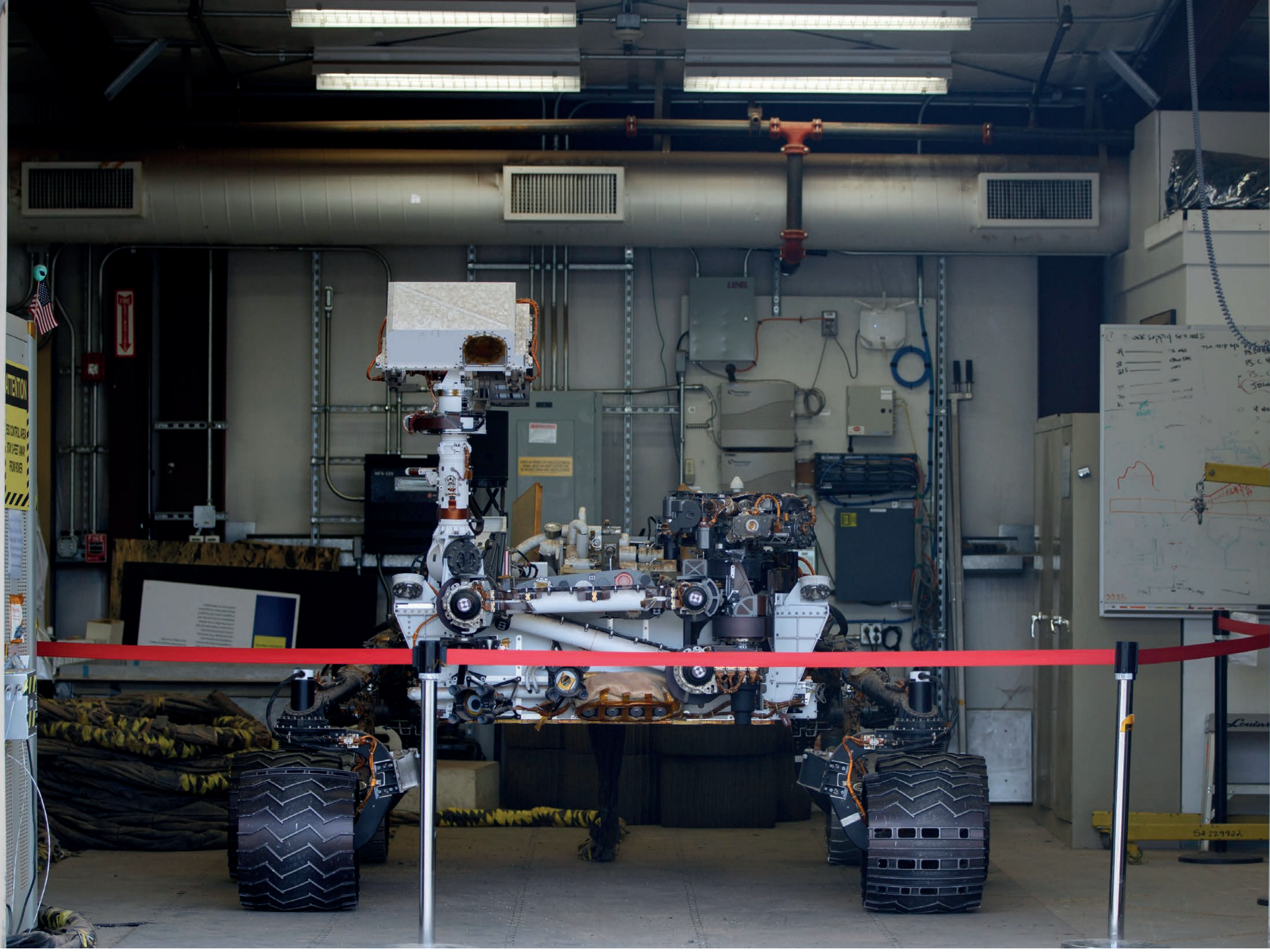


NEXT STOP, MARS

The best way to look for life on Mars is to bring back rocks from the red planet. Now NASA is gambling $2.4 billion on a high-risk mission to do it.

BY ALEXANDRA WITZE

Adam Steltzner rose to engineering stardom in 2012, when NASA's Curiosity rover plummeted to a perfect landing on Mars, thanks to a daring, fiery manoeuvre designed by his team. Now, all Steltzner wants to talk about is how to clean.

The object of his sanitary obsession is a dark-grey metallic tube about the size of his hand. It sits on a workbench inside a warehouse-like building at the Jet Propulsion Laboratory (JPL) in Pasadena, California, where Steltzner works as chief engineer for NASA's next Mars rover. He needs the tube to be one of the cleanest objects ever created so that the rover can complete its mission.

As early as July 2020, the 1-tonne, 6-wheeled vehicle will blast off from Florida, carrying 43 such tubes on a 7-month trip to the red planet. Once it arrives, the rover will drive across the Martian surface and fill each tube with dirt, rock or air. Then it will seal the tubes, place them on the ground, and wait — for years, or possibly decades — for another spacecraft to retrieve them and fly them back to Earth. It will be humanity's first attempt to bring back part of the red planet.

If all goes to plan, these will become the most precious extraterrestrial samples ever recovered. Tucked inside one of those metallic tubes could be evidence of life beyond Earth in the form of a microorganism, biominerals or organic molecules.

Which is why Steltzner and his team have to be very, very clean. Just one Earth cell or specks of other contaminants would ruin any chance of unambiguously detecting a Martian microbe. So the project team is trying to design a robotic sampling system that will keep things spotless. "We are going to be more serious about cleanliness than anyone's been before," Steltzner says, shaking the tube as if to knock errant microbes off it. "We're just going to engineer this shit."

The stakes could not be higher. NASA is gambling $2.4 billion and the future of its Mars exploration programme on the 2020 rover. If it gathers a pristine set of rock samples that eventually return to Earth, they will shape the course of Solar System science. If it fails — and Mars is notorious as a graveyard for space missions — the agency will have to relinquish a dream it has had for decades.

In conference rooms, laboratories and

PATRICK FALLON FOR *NATURE*

A replica of Mars Curiosity is being used to test interplanetary rovers.

PATRICK FALLON FOR *NATURE*

clean rooms at the JPL, scientists and engineers are now finalizing crucial decisions for the mission. They are exploring and questioning every detail, from how to keep the tubes cool on the Martian surface to what the rover will do every minute on the planet in order to accomplish all of the planned work. Next month is a key period, because NASA will both narrow down the shortlist for possible landing sites and perform a crucial design review that the project must pass to keep moving ahead. By the time the mission blasts off in 2020, its success or failure will have been dictated, in part, by choices being made now.

A ROVER IS BORN

On the JPL's sunny campus, nestled against the mountains north and east of Los Angeles, engineers in shirtsleeves stroll along a eucalyptus-shaded path. Some turn and enter the building from which mission controllers drive the two working rovers on Mars. Others continue on to Building 179, the historic spacecraft-assembly facility where numerous missions to the Moon, Mars and interplanetary space were born.

Today, this is also where the Mars 2020 rover is taking shape. So far, the building's enormous clean room contains only one major item for the mission — a disc-shaped heat shield, wrapped in a crinkled silvery sheet. It was left over from the Curiosity mission, and will be reused for the new spacecraft.

NASA touted this reusability when it announced the 2020 mission four years ago. The agency had already sent a string of successful rovers to Mars, beginning with the 11-kilogram Pathfinder in 1996, through the 180-kilogram twins known as Spirit and Opportunity in 2003, to the behemoth 900-kilogram Curiosity in 2012. The JPL engineered all of these machines, each a step up in complexity and scientific ambition.

But now, from an engineering standpoint, the 2020 rover can partly coast on work done for Curiosity. Roughly 85% of the new rover will be heritage designs — the chassis, the power and communications systems and other elements can be copied from the previous rover. "We're getting a lot of bang for our buck," says Matt Wallace, a deputy project manager who worked on several rover missions.

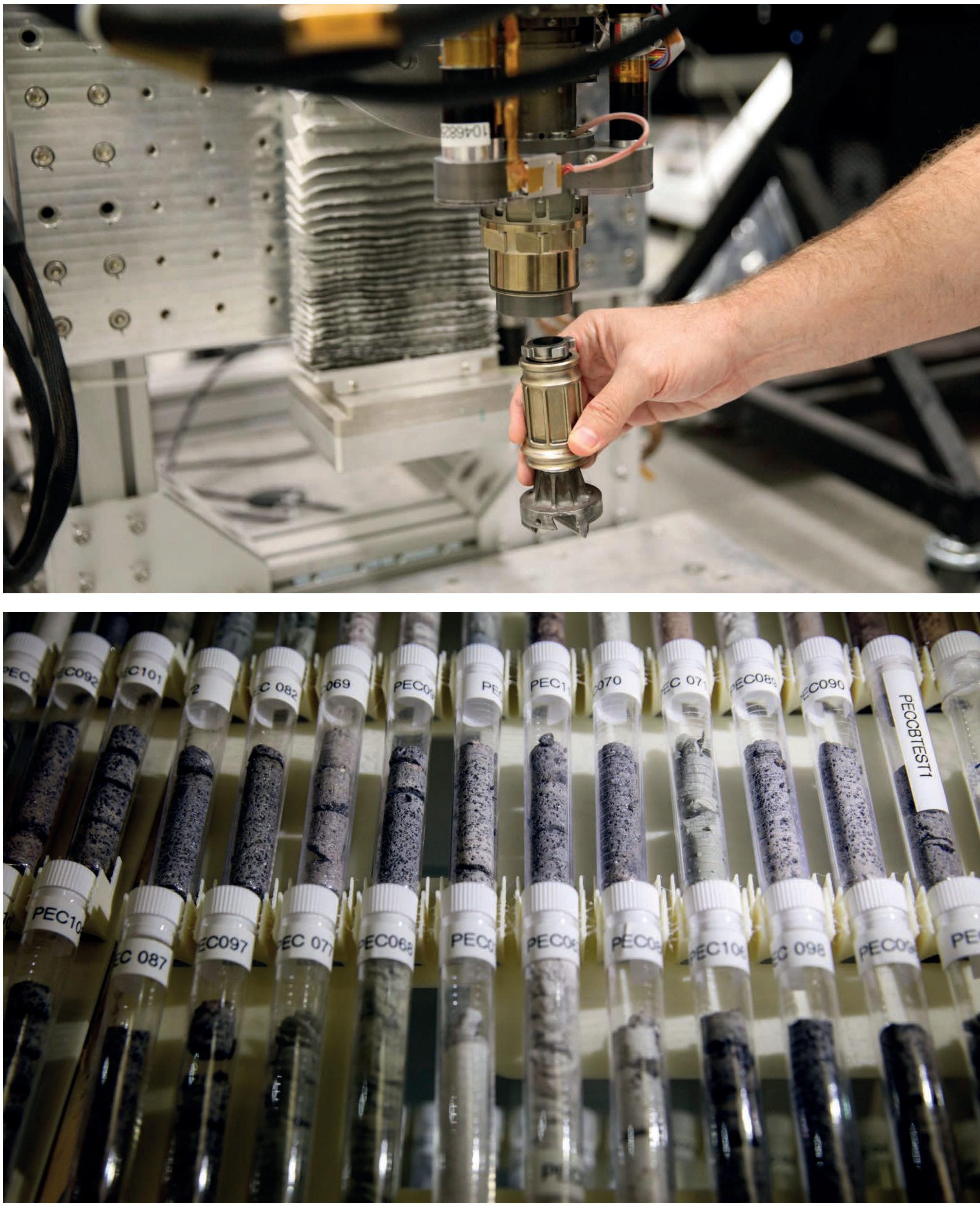
What's new are the parts that will do science: the tools that will make measurements on Mars and those that will gather and store the rock samples. The rover's scientific payload will consist of seven instruments, all either brand new or improved designs. The panoramic camera atop the rover's mast, for instance, will have a zoom function to zero in on areas of interest. The vehicle's laser instrument will add extra wavelengths to augment investigations of rock chemistry and mineralogy. And the rover's robotic arm will sport ultraviolet and X-ray spectrometers that will map rocks in more detail than the instruments on Curiosity can.

These tools represent the mission's only chance to collect geological context for the precious rock samples. That information is key to understanding the Martian material — and the planet, say scientists. After all, they already have hundreds of rocks from Mars — but those samples are context-free. They arrived on Earth as meteorites that had been blasted off the red planet during impacts millions and billions of years ago. The point in flying there, picking up rocks, and bringing them back is to help researchers to decipher the history of the Martian landscape where the samples were collected and to piece together the planet's evolution.

"We want a really good set of field notes that people can refer to for centuries," says Abigail Allwood, principal investigator of the X-ray spectrometer and an astrobiologist at the JPL. "If we're going to prove this is life, we're going to have to scrutinize it at the highest level."

TREASURE HUNT

That's where Steltzner and his team come in. They started from scratch to try to dream up the best sample-collection system possible. Early ideas included wild configurations, such as a rover with multiple arms to deploy different science instruments. In the end they settled on a system in which the rover will reach out its arm to a rock, then drill and extract a 15-gram sample (see 'Sampling Mars'). It will seal the tube hermetically and stash it back inside the rover's body — all in the course of an hour, to reduce the time the samples are exposed to the ▶



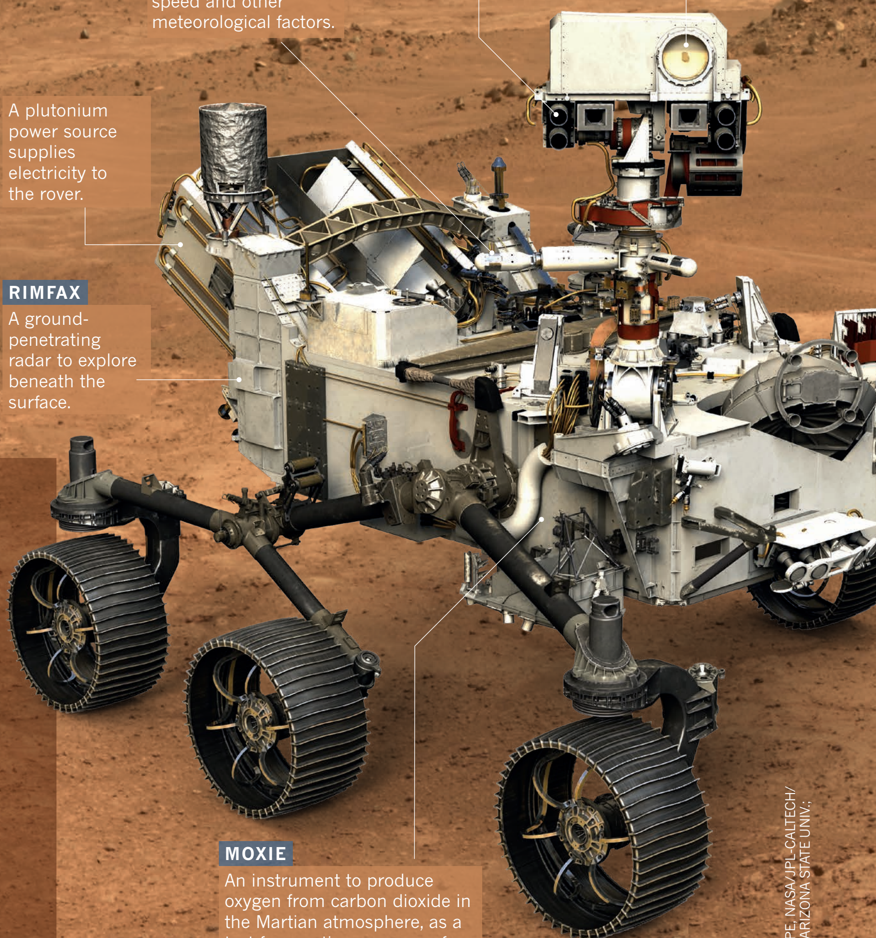
Engineers designed the Mars 2020 rover's drilling system (above) to extract about 15 grams of sample (below) from each rock.

SAMPLING MARS

THE AUDACIOUS PLAN TO COLLECT RED-PLANET ROCKS.

BY ALEXANDRA WITZE
DESIGN BY JASIEK KRZYSZTOFIAK

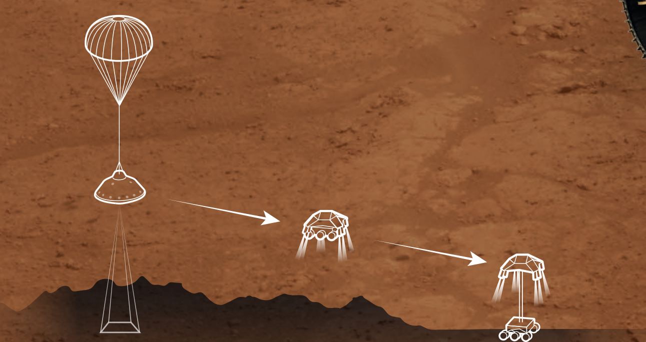
In 2020, NASA plans to send a rover to Mars to collect and store tubes of rock and dirt. If it succeeds, it will be the first step in bringing carefully documented Martian samples back to Earth for study. Engineers are now designing the robotic system to gather the samples — and they have to make it excruciatingly clean, so as not to contaminate any possible traces of Martian life.



LANDING

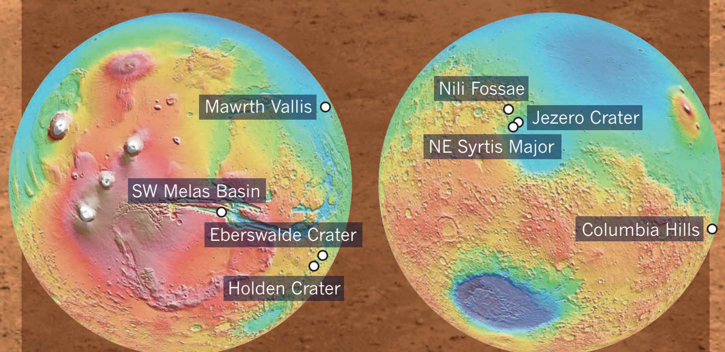
NEW LANDING TECHNIQUE

When it reaches Mars, the mission will use an updated version of the entry, descent and landing sequence used by the Curiosity probe in 2012. The new method, known as 'terrain relative navigation', allows the spacecraft to land closer to its area of interest because it can divert from dangerous situations in the last moments before landing, if necessary.



POTENTIAL LANDING SITES

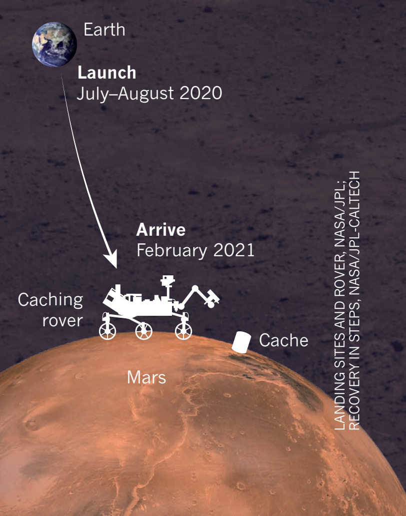
Eight landing sites are being considered for the 2020 rover. Where it goes will dramatically shape the future of Mars science.



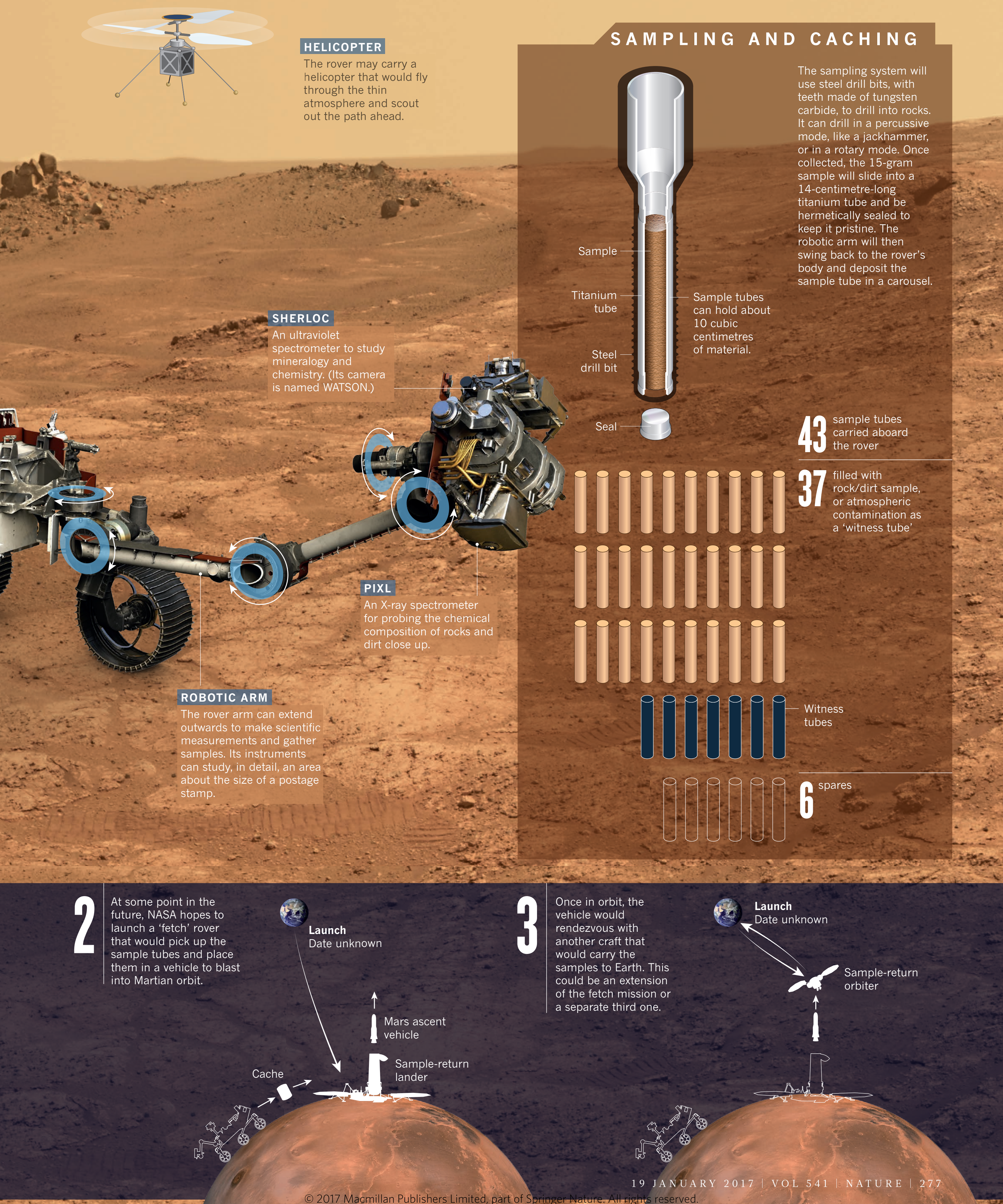
RECOVERY IN STEPS

1

The 2020 rover is only the first stage in bringing Martian rocks to Earth. After collecting samples and storing them in sealed tubes, the vehicle will set them on the planet's surface, in one or more cache spots.



MARS LANDSCAPE, NASA/JPL-CALTECH/CORNELL UNIV./ARIZONA STATE UNIV.; LANDING SITES AND ROVER, NASA/JPL; RECOVERY IN STEPS, NASA/JPL-CALTECH


HELICOPTER
The rover may carry a helicopter that would fly through the thin atmosphere and scout out the path ahead.
SHERLOC
An ultraviolet spectrometer to study mineralogy and chemistry. (Its camera is named WATSON.)
PIXL
An X-ray spectrometer for probing the chemical composition of rocks and dirt close up.
ROBOTIC ARM
The rover arm can extend outwards to make scientific measurements and gather samples. Its instruments can study, in detail, an area about the size of a postage stamp.
SAMPLING AND CACHING
The sampling system will use steel drill bits, with teeth made of tungsten carbide, to drill into rocks. It can drill in a percussive mode, like a jackhammer, or in a rotary mode. Once collected, the 15-gram sample will slide into a 14-centimetre-long titanium tube and be hermetically sealed to keep it pristine. The robotic arm will then swing back to the rover's body and deposit the sample tube in a carousel.
Sample
Titanium tube
Steel drill bit
Seal
Sample tubes can hold about 10 cubic centimetres of material.
43 sample tubes carried aboard the rover
37 filled with rock/dirt sample, or atmospheric contamination as a 'witness tube'
Witness tubes
6 spares
2
At some point in the future, NASA hopes to launch a 'fetch' rover that would pick up the sample tubes and place them in a vehicle to blast into Martian orbit.
Launch
Date unknown
Mars ascent vehicle
Sample-return lander
Cache
3
Once in orbit, the vehicle would rendezvous with another craft that would carry the samples to Earth. This could be an extension of the fetch mission or a separate third one.
Launch
Date unknown
Sample-return orbiter

Martian air and to possible contamination.

The rover will carry enough supplies to fill and seal at least 31 tubes, each roughly 14 centimetres long and 2 centimetres across. (It carries several spares in case of problems.) Not all of the tubes are destined to hold Martian samples. Some will serve as 'witness' tubes, filled with material such as aluminium mesh or ceramics to trap environmental contaminants. On the way to Mars, one of the tubes will be left uncovered to capture whatever might vaporize off the spacecraft during flight. That tube will be sealed on arrival. Other tubes will be exposed sequentially on the Martian surface to gather samples of anything that happens to be blowing in the air at each location. Later, scientists will be able to use the witness tubes to work out whether the drilled samples were contaminated and when.

Project scientist Ken Farley and the rest of the Mars 2020 team decided to carry the witness tubes only recently, on the advice of a scientific panel that represents the researchers of the future. "We need to read their minds about what kinds of investigations they will want to do on returned samples," says Hap McSween, a planetary geologist at the University of Tennessee in Knoxville who co-chairs the panel.

Above all, that means ultrapure samples. By the time the tubes are built, cleaned, baked and tucked away inside the spacecraft, they might just be the most pristine environments on this planet. "It's the combination of inorganic, organic and biological requirements that makes this so challenging and makes it unique among missions flown by NASA so far," says Ken Williford, the deputy project scientist.

Other spacecraft have accomplished impressive levels of cleanliness, driven by concerns about not contaminating planets with Earth microbes. As early as the 1970s, the Viking Mars landers had their key instruments cleaned with solvents and then baked in helium gas for four days. Similar protective cleaning is planned for the European Space Agency's ExoMars rover, which is also slated to launch in 2020 and search for signs of past life. China plans to send its own Mars rover in 2020, but not with life-detection capabilities.

NASA's 2020 mission has to go beyond the usual planetary-protection requirements to ensure the scientific integrity of the samples slated for the return trip to Earth. They will be handled as carefully as — and perhaps even more so — the Moon rocks brought back by the Apollo astronauts, says Cassie Conley, NASA's planetary-protection officer, who works at the agency's headquarters in Washington DC.

Practically speaking, there is no way to get the spacecraft entirely clean. Instead, mission scientists are deciding what levels of contamination they can live with. Both organic and inorganic materials must be kept beneath certain limits — an advisory panel has recommended no more than 40 parts per billion of total organic carbon in any sample, for instance.

But the samples will be unavoidably contaminated with tungsten because the drill teeth are made with tungsten nitride. That means that future scientists won't be able to date the Martian rocks using a radioactive decay system that relies on tungsten and hafnium; they will have to choose from several other alternatives. "We're just going to have to live with that," says McSween.

Another consideration is how hot the tubes might get while sitting on the Martian surface waiting for a flight home. At Farley's request, McSween and his panel analysed what scientific information would be lost at different temperatures. They concluded that 60 °C was the acceptable upper limit; above that, some organic compounds begin to degrade, some minerals begin to break down and other changes happen that could compromise the research. So engineers decided to coat the tubes with aluminium oxide to reflect sunlight and keep them beneath that 60 °C threshold.

NASA has not yet planned a mission to bring the samples back, but when they do reach Earth, researchers will have an arsenal of techniques to test for possible Martian life. They will hunt for amino acids, the precursors of proteins, and for other complex organic compounds. Other evidence could come from the ratios of isotopes in key molecules, which on Earth can provide clear signals of biological processes. There is no combination of measurements that researchers agree will prove the existence of Martian life — but by building up a suite of observations about the rock and what it contains, scientists might be able to make a convincing case.

That doesn't mean it will be easy. Farley is a geochemist who studies how cosmic rays alter the chemistry of rocks. As such, he worries that any organic compounds from ancient Mars would have degraded over millions of years of lying around on the surface. A strategy to get the best samples might be to target areas such as the base of Martian cliffs, where fresh material is exposed when rock from high up breaks off.

NASA's plans call for gathering 20 carefully chosen and documented samples in 1–1.5 Martian years. That means driving between many possible sampling locations and assessing which is likely to yield the most intriguing information from a diversity of geological environments. As it collects, the rover will probably stash the tubes on the ground in one or more locations.

In its 4.5 years on Mars, Curiosity has drilled just 15 holes and driven more than 16 kilometres. The 2020 team will have to work much, much faster. "It's very clear that we have to maintain a very high pace," says Farley. "The science team can't just sit around and discuss, do we want to drill here?"

"WE ARE GOING TO BE MORE SERIOUS ABOUT CLEANLINESS THAN ANYONE'S BEEN BEFORE."

SETTLING DOWN

In the end, the scientific success of the 2020 rover depends heavily on where it lands. NASA is currently considering eight sites. Half of those are in environments featuring former lakes, deltas or other evidence of long-standing water and sediments that can preserve evidence of ancient life. The other possible landing sites are among older rocks, where water once percolated through the Martian crust in warm hydrothermal springs that might have allowed life to thrive long ago. Which of them gets selected will shape the direction of Mars science, says Bethany Ehlmann, a planetary geologist at the California Institute of Technology in Pasadena.

Scientists will shorten the list by half at a workshop next month in Monrovia, California, and recommend a final site for NASA's consideration a year or two before launch.

Also in February, the mission will go through a final review of all aspects of its design. If it passes, the JPL will continue building the scientific instruments, the sampling system and other hardware in earnest. Once the machine is completed, it will go through testing before being shipped off for a launch in July or August 2020.

NASA has yet to decide on when the samples might come home. It has no Mars missions budgeted or approved after the 2020 rover. Managers at the agency's headquarters have begun to hint that they would like to see an orbiter launch in 2022, to serve as a communications relay for future missions and to replace the ageing orbiters already there. After that, the priority will be to get the Martian samples back to Earth, while also supporting possible plans for human exploration of Mars. NASA is funding early studies into the idea of a Mars ascent vehicle — which would carry a small package of samples, perhaps the size of a bowling ball — into Mars orbit. Then an as-yet-unplanned spacecraft would collect the orbiting package and return it to a strict quarantine on Earth.

Farley recalls that he first started talking seriously about Mars sample return in the late 1980s. At the time, NASA estimated that it might take a decade to accomplish. It will still be at least a decade before Martian samples will be carried back to Earth, says Farley. "But at least we're starting now." ■

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