GLOW WITH THE FLOW DIVING INTO THE MARINE CREATURES THAT CREATE LIGHT

COSMOS

THE SCIENCE OF EVERYTHING

Issue 97

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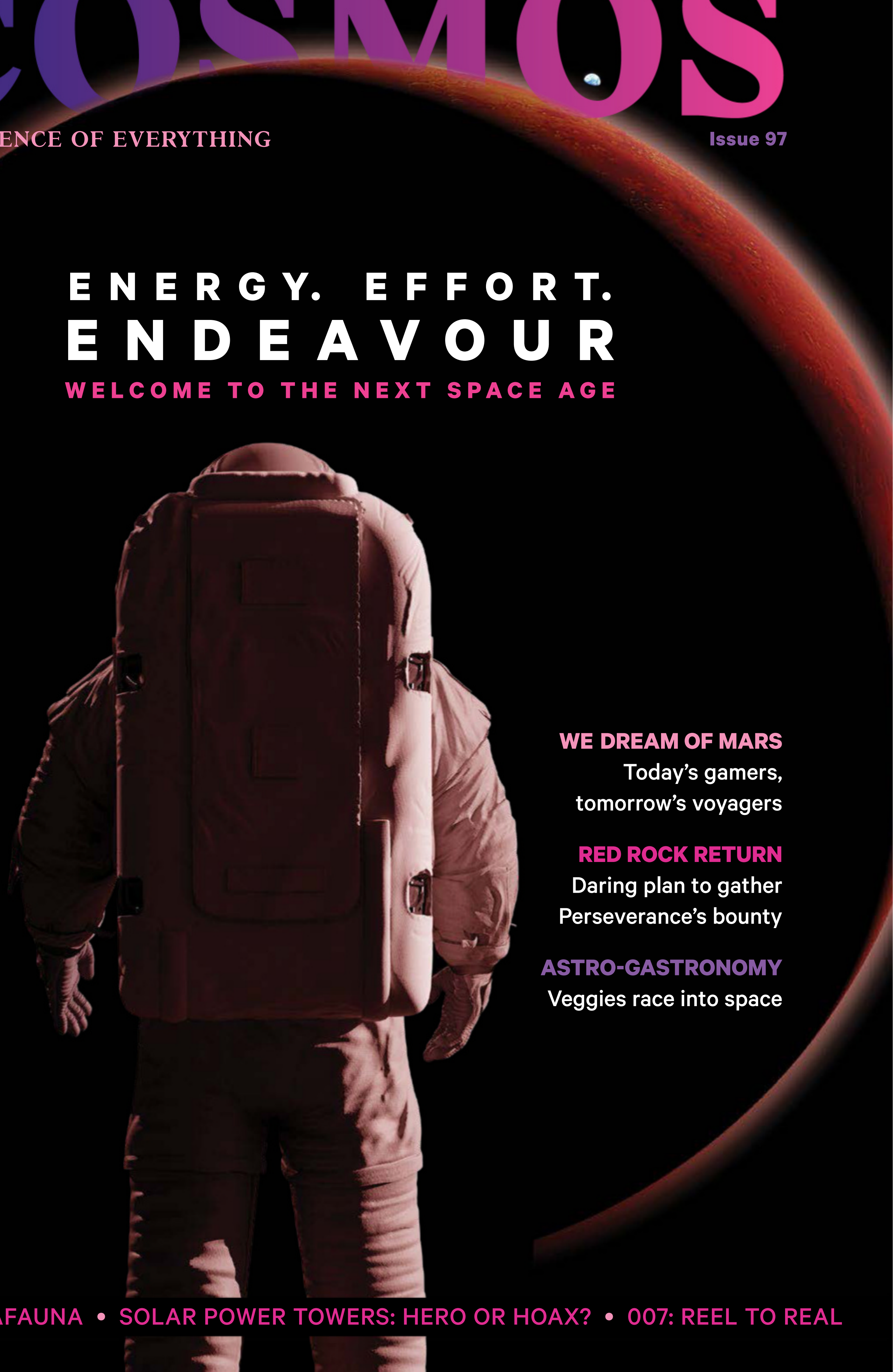

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MARS

An illustration of the joint NASA and ESA (European Space Agency) concept for a multiple-robot team to return Perseverance's Martian samples back to Earth. The current concept envisions delivering a Mars lander near Jezero Crater, where Perseverance, right, collects samples. A NASA Sample Retrieval Lander, opposite bottom, would carry a rocket (the Mars Ascent Vehicle –MAV). Perseverance would transport the sample tubes to the Lander, where a Sample Transfer Arm would place them into the MAV, opposite top, which would take them into Mars orbit. There, the Earth Return Orbiter, above, would rendezvous with the samples, Also shown is one of two NASA Sample Recovery Helicopters, which would travel to Mars on the Sample Retrieval Lander to support Perseverance if required.

NASA / JPL-CALTECH

Material retrieved from the Moon and asteroids is all very fascinating, writes **RICHARD A LOVETT**, but it's samples from Mars, projected to reach Earth in the early 2030s, that has scientists most excited.

ROCKS:

COMING SOON TO A LABORATORY NEAR YOU

Two years ago, a Japan Aerospace Exploration Agency (JAXA) capsule parachuted to Earth in the desert near Woomera, South Australia. On board were precious grains from the surface of the asteroid Ryugu, whose secrets will be studied for years to come in laboratories around the world.

Of course, it wasn't the first time extraterrestrial material had been brought back to Earth for study. NASA's Apollo program returned a total of 382 kilograms of rocks from six separate Moon landings, and the Soviets also successfully returned lunar soil samples in three less-heralded robotic missions between 1970 and 1976. The Chinese have also entered the act, successfully retrieving 2kg of lunar soil samples in December 2020 – only 10 days after JAXA's asteroid triumph.

But the big prize for scientists salivating to get extraterrestrial samples into their highest-tech lab equipment is Mars.

The Moon is interesting because it was built from pieces blown off the Earth by a giant collision and can tell us much about our own planet's history. Asteroids are interesting because they contain fragments from the early history of the Solar System, from which we can piece together not only the origins of the Earth, but how our planet may have acquired the building blocks of life.

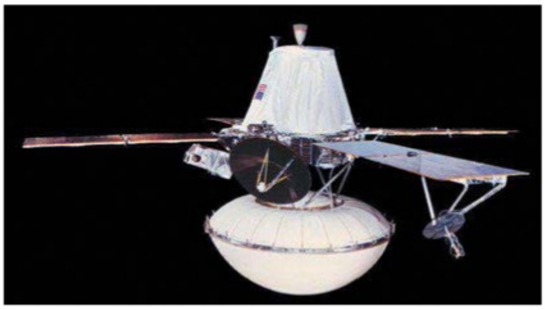
But Mars? Since the 1970s, planetary scientists have known that it had water, with rivers, lakes, and possibly an ocean. At one time it was warm and wet, and even as its lush, early climate faded, it still had parts that may have looked a lot like portions of Iceland, Australia, the Canadian Archipelago, the American Southwest, and Chile's Atacama Desert. And while some of these earthly places are pretty barren, all have life.

If we're looking for signs of one-time life on another planet – at least one we can get to with today's technology – Mars is the place. Not that this means Mars had life. But there is little doubt that it was once habitable.

AUDACIOUS PLANS – AND HOW TO IMPROVE THEM

The search for signs life in the rocks and soils of Mars is nothing new. NASA's two mid-1970s Viking landers were primitive by today's standards, but they still were able to carry chemical labs whose primary goal was to find metabolic traces of life on the Martian surface. (They failed to do so, though the results were not without controversy: see "Viking life test", at right).

Since then, the focus has shifted to hunting for signs of one-time habitable environments, many of which have been found by the last suite of NASA rovers: Spirit and Opportunity (2004–18), Curiosity (2012 to present), and Perseverance (February 2021 to present). But as sophisticated as these rovers have become, they are no match for Earth's labs, which can perform microanalyses impossible to do with even the most sophisticated robotic laboratories.



Best known for his acclaimed public television series *Cosmos*, Carl Sagan (top right) poses with a model of the Viking lander in Death Valley, California, in the 1970s. The Viking spacecraft (above right) flew with its lander encased in a "bioshield".

COSMOS • A PERSONAL VOYAGE / DRUYAN-SAGAN ASSOCIATES, INC; NASA

VIKING LIFE-TEST CONTROVERSY

A primary mission of both of NASA's 1976 Viking landers was to look not just for signs of ancient life on Mars, but signs that the Red Planet might still be inhabited.

To do this, they scooped up soil samples and conducted a number of tests, one of which was to add a C14-labelled nutrient solution to the soils and incubate them.

If Earthlike life was present, the theory was, it would metabolise these nutrients and produce C14-containing gases such as carbon dioxide or methane.

All of the other tests came up negative, including ones looking for organic carbon (from bits and pieces of microorganisms) in the soil samples. But, the "labelled release" experiment – as it was called – did indeed produce positive results.

As a video from the New Mexico Museum of Space History puts it, "evidence for life was seen, but no bodies were found".

Just why isn't clear, although most scientists don't believe that the Viking experiments actually found life. The leading theory is that oxidising chemicals like perchlorates, now known to be contained in Martian soils, could have reacted with the nutrients and released C14-containing gases, without the need for life.

But other scientists disagree, and one of NASA's currently operating rovers, Curiosity, has repeatedly detected anomalous levels of methane, a compound that might (or might not) be a sign that Mars *still* has life, waiting to be more conclusively detected.

ULYANA HORODYSKYJ PENA

The harsh landscape of the Atacama Desert, Chile, has been used for Mars expedition simulations. Covering more than 100,000km^2, the Atacama is the driest non-polar desert in the world.

Now, the dream is nearing reality. Last July, NASA and the European Space Agency (ESA) announced the final phases in an ambitious program to get pristine Martian material samples back to Earth by 2033. And not just one sample, but as many as 33, each from a different site, totalling as much as 4.5–5kg.

Yes, that's a tiny fraction of what Apollo brought back from the Moon, but given the distance, it's a stunning step forward. The program is called Mars Sample Return (MSR) and at its heart is the Perseverance rover and its plucky helicopter Ingenuity.

Getting a sample back from Mars isn't a simple process – it's much more complex than Apollo bringing rocks back from the Moon or JAXA visiting an asteroid. NASA has compared it to a relay team, in which, in the initial concept, six separate vehicles were going to be involved.

The first was Perseverance. Its job was to collect samples, and, like a sea turtle nesting its eggs on a beach, deposit them in a series of caches. Perseverance would be followed by two other landers. One would deploy an ESA-built Sample Fetch Rover designed to chase down Perseverance's trail, retrieve the samples from their caches (and possibly from Perseverance itself, if it was still functional), and bring them back to a second lander. Quick, fast, and efficient: that was the goal.

"The engineer in me was fascinated by [that], because it's designed to travel much faster than previous Mars rovers, probably about four or five times as quickly," says MSR program manager Richard Cook, who's based at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California.

The second lander, called the Sample Retrieval Lander, would carry a rocket called the Mars Ascent Vehicle. The samples would be put in the rocket (which in artists' renderings looks a lot like a torpedo). That rocket would blast off from the lander and rendezvous with a sixth and final vehicle, an ESA-built orbiter that would scoop up the sample package, stow it away, and ease out of orbit for a slow return to Earth.

"Relay team" is indeed a good description, with the samples playing the role of the baton. The plan was also rather complex, with a lot of parts that had to operate flawlessly, millions of kilometres from Earth. Audacious barely begins to describe it.

The current plan is still audacious … but two of the major parts have been eliminated and a new, never-before-dreamed-of backup has been added.

The deleted parts are the Sample Fetch Rover and the lander intended to deploy it. Perseverance has performed so well, NASA scientists said in a 27 July briefing, that there's little fear it will perish before the Sample Retriever Lander arrives in 2028. After all, its cousin, NASA's Curiosity rover, is still going strong more than 10 years on, and NASA's Mars rovers have a good track record for being durable. That means that

The illustration below focuses on a concept for a proposed NASA Mars lander-and-rocket combination that would play a key role in getting Mars samples back to Earth. The machine at bottom, the Sample Retrieval Lander, would carry a small rocket, above, about 3m tall, called the Mars Ascent Vehicle (MAV) to the Martian surface. After loading the rover's sealed sample tubes into the rocket, the lander would launch the MAV into orbit around the Red Planet.

HEROIC HELICOPTER

When it was included on NASA's Perseverance rover as an additional 1.8kg of payload, the mission's tiny Ingenuity helicopter was supposed to be a one-month affair, intended simply to test whether it was possible to fly in the thin air of Mars. But the intrepid helicopter wasn't just a crowd-pleaser for space buffs; it worked wildly beyond expectations. As of midsummer 2022, it had completed 29 flights – 24 more than planned – and proven itself an invaluable companion for the Perseverance rover.

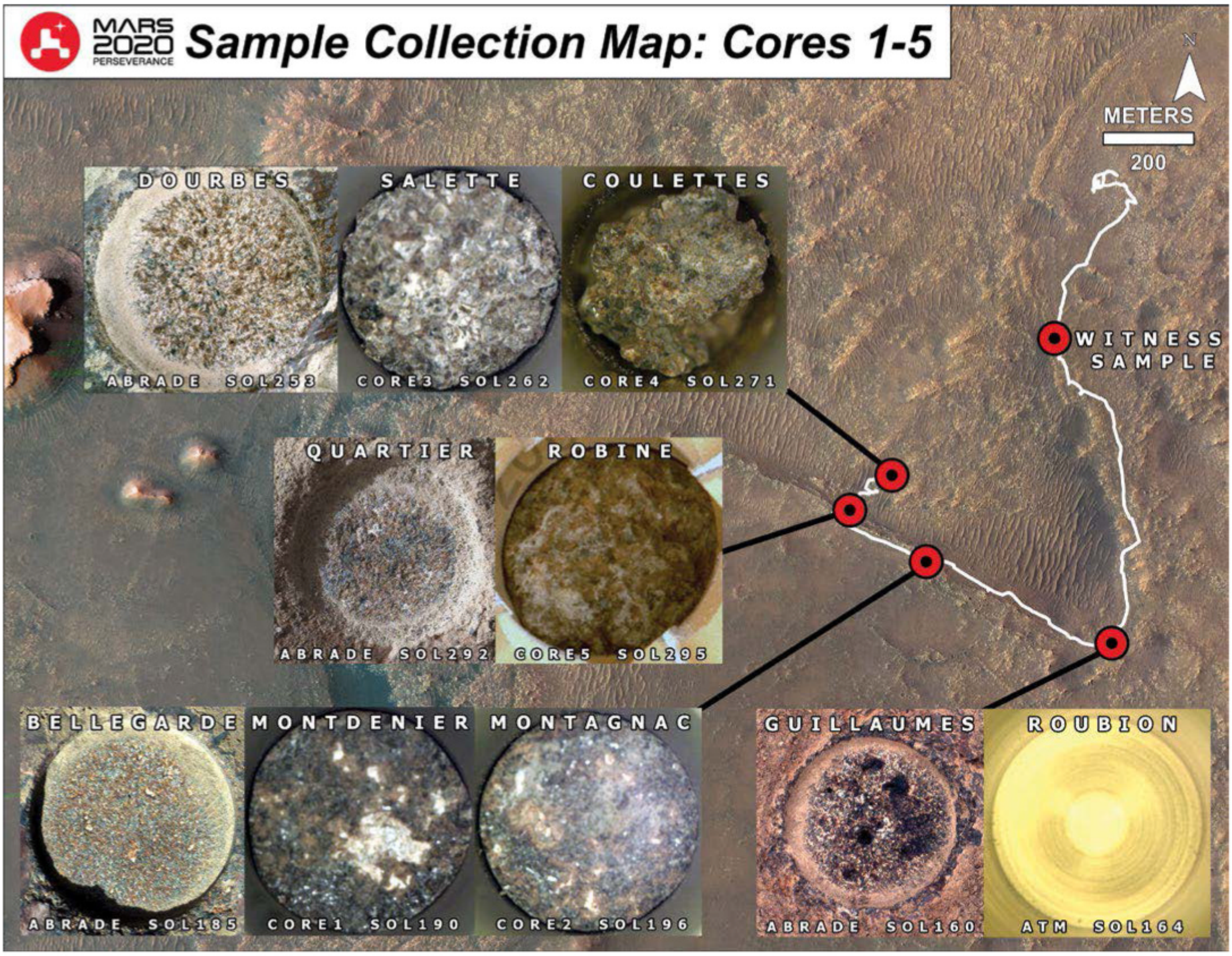
Initially, its biggest limitation had been the combination of its three-minute battery life and the need to find safe landing sites before its battery died. The safest thing to do was to scout no more than 60 or 70 seconds ahead, then return to its prior base to recharge its batteries, while scientists back on Earth looked to see if, in the process, it had found a safe place to land on its next foray. But that's cumbersome, time consuming, and with all of those back-and-forths reduces the helicopter's maximum speed across the terrain by a factor of four.

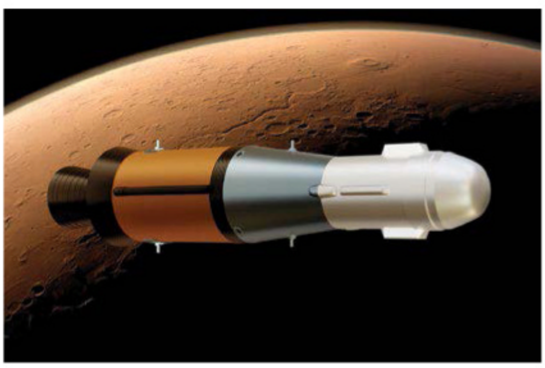
"We quickly figured out that if we had to scout out every site before we landed, we would dramatically restrict operations," Matt Golombek, a planetary geologist at NASA's Jet Propulsion Laboratory, said at the 2022 Lunar and Planetary Science Conference in The Woodlands, Texas. In fact, there were concerns that the helicopter would eventually get outrun by the rover and have to be abandoned.

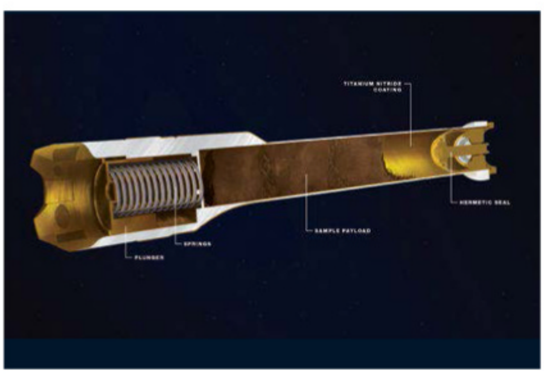
What was needed was to find a way to find safe landing zones from space, so the helicopter could go directly from one to another. And luckily, that was Golombek's specialty – something he'd been doing ever since the Mars Pathfinder landing in 1997.

"My day job is selecting landing sites on Mars," he says. "I've spent most of my career looking for rocks." With 29 helicopter safe landings (and counting), it looks like he knows what he's doing.

NASA / JPL-CALTECH







NASA / JPL-CALTECH / MSS; NASA X 2

This annotated map (above) shows the locations where Perseverance collected its first witness tube and filled its first samples. The name that the rover's science and operations teams used to define a rock target on the Martian surface appears at the top of each inset image. Also indicated is the Martian day, or sol, of the rover's mission and whether the image shows a target that has been abraded – by drilling the upper few millimetres of the rock surface – or is one from which a core sample was taken (the anomalous Roubion sample was drilled, but no material collected). All things being equal, these samples and up to 27 others will leave Mars' surface aboard the Mars Ascent Vehicle (left).

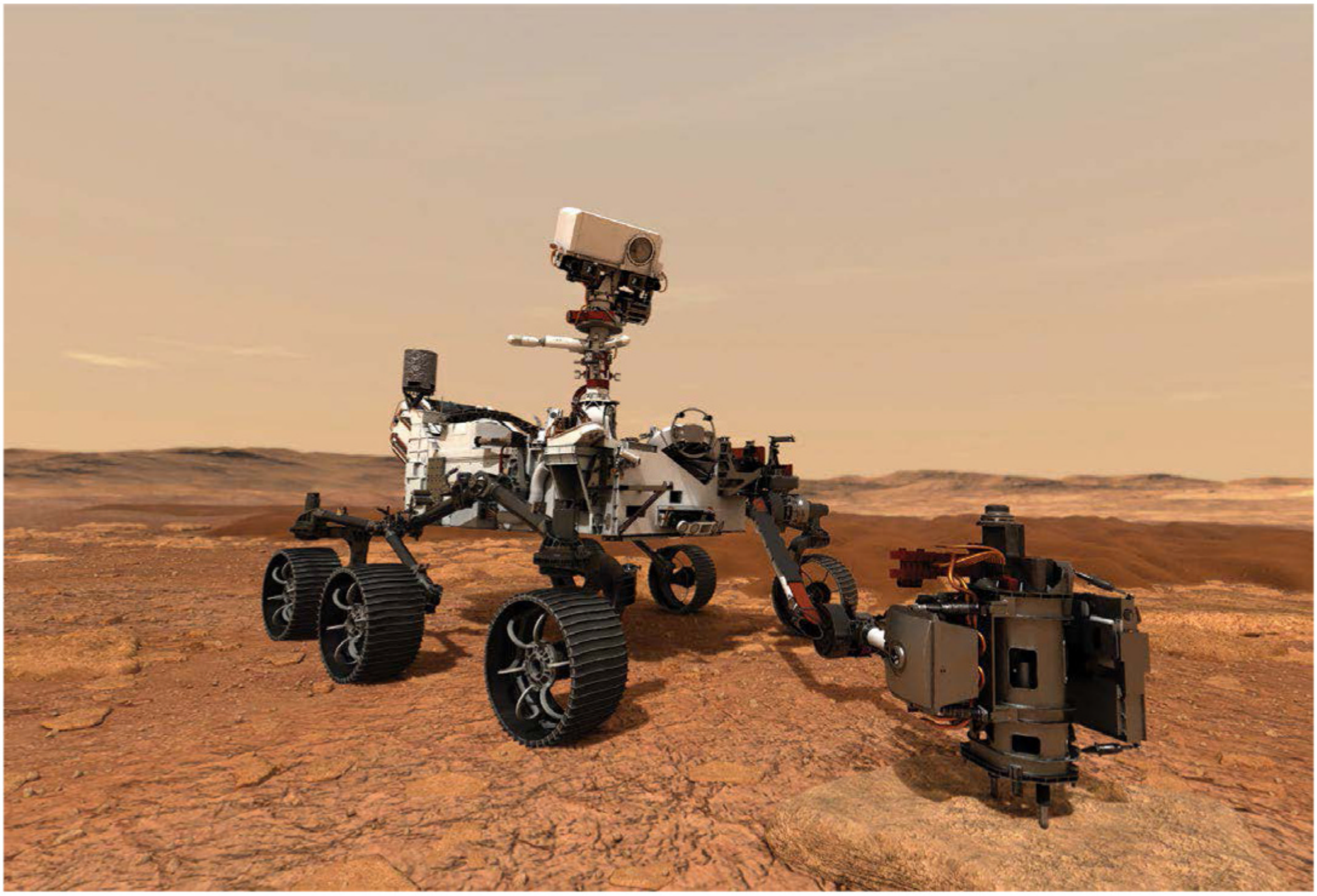
instead of relying on the Fetch Rover (and its lander), NASA will simply aim to land the Sample Return vehicle, with its ascent rocket, as close as possible to Perseverance and let Perseverance roll over to deliver the samples itself.

That's a major improvement in the plan, Michael Meyer, NASA's lead scientist on the project, told *Cosmos*, because however much success recent missions have had, landing on Mars "[is] always a risky proposition".

How close to Perseverance the Sample Retrieval Lander will set down is yet to be determined. "Right now, I think they are considering about 270 metres as the closest distance," Meyer says. Landing closer, is technically possible, but not worth the risk of accidentally coming down on top of Perseverance. Also, he says, "part of the trade [off] is fuel versus landing accuracy. The more pinpoint you want to be, the more fuel you need to carry."

At the same time, landing reasonably close is important, because in addition to the ascent vehicle, the lander will now carry two Ingenuity-class helicopters.

That's because the current helicopter has proven so durable that NASA has decided that similar ones,



equipped with some form of grabbing device, can serve as backup sample-retrievers if Perseverance itself is no longer up to the task. These helicopters, however, have limited range, so it's important not to hedge so far in favour of safety that the lander comes down out of helicopter range from Perseverance. "The goal is a minimal but safe distance," Meyer says.

MEANWHILE, BACK ON MARS...

In the meantime, Perseverance is busily collecting samples. As of 24 August, Meyer says, it had 15 on board, with more soon to come. Many of these samples are duplicates, taken two from a site. The plan is that when the total reaches about 20, one of each pair will be deposited in a cache where, if something disastrous happens to the rover and its onboard collection of

The primary instrument aboard Perseverance (above) for coring rock samples is its go-go gadget-arm drill. A concept model (left) of NASA's orbiting sample container shows how tubes of Martian rock and soil samples will be stored while being returned to Earth; at bottom left sits a model of the sample-holding tube. The sample container will help keep contents at less than 30°C to help preserve the Mars material in its most natural state.

PREPARING TO SEARCH FOR LIFE ON MARS... ON EARTH

Before Perseverance set off to collect its precious samples, scientists were honing their techniques on Earth. One place that particularly appealed to them was the driest place on Earth, Chile's Atacama Desert, where the city of Calama went 401 years – from 1570 to 1971 – without a single recorded drop of rain. Except around springs and other water sources, there's not a lot of signs of life on the Atacama's surface – where harsh sunlight and extreme temperatures also mimic those of Mars. "NASA has used this site as an analogue for Mars in order to test instrumentation [and] see what it takes to detect the slightest hints life," says Ulyana Horodyskyj Pena, founder and expedition leader for Science in the Wild, a citizen science group based in Boulder, Colorado.

Also useful, Horodyskyj Pena says, is to study rocks on Earth comparable in age to those Perseverance is exploring on Mars. Particularly important are those in the Pilbara region of Western Australia (Read more about NASA's visit there in *Cosmos* 86). At 3.5 billion years old, they are only 300 million years younger than those in Jezero Crater. They also have similar mineralogy to Jezero rocks and preserve ancient structures known as stromatolites, which appear to have been created by large mats of bacteria that grew into pillars a metre or so high.

NASA / JPL-CALTECH X 2

samples, the backup cache can still be retrieved by the Sample Retrieval Lander and its twin helicopters. (If the rover operates as expected, the duplicates in the cache will be not be retrieved.)

Already, though, scientists are learning a lot about the rocks they are collecting. One big surprise has been the discovery that even though Perseverance's landing site in 45-kilometre-wide Jezero Crater is known to have once contained a large lake, the rocks in its vicinity weren't composed of the lakebed sediments. Instead, they are volcanic rock that must have been there as bedrock before the water arrived.

That's an exciting find, scientists say, because volcanic rocks are known to be excellent timekeepers, containing crystals whose levels of certain trace isotopes reveals the precise moment when they formed. That means that these crystals provide a very precise date for the formation of the lakebed, and by extension an important constraint on when in the planet's history the lake existed. (It has to be younger than the volcanic rocks beneath it.)

"This will address some major questions," says the rover's project scientist Ken Farley, of California Institute of Technology (Caltech). "When was Mars's climate conducive to lakes and rivers on the planet's surface, and when did it change to the very cold and dry conditions we see today?"

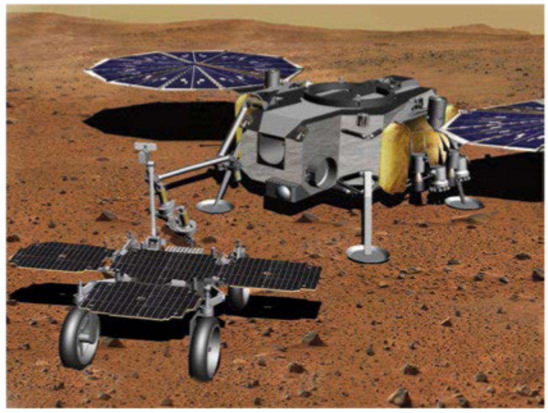
Also valuable is the fact that by happenstance, Perseverance came down right near the boundary of two distinct volcanic formations, now named the Máaz and Séítah.

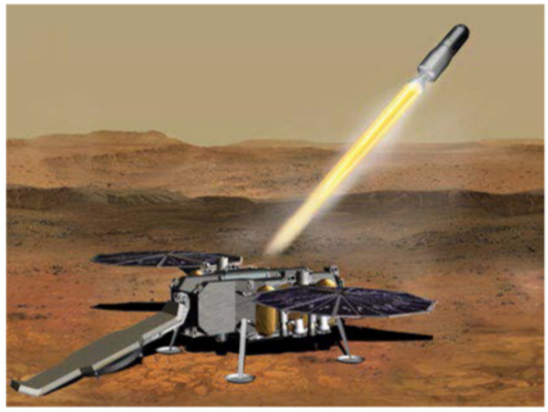
The Máaz formation (whose name means "Mars" in the Navajo Native American language) appears to be the younger of the two, Vivian Sun, a planetary scientist and systems engineer at JPL said earlier this year at the annual Lunar and Planetary Sciences Meeting in The Woodlands, Texas.

Séítah appears to be a bit older (though how much older won't be known until samples are returned to Earth). Its name means "amidst the sand" in the Navajo language – an apt description of why NASA flight engineers had marked this region on landing maps with the equivalent of a skull-and-crossbones.

Getting samples from Máaz was easy. It was the area in which Perseverance landed, chosen because it is firm, flat, and largely free of dangerous boulders. Getting samples from Séítah was harder, because the region really is full of potentially fatal sand traps. That's where the Ingenuity helicopter proved its worth, not only helping Perseverance locate suitable rocks for study, but assisting it in plotting an approach to them and then a safe retreat. But getting multiple samples from each formation, along with other geological evidence about their settings was worth the effort.

"Even before landing, our science team realised that understanding the crater floor is a very high priority," Sun says. "The goal is to piece together the overall story of how the lake in Jezero Crater formed – putting together the ancient history of what happened at Jezero Crater."





Two of the many moving parts (above right) in the first Mars retrieval plan have as of mid-2022 been deleted. The Sample Fetch Rover, at left, and the lander intended to deploy it aren't necessary, say NASA scientists, because Perseverance has performed so well that there's little fear it will perish before the Sample Retriever Lander arrives in 2028. Deleted parts notwithstanding, it will still be an outstanding feat for NASA and ESA to successfully get the samples off Mars (below right) and successfully back to the Earth.

NASA / JPL-CALTECH X 2

With that part of its mission completed, Perseverance is now on its way to climbing out of the crater floor, beginning by exploring rock formations along the slopes of a giant delta, formed when a billions-of-years-ago river spilled from the highlands, through the crater rim, and into the lake.

Now high and dry, the delta marks the spot where flowing water hit the lake, slowed, and dropped its sediments in what is now a steep bluff about 45m tall. Already Perseverance is collecting rock samples from around its base – rocks that may even preserve ancient signs of life, if life once flourished in the shallow waters near the delta.

And from there? Who knows what treasures Perseverance will find as it climbs through the delta, then up the ancient river channel toward the highlands beyond. After all, it still has at least 25 remaining sample tubes, and six years to find the best places to fill them before the Sample Retrieval Lander comes to complete its mission. With that kind of timeline, Perseverance has plenty of opportunity to live up to its name. ◉

RICHARD A LOVETT is based in Portland, Oregon. His previous story, on DART's mission, appeared in Issue 94.