not have been released in the GC-MS test. "The surface could easily have had several orders of magnitude more organics than the Viking detection limit," says Navarro-González.

Even so Quinn and McKay believe they are close to being able to specify an experiment for a future Mars mission that will finally reveal whether there are living microbes on the planet. Understanding the chemistry of the soil is no longer the main issue: the key, Quinn says, is the chiral LR test. Testing the soils of the Yungay region will play a vital role in finding the right nutrients and validating this new test's effectiveness. "I've become so enthused about this whole approach that I emailed Gil Levin and said why don't we propose a mission to Mars," McKay says.

Advances in microengineering mean that the whole experiment could be shrunk to the size of a soda can, and weigh no more than a kilogram. Drop a group of these across the Martian surface and they shouldn't easily be fooled by localised variations in soil chemistry. An economy-minded NASA is now looking for just such low-cost science "micromissions". "The work we've done in the Atacama provides a more complete scientific basis for saying 'let's do it'," McKay says.

It may be a long time before we can pin down the chemistry of Martian soils. But the experiment by Quinn and others in the Atacama means that this is no longer an obstacle to finding out whether there is life on Mars. "We're almost ready to answer that one," McKay says.

From issue 2575 of New Scientist magazine, 30 October 2006, page 48-52

Sterilising the soil

What is it about the chemistry of Martian soil that destroys organic material so effectively? According to NASA planetary scientist Richard Quinn, the results from the Viking landers point to at least three different types of oxidising molecule that could do this: superoxides, peroxynitrates and hydrogen peroxide.

Earlier this year Sushil Atreya of the University of Michigan, Ann Arbor, published an analysis showing that electrochemical reactions capable of generating hydrogen peroxide could be triggered by large electrostatic fields formed by charged dust particles moving in strong winds. Atreya claims this process could produce enough hydrogen peroxide - a chemical commonly used as an antiseptic - to prevent any organisms from surviving on the surface of Mars. This could account for Viking's results when combined with the catalytic action that would be expected from iron particles in the soil, he says.

Henry Sun, a microbiologist from the Desert Research Institute in Las Vegas, Nevada, has a similar idea, but suspects that photochemistry triggered by the region's harsh sunlight plays an important role in creating these electric fields.

Along with Kelly Snook, a researcher from NASA's Goddard Space Flight Center in Greenbelt, Maryland, Sun spent this summer measuring the strength of electric fields in the Atacama soil. This required a great deal of trial and error, adapting an electrometer that had been designed for a different purpose, and involved long measurements in the blazing sun followed by others during the night with temperatures below freezing. Preliminary data shows that electric fields build up during the day but drop dramatically after dusk, and seems to back Sun's theory.

Seeking the signs of life

Launched in 1975, Viking 1 and 2 arrived on Mars in 1976. Each carried three biology experiments to determine whether the Martian soil contains any form of life

THE LABELLED RELEASE EXPERIMENT

Added radioactively labelled nutrients to the soil and tested for the release of radioactive gas

RESULT: At first there was a rapid release of carbon dioxide, but this soon died down, suggesting that organisms were not responsible

THE GAS EXCHANGE EXPERIMENT

Designed to test whether exposure to water vapour could reactivate dormant organisms in the soil. Detectors looked for changes in gases above the sample

RESULT: Oxygen was given off, but this could have been caused by chemical decomposition

THE CARBON ASSIMILATION EXPERIMENT

Organisms thriving in a carbon-rich Martian atmosphere would use carbon biochemically. This test added radioactively labelled carbon monoxide and CO_2, then heated the soil to drive off organics

RESULT: Labelled carbon compounds were detected, but chemical reactions in the soil could have been responsible