CHANG'E 5 IS REWRITING LUNAR HISTORY p. 40

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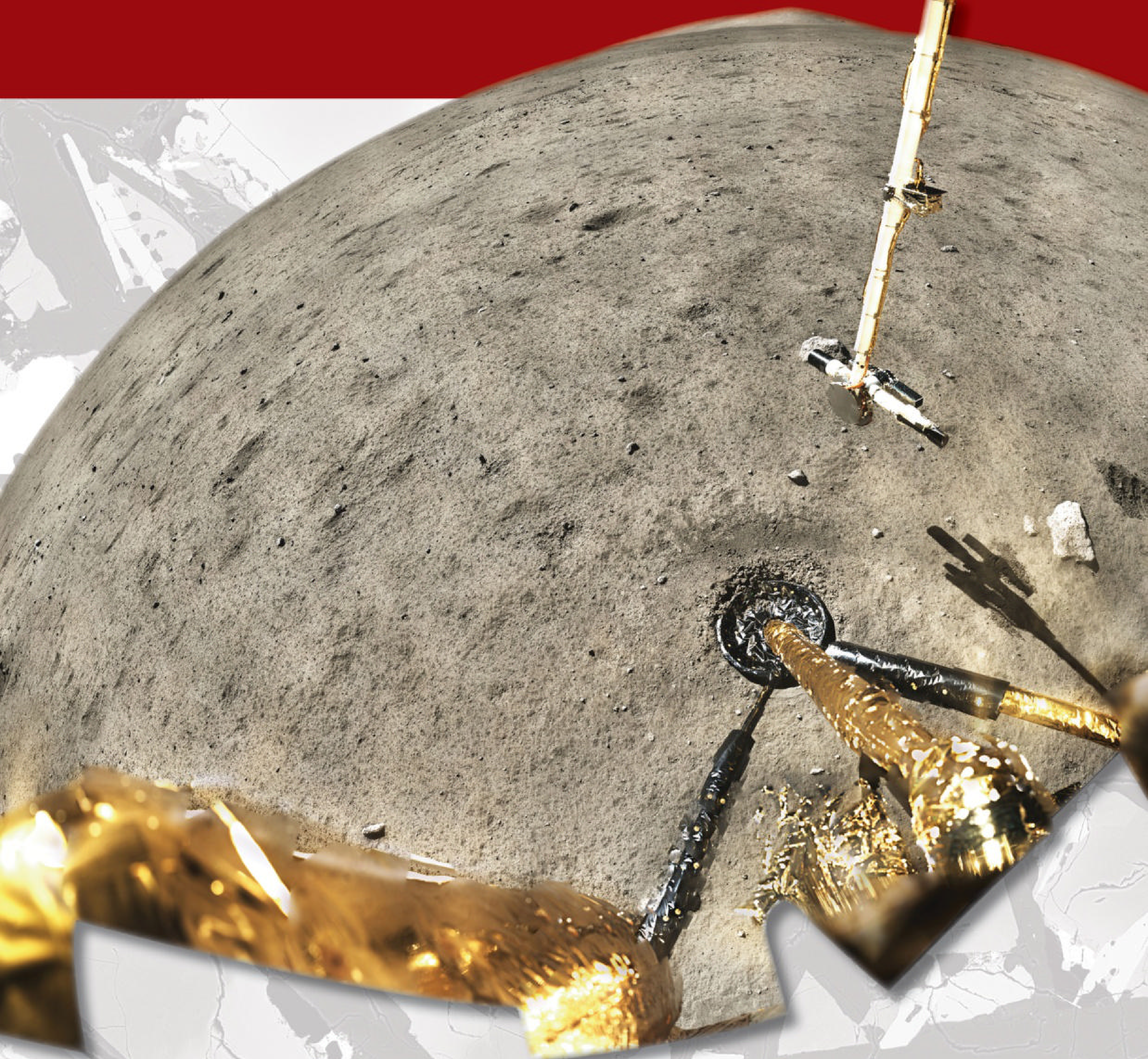


# CHANG'E 5 rewrites lunar

# The mission's samples are the youngest lunar rocks yet found, leaving scientists wondering how the Moon stayed hot for so long.

**BY MARK ZASTROW**

**IN DECEMBER 2020,** China's Chang'e 5 mission touched down northeast of the ancient volcano formation Mons Rümker in northern Oceanus Procellarum — a region of the Moon that was once a vast plain of molten lava. The site had been targeted by scientists for decades: Curiously, the surface there is somewhat sparse of impact craters, suggesting that its last lava flood occurred quite recently, in lunar terms. Determining its age was one of the mission's top priorities.

In all, the Chang'e 5 lander scooped and drilled 3.8 pounds (1.7 kilograms) of lunar material, which its return stage delivered to the grasslands of Inner Mongolia Dec. 16, 2020. They were the first Moon rocks returned to Earth since the Soviet robotic mission Luna 24 in 1976. Chang'e 5's samples were collected and parceled out to several research groups around the world. Now, scientists are beginning to report what they have found.

The first major scientific paper detailing mission findings was published Oct. 7 in *Science*, followed by a trio of papers in *Nature* Oct. 19. The *Science* paper found that the samples confirm the relative youthfulness of the landing site's volcanic basalt rocks: 1.96 billion years old, give or take a few tens of millions of years. One of the teams publishing in *Nature* independently found nearly the same result: 2.03 billion years, give or take 4 million years. This is about a billion years younger than any of the volcanic lunar samples returned by the Apollo and Luna missions.

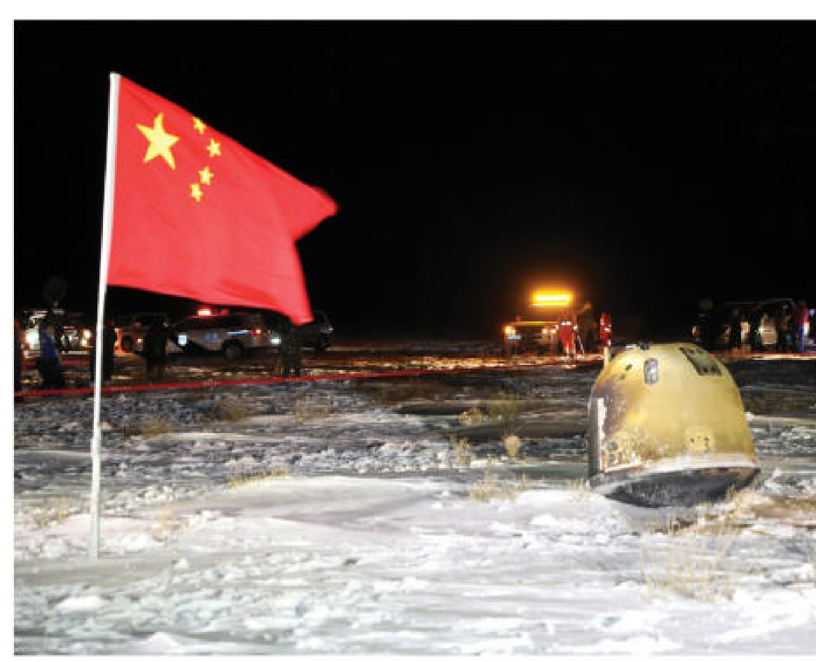
These findings indicate that volcanoes were erupting on the Moon just 2 billion years ago — which throws a wrench into our understanding of how bodies like planets and moons form. Scientists think that when such bodies are young, radioactive uranium and thorium sink deep into their interiors. These slowly decay and release heat, which can keep the mantle molten for billions of years. But models suggest that a body as small as the Moon should have lost all of its heat by then.

"We always said that, OK, 3-billion-year-old basalts is fair enough, probably it can be sustained by this radioactive decay," says Alexander Nemchin, a geochemist at Curtin University in Perth, Australia, and one of the *Science* team's leaders. But 2 billion years is too young for current models, he says — "so now we've got a problem."

Nevertheless, the result is exactly what scientists hoped for when they chose the probe's landing site, says Brad Jolliff, a planetary scientist and mineralogist at Washington University in St. Louis and a co-author of the *Science*

The Chang'e 5 mission landed on the Moon Dec. 1, 2020, and lifted off 48 hours later with a stash of lunar rocks. CHINESE NATIONAL SPACE AGENCY'S (CNSA) LUNAR EXPLORATION AND SPACE ENGINEERING CENTER

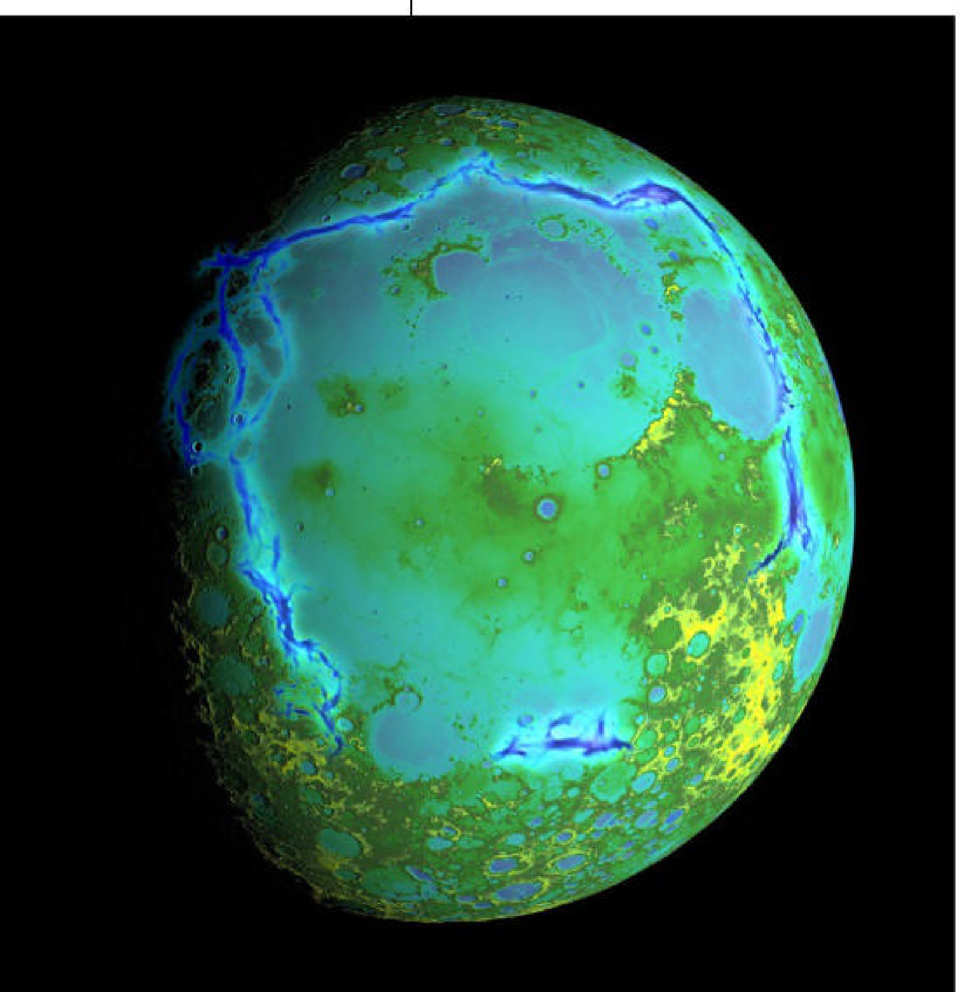
history



A recovery crew secured the samples after the return capsule's touchdown on the grasslands of Inner Mongolia Dec. 16, 2020. CHINESE NATIONAL SPACE AGENCY'S (CNSA) LUNAR EXPLORATION AND SPACE ENGINEERING CENTER

RIGHT: Oceanus Procellarum is the only feature on the Moon to earn the designation of the Latin word for "ocean". At over 1,600 miles (2,500 km) across, it's vaster than the multitude of lunar maria, or "seas."

BELOW: Rifts outlining Oceanus Procellarum can been seen in gravitational anomalies (in blue) as measured by NASA's Gravity Recovery and Interior Laboratory (GRAIL) mission. NASA/GSFC/ARIZONA STATE UNIVERSITY; NASA'S SCIENTIFIC VISUALIZATION STUDIO



The Chang'e 5 soil sample allocated to the Beijing SHRIMP Center weighs just 0.07 ounce (2 g), but with careful planning, researchers can extract a lot of information from it. BEIJING SHRIMP CENTER, INSTITUTE OF GEOLOGY, CAGS

study. "This actually shows that the main science goal was met — and that's pretty awesome."

## Filling in the age gap

The age measurements of the samples were taken in two labs in Beijing. The *Nature* work was performed at the Institute of Geology and Geophysics at the Chinese Academy of Sciences; the sample published in *Science* was analyzed at the Beijing SHRIMP Center in collaboration with an international consortium. (A SHRIMP, or Sensitive High-Resolution Ion MicroProbe, is an instrument used for chemical analysis.)

Both teams used similar techniques: analyzing various isotopes of lead, which are produced by the decay of radioactive uranium and thorium. Since these processes happen at a predictable rate, measuring how much of each isotope existed relative to each other allowed the team to determine the age of the samples.

For some researchers, the most exciting part of the analysis isn't just learning the age of Chang'e 5's landing site — it's that these measurements will also help determine ages of many other regions of the Moon's surface. That's because the age of Oceanus Procellarum is key to improving a completely different technique for understanding the Moon's history: counting impact craters.

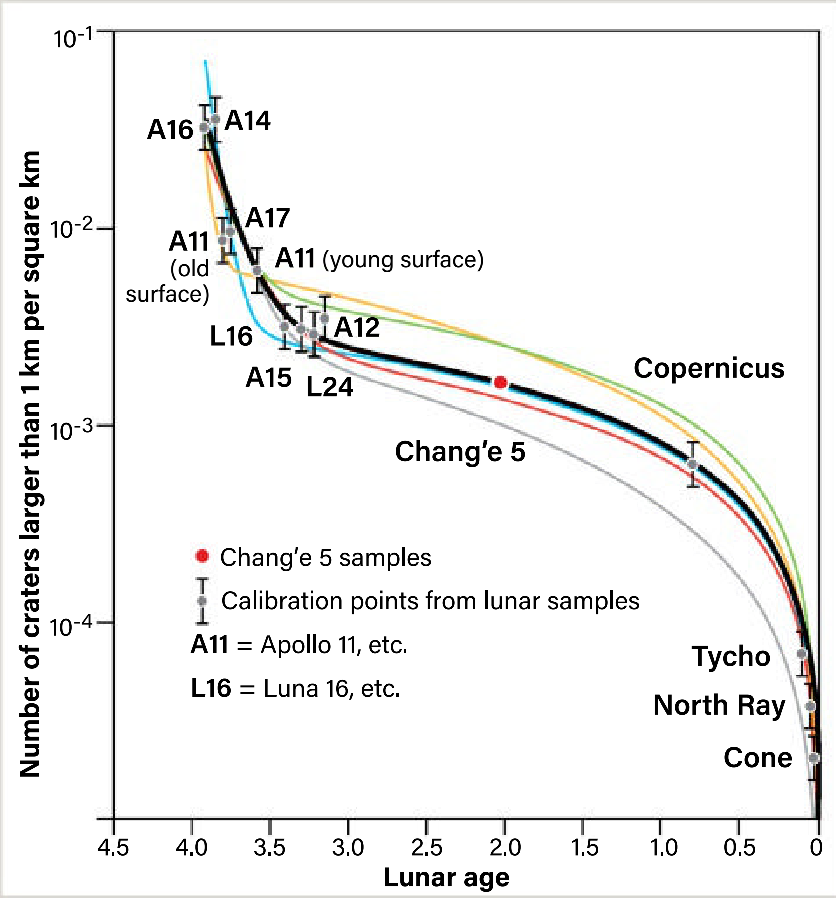
Generally, the more impact craters there are in a given area, the older that area is, as it's had more time to accumulate impacts. "We know that kind of in a relative way, and we've known that for many years," says Jolliff. "But to actually put numbers on that required samples."

To this point, the most accurate ages that existed were linked to rock samples 3 billion years or older from the Apollo and Luna missions. A handful of Apollo samples also allowed researchers to infer dates for some young impact craters formed within the past billion years.

But between 3 billion years ago and 1 billion years ago, "we just had this giant gap of 2 billion years — which is like half the age of the Moon," says Carolyn Crow, a planetary scientist at the University of Colorado in Boulder.

At 2 billion years old, the Chang'e 5 samples fall right in the middle of that gap, significantly improving the technique's calibration. "We're filling this gap, which is awesome," says Crow. "The ability to get some anchor in that time period is just so important."

And not just for the Moon: Counting craters is also how scientists estimate the ages of surfaces on bodies like Mars and Mercury. "They just have such big




*ASTRONOMY*: KELLIE JAEGER, AFTER LI ET AL. (2021)

## THE CRATER-COUNTING CURVE

The number of locations on the Moon whose ages have been directly measured is so limited, they can all be identified on the graph at left. They come from the Apollo and Luna missions, which returned samples that revealed the age of their landing sites — all older than 3 billion years.

In addition, the missions returned fragments from young nearby craters, whose lab-measured ages yield the dates of those impacts. For instance, Apollo 12 landed on one of the rays of debris emanating from the crater Copernicus. The ejecta samples they brought back revealed Copernicus formed 800 million years ago.

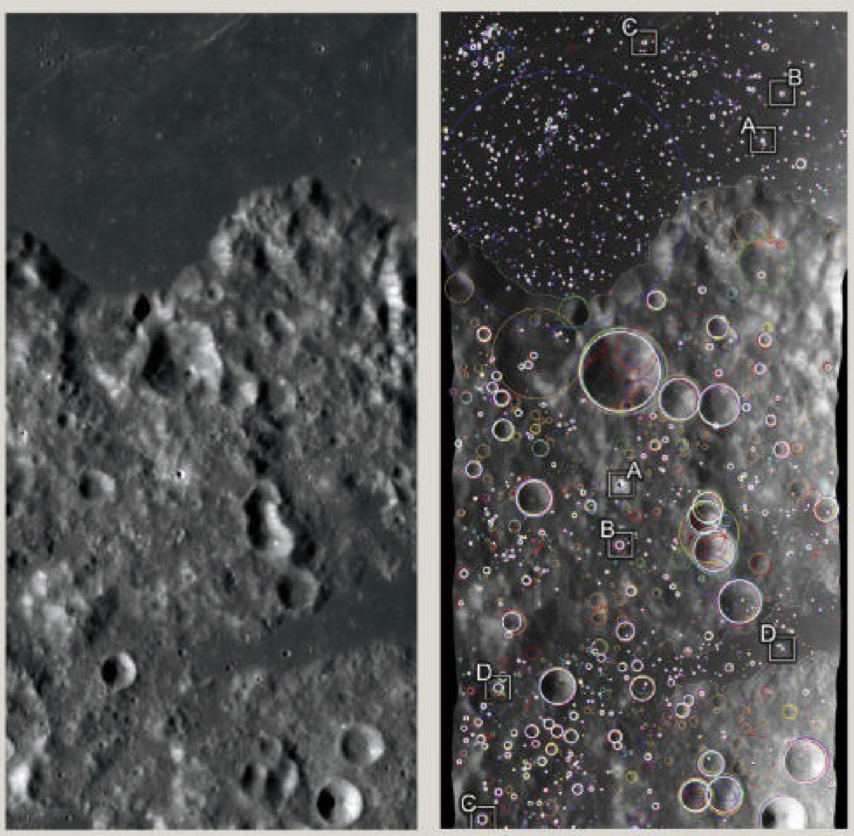
The thick ejecta blanket from such impacts erases or subdues existing craters, effectively "resetting" the apparent age of the surrounding surface. This means researchers can count the new craters that formed since the impact, obtaining another calibration point for the crater-counting chronology.

Similarly, Apollo 17 returned samples from the crater Tycho, Apollo 15 brought back ejecta from North Ray Crater, and Apollo 14 visited Cone Crater. All of those craters are younger than 1 billion years.

In this graph, the vertical axis is the density of craters in an area, given as the number of craters per square kilometer (0.39 square mile) that are larger than 1 kilometer (0.62 mile) in diameter. The array of lines represents the various crater chronology models that researchers have constructed in the last 20 years to fit these data points. The curve is the key to the technique: Researchers measure the crater density for a region of the Moon, then use a model curve to find the region's corresponding age along the horizontal axis.

While the models mostly agree at ages where there are data points, in the 2-billion-year gap in between, the technique is very uncertain: For a given density of craters, the variability in age given by the models is vast.

But Chang'e 5's landing site, at 2 billion years old, begins to fill this gap and narrow the range of models. The black line is the model that best fits the Chang'e 5 samples — very nearly a perfect match. While researchers will continue to refine their models and wait for even more data points, the Chang'e 5 samples provide a key anchor for the curve, improving confidence in the technique. *— M.Z.*




The older a surface is, the more craters of a given size it is likely to have. This is demonstrated clearly in this view of Mare Crisium and the rugged highlands bordering it to the south (left). In a 2014 study, several researchers and an algorithm identified craters in both regions (right). Based on the crater-counting method, the highlands are roughly 3.7 billion years old, whereas the mare surface is roughly 1.7 billion years old. ROBBINS ET AL. (2014)/ICARUS

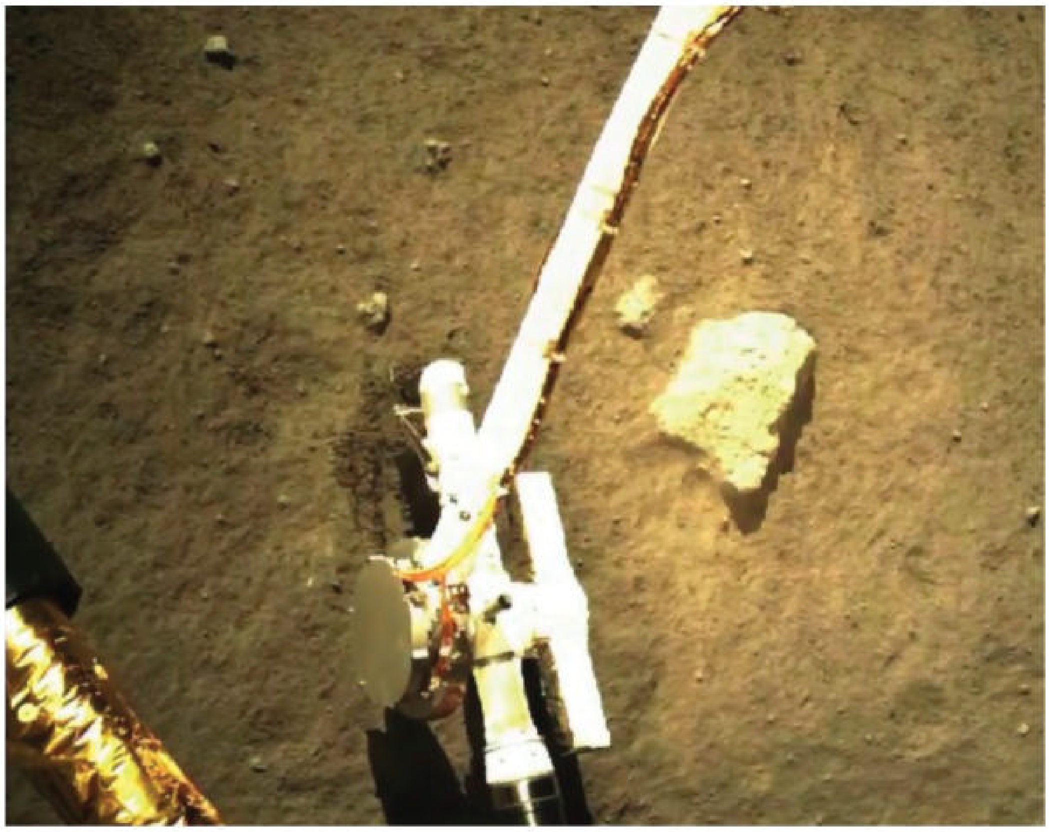
uncertainties on them and having at least one data point just helps constrain that so much better," says Crow.

## Bringing the heat

While the results help clarify the crater-counting technique, our understanding of how magma could have been spewing from the Moon as recently as 2 billion years ago is murkier. That's because there's no clear source of heat.

The simplest explanation is that there are more radioactive minerals buried deep in the Moon than models predict. But the analyses reported in *Science* and one of the other *Nature* papers from a Chinese team give no indications that Chang'e 5's samples originally contained any more uranium or thorium than samples from the regions visited by Apollo and Luna.

In fact, according to the *Nature* paper, Chang'e 5's basalts have *less* of one type of radioactive material



ABOVE LEFT: It's possible that Chang'e 5's samples contain ejecta from Aristarchus Crater (seen here on Apollo 15), located some 370 miles (600 km) southeast of Chang'e 5's landing site. If researchers can identify fragments from Aristarchus, the crater's age could be determined in the lab — providing another calibration point for the crater-counting chronology. NASA

ABOVE RIGHT: Chang'e 5's sampling apparatus collected 3.8 pounds (1.7 kg) of lunar soil. CHINESE NATIONAL SPACE AGENCY'S (CNSA) LUNAR EXPLORATION AND SPACE ENGINEERING CENTER

found in previous lunar samples — a mixture called KREEP, made of potassium (K), rare Earth elements (REE), and phosphorus (P). "According to the previous theory, the KREEP-like components would provide heat to sustain the longevity of young magma," said Li Chunlai, study co-author and a researcher at the National Astronomical Observatories of the Chinese Academy of Sciences, in a statement. If that's not the case, "we should rethink the mechanisms" that are involved.

One possibility is that the Moon's interior consists of different minerals than scientists thought and can melt at lower temperatures, says Nemchin.

But there are alternative hypotheses — like tidal heating. Perhaps when the Moon was younger and orbited closer to the Earth, the tidal force of our planet's gravity stretched and deformed the Moon, heating it enough to keep it molten. To test either scenario will require more sample analysis and detailed modeling.

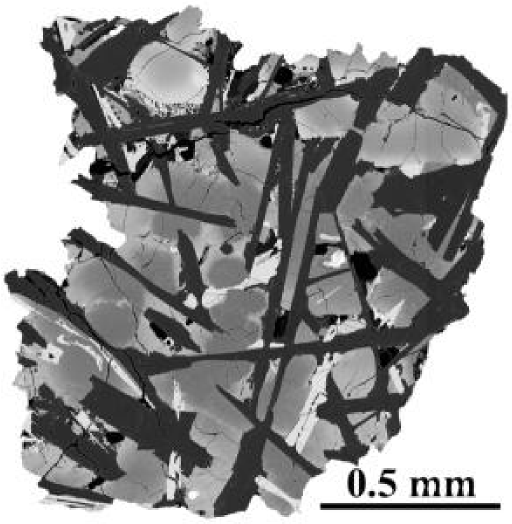
Scientists hope to glean many more insights from the Chang'e 5 samples and eventually reconstruct their history in detail.

The third *Nature* paper opened another line of investigation into Chang'e 5's lunar loot by measuring the water content of basalt samples. Analysis of grains of apatite, a phosphate mineral, found they were no more than 0.03 percent water, indicating the Moon's mantle is very dry.

This gives scientists some insight into the Moon's formation. In the currently favored giant-impact theory, Earth collided with another small planet, creating a hot debris disk out of which the Moon eventually coalesced. "One of the big constraints on that process — how that works, or if it was something else entirely — is how much water you have in the mantle," says Crow. "If there's a big debris disk, and it's really hot, you're going to get rid of all your water."

Scientists hope to glean many more insights from the Chang'e 5 samples and eventually reconstruct their history in detail. Lead dating is just one technique to apply to a rock — "there's a whole other suite of them, and they all give different kinds of information," says Crow. "When did it form? When was it last heated? … When was the last time it saw a giant impact? When was it excavated and put on the surface?"

Those analyses often require destroying the samples to some extent, like melting them in acid or heating them with lasers and measuring the noble gases they release. So, because the amount of Chang'e 5 material is so limited — the Beijing SHRIMP center was granted just 0.07 ounce (2 grams) of soil — researchers are meticulously planning their analyses to get the most out of the material, saving the most




As magma cools and solidifies, it forms irregular crystalline patterns, as seen in this scanning electron microscope image of a lunar basalt fragment used in the *Science* study. BEIJING SHRIMP CENTER, INSTITUTE OF GEOLOGY, CAGS

destructive techniques for last. "I want to melt them with laser beams," Crow says with a laugh.

## Lunar return

Researchers had to wait 44 years between receiving samples from Luna 24 and from Chang'e 5. They won't have to wait nearly as long for the next haul: Chang'e 6, which was built as a backup to Chang'e 5, is scheduled to launch in 2024. Then, perhaps as early as 2025, NASA intends to return astronauts to the Moon with the Artemis program, which will be able to return many more samples than a robotic mission.

This coming second era of lunar sample return could help scientists pin down the dates of many of the Moon's largest and oldest impact craters, known as impact basins. Only one basin has been directly sampled and its age measured: Imbrium on the Moon's nearside, at 3.9 billion years old. Getting samples from others could help clarify the early history of not just the Moon, but the entire solar system.

For instance, NASA is hoping to land Artemis missions at the lunar south pole. There, astronauts should be able to collect samples from the mysterious South Pole-Aitken (SPA) basin. The oldest and largest of the Moon's basins, it stretches from the South Pole roughly 1,550 miles (2,500 kilometers) into the lunar farside. Data taken from orbit suggest the SPA basin has a composition that doesn't match any previous lunar samples.

Samples from the SPA and other basins around the Moon will tell researchers if they all formed at the same time — during the solar system's chaotic early period known as the Late Heavy Bombardment — or if they were spaced out over a longer duration. "It would be great to go to the farside," says Crow. "If you get away from Imbrium, you can try and get other material."

One thing is certain: The Chang'e 5 samples are likely to ignite a new wave of interest in the Moon's early history to explain its late volcanism.

"When it's just a suggestion, everybody tends to ignore it," says Nemchin. "Yes, we suspected that younger basalts are on the Moon, but it wasn't on the forefront of everybody's thinking. Right now, it's probably gonna be."

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**Mark Zastrow** *is senior editor of* Astronomy.

Copernicus Crater (near the Moon's limb) is one of the most prominent craters on the near side of the Moon. This shot was taken from lunar orbit during the Apollo 12 mission, which sampled the crater's ejecta. NASA