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Our obsession with the Moon – and what's behind Nasa's mission to get back there

The space race is back on... as Nasa's imminent Moon mission seeks to unlock

its secrets and pave the way for human habitation | *By OLIVER MORTON*

The crew members of the nine Apollo missions to the Moon remain, to this day, the farthest-flung human beings in history. The Moon is, on average, 250,000 miles from the surface of the Earth; if there were a piece of string that long, you could wrap it round our planet's equator almost 10 times.

By contrast, the farthest any astronaut has been since the Apollo programme ended in 1972 is just 870 miles, on a private mission flown in 2024. In string terms, that's only London to Rome. Once sailors of a new sea, astronauts have become paddlers on its shore.

But while the Apollo astronauts went farther than any of their successors, they also brought back evidence that the Moon was, in an unexpected way, a home from home. In the very distant past, the Moon and Earth were one.

The Apollo project led to this discovery in two ways. One was direct: chemical analysis of the Moon rocks brought back by the astronauts showed that the raw material for the Moon had been remarkably similar to the rocky mantle that sits between Earth's crust and its iron core. On top of that, the lunar rocks were remarkably low in "volatiles" – light and simple molecules that might form gases or ices.

The other clue was more circumstantial. To guide the Apollo astronauts' endeavours, scientists led by the first great "astrogeologist", Eugene Shoemaker – teased behind his back as "Dream Moonshaker" – painstakingly pieced together geological maps of the Moon. These show the relationships between parts of the surface in a way that allows their history to be inferred.

These Moon maps revealed that almost every feature on the Moon, from the smallest visible craters to its great basins, had been shaped by other things hitting the surface; the dark "seas" visible from the Earth were places where the interiors of "impact basins" had subsequently been filled with lava.

The biggest impact basins showed that the early history of the solar system had been incredibly violent. The Moon had been pummelled by solid objects – "planetesimals" – as big as or bigger than the largest asteroids around today.

Those two insights, brought together in the years immediately after the Apollo programme halted, formed the basis of a new theory of the Moon's origin: that it was created in the most extreme impact the solar system had ever seen. Around 4.54 billion years ago, two "protoplanets" – Theia, which was about the size of Mars, and a larger one, Tellus, almost as big as Earth – collided.

Briefly they were one; their molten rocky mantles mixed; their iron cores coalesced. But such was the violence of their meeting that their combined gravity was not strong enough to hold the whole infernal caboodle together. Some of the liquidised, pulverised, vapourised rock splashed out into orbit, where it eventually solidified into the Moon. The rest of the debris formed the Earth.

This story is still a work in progress – scientists argue strenuously about the details of how exactly the two sibling planets crashed into each other and how they subsequently divided up everything from their chemical isotopes to their angular momentum. But the Apollo missions have no greater scientific legacy than the fact that, after thousands of years of looking at the Moon in wonder, humans learnt for the first time how the Earth's inconstant companion in the sky had come to be there.

Now, long space voyages are coming back. At the start of April, Nasa hopes to roll a huge booster rocket back out to the launchpad at Kennedy Space Center in Florida, from which all the Apollo missions set out. (The rocket has already made the trip to the pad once, but a leaky fuel connection forced it back to its hangar for further work.) The space capsule on top of that booster, named *Integrity* by its crew, will take that foursome farther from the Earth even than their Apollo forebears. Come blast off, currently envisioned for 1 April, the engines of the booster rocket, the prosaically named Space Launch System (SLS), will send *Integrity* into a high orbit around the Earth. *Integrity*'s own engine will then propel it on a journey that loops all the way around the Moon – the trajectory that establishes the distance record – before returning to Earth 10 days later.

The purpose of this mission – known as Artemis II – is to show that space capsules such as *Integrity* can support crews in the way they are meant to. In itself it will add little to humankind's knowledge of the Moon, since it will not actually visit its surface. What can be learnt about the Moon from space has been learnt by satellites for decades – there is little human eyes can add.

The science begins, all being well, with Artemis IV. In that mission – notionally scheduled to set off in 2028, but likely to be delayed – the capsule launched from Cape Canaveral will, after getting to the vicinity of the Moon, dock with a second, separately launched spacecraft able to take astronauts and equipment down to the lunar surface and back up again. It is at that point that the scientific studies initiated in the Apollo era will resume.

Clearly these scientific studies are not the main purpose of the programme. The US is undertaking Artemis – on which it has already spent $93 billion (£69 billion) – because China intends to land people on the Moon by 2030; success is a matter of national pride. Another factor is that the International Space Station (ISS), which has been Nasa's focus for the past 30 years, is near the end of its life.

Clockwise from above: Harrison Schmitt collects samples, 1972; the South Pole-Aitken basin on the lunar far side; astrogeologist Eugene Shoemaker

That means a new big project is needed, whether it has scientific merit or not. (The ISS, in the eyes of many, has been rather lacking on that front.)

In the 1960s, Apollo was dreamt up as a magnificent enterprise that would make the US's superiority to the Soviet Union plain for all to see. Its scientific side was added later through the hard work of brilliant opportunists, Shoemaker foremost among them. They convinced Nasa that there was important science to do on such missions, and that the astronauts, though not trained scientists (with the exception of Harrison Schmitt in 1972), would be able to do it.

That set the template for Artemis. Science is not the driving force behind the programme. But it is seen as a natural piece of the endeavour; a clear and understandable answer to the question of what Artemis is for. The scientific work carried out by Artemis astronauts will also, like that done by Apollo astronauts, be symbolic; it adds high-mindedness and a common human purpose to the proceedings. But that will not stop it from being good science. And this time round it will have a practical purpose, too.

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Nasa has a whole series of Artemis missions planned as precursors to a permanently crewed Moon base. Preparing to build a base will require a new fine-grained understanding of the place where it is to be built: how can the local rocks be worked into the base? What needs to be done to the surface to allow rockets to land and take off repeatedly from the same place? How can the Moon's dangerous dust be stopped from infiltrating every life-supporting nook and cranny? And a dozen other crucial, if not entirely inspiring, details that can only be gleaned from scientific study.

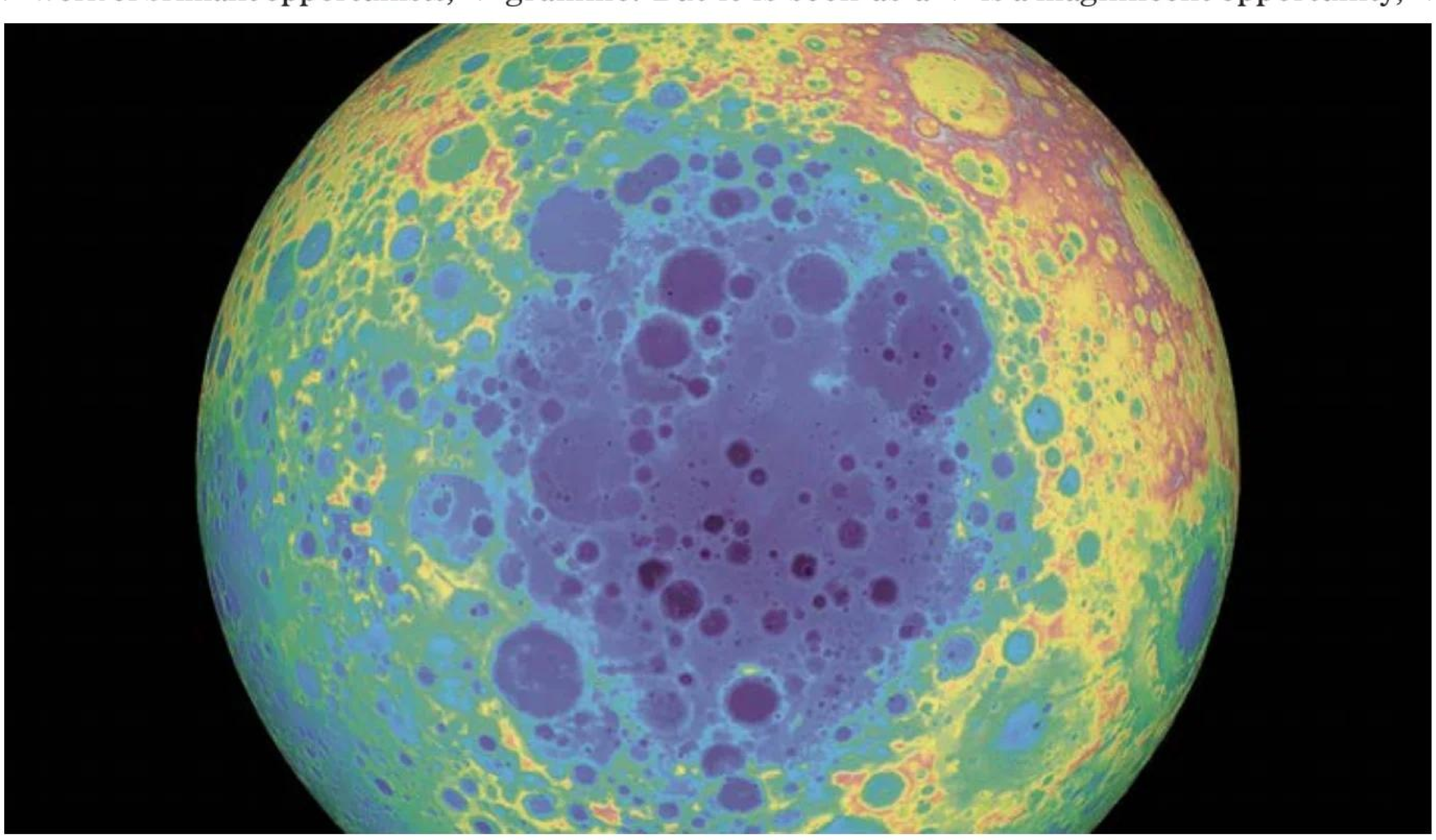
But there are big revelations to anticipate, too. Both the US and China want to build their putative bases close to the Moon's South Pole. And for many scientists that is a magnificent opportunity, because the South Pole is on the rim of a huge impact basin.

The South Pole-Aitken (SPA) basin is about 1,600 miles in diameter: 70 per cent of the diameter of the Moon as a whole. It is almost entirely on the far side of the Moon – the side never seen from Earth – and takes up a remarkable amount of room. The point opposite the South Pole on the north side of the rim is a crater called, predictably, Aitken. It is just 15 degrees from the Moon's equator. A crater of proportionate size on the Earth would reach from the South Pole to northern Australia, and take up huge chunks of the Indian Ocean and the South Pacific.

The SPA basin is the oldest recognisable feature on the Moon. And samples of rocks that melted in the impact – which should be accessible from Artemis landing sites – could be used to establish fairly precisely how long ago it was created. That would be a huge step forward for lunar science.

The geological maps made for Apollo, and since improved, establish when major geological events on the Moon happened with respect to one another. But they do not establish absolute dates, and there is now doubt over some of the dates assigned on the basis of rocks brought back by the Apollo missions. A firm date for the SPA basin would bring precision to our understanding of the Moon's pummelled infancy, revealing how the size and frequency of impacts changed over time.

This matters far beyond the Moon. Theories about the early history of the solar system vary as to whether the number of impacts on not just the Moon but all the inner planets – Mercury, Venus, Earth and Mars – simply slowed down over time, or whether there was a second spate of impacts long after the first, perhaps as the result of shifts in the orbits of the larger planets in the outer system. But only the Moon offers an



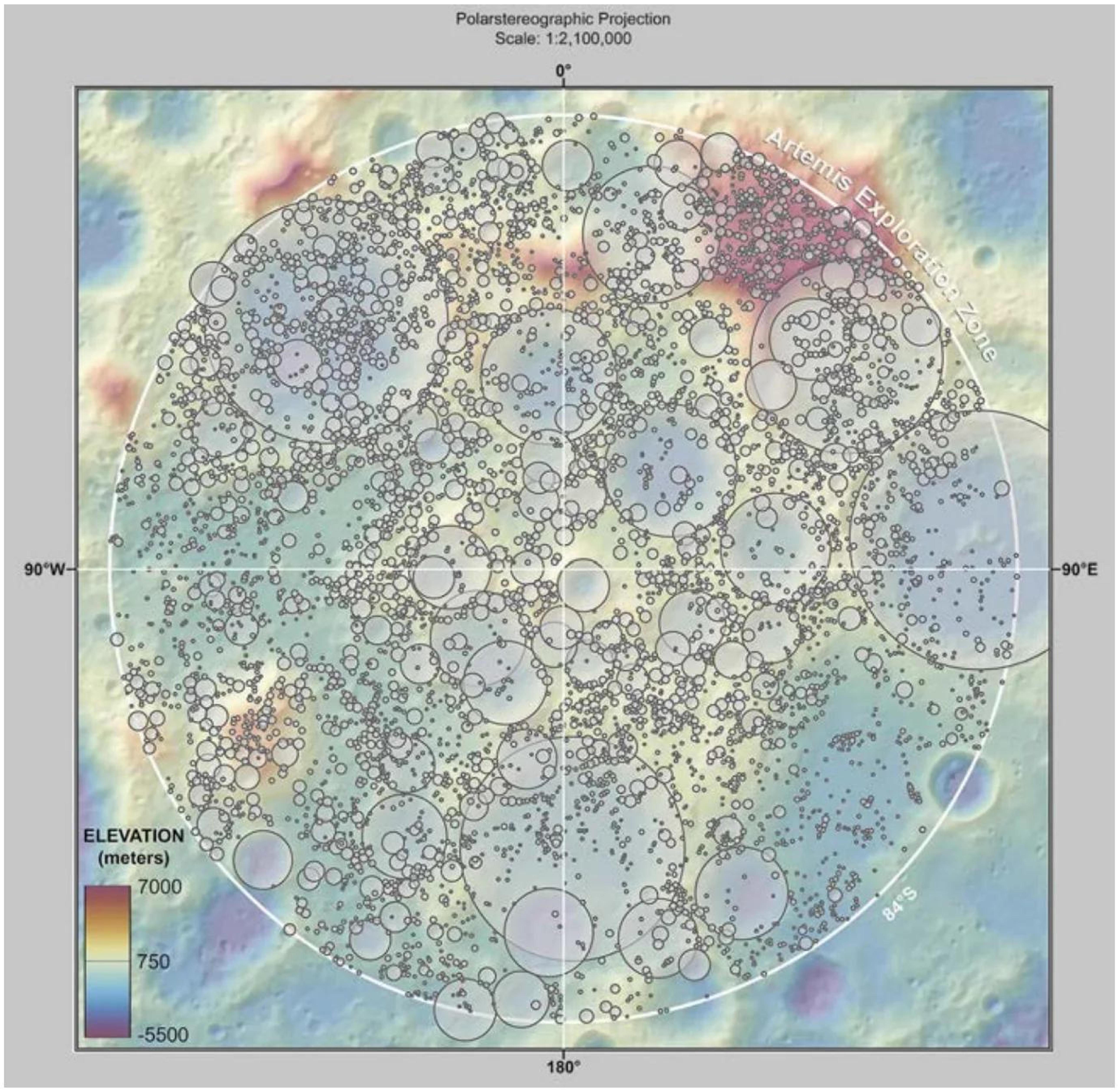
PREVIOUS PAGE: NASA. THIS PAGE: NASA, GETTY IMAGES, NASA/GSFC/UNIVERSITY OF ARIZONA accessible record of that tumultuous time.

If the chronology of the lunar impacts can be dated by new samples from the SPA basin, then the early history of all the rest of the solar system will become clearer, too. That may well provide insights into when the Earth became habitable – a fundamental question about the home planet that cannot be answered any other way.

The reason for building bases at the South Pole is not for the scientific possibilities of the huge hole that stretches away from the site; it is for riches closer to hand, namely ice. On Earth, ice at the poles is to be expected. Ice anywhere at all on the Moon is quite remarkable, for there is almost no atmosphere to provide frost, and the temperature in direct sunlight is way more than 100C.

At the Moon's South Pole, though, there are places that never see any direct sunlight. As in Antarctica, at the South Pole of the Moon, the sun stays close to the horizon. But unlike on the Earth, at the Moon's South Pole, the sun does not move up and down with the seasons, rising in summer, disappearing in winter. It just hangs there, circling the pole every 709-hour-long lunar day, casting long, slow-moving shadows.

These shadows fill the craters with which the Moon's South Pole is pockmarked. In what Nasa calls the "Artemis Exploration Zone" – an area a bit bigger than the UK that runs up from the South Pole to a latitude of 84 degrees – there are 5,251 craters more than 0.6 miles across.



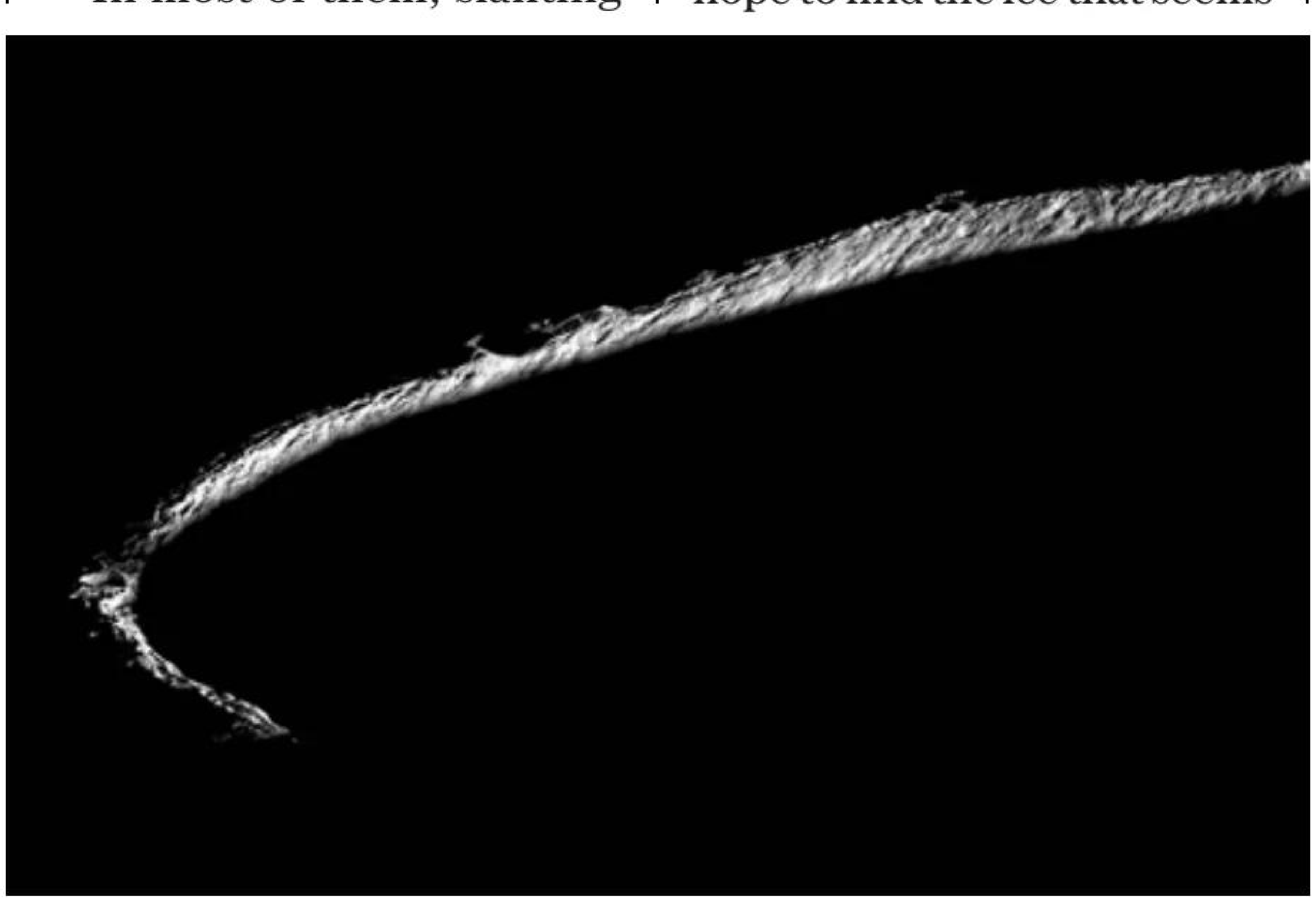
Above: a map showing craters within the Artemis Exploration Zone. Below: the Shackleton crater – the illuminated area is the rim where the sun shines 90 per cent of the time, making it an attractive site for a solar-powered base

In most of them, slanting sunlight is available for some or most of the time. Indeed, there's a ridge at the edge of a crater called Shackleton where the sun shines 90 per cent of the time – something that makes it an attractive site for a solar-powered base. But there are also places in deep craters that never see the sun at all. It is in these dark crannies that scientists hope to find the ice that seems next to impossible on an airless world, where the temperature rises so high.

Though the Moon has next to no permanent atmosphere it has transient ones. If it is hit by a comet, say, or by some sorts of asteroid, small volatile molecules from the impactor get released. And if any of them end up in one of the permanently shadowed regions near the pole, where temperatures are typically lower than minus-100C, the chances are they will stay frozen there a long time – in some cases, permanently.

The same is true for gases given off by the Moon's infrequent volcanic reactions, and even for particles that arrive from the Sun as part of what is known as the "solar wind". If there are any other processes that produce volatiles on or near the Moon – and scientists have suggested a few – they will probably add to the ice, too.

The permanently shadowed regions in and around the Artemis Exploration Zone are reckoned to cover around 8,100 square miles – roughly the size of Wales. Parts may be iceless. But in other areas there will be records of all sorts of events that have provided volatiles to the otherwise dry rocks of the Moon. A record of how frequent comet impacts have been, records of changes in the solar wind over time, of lunar volcanism, and maybe of other things, too.



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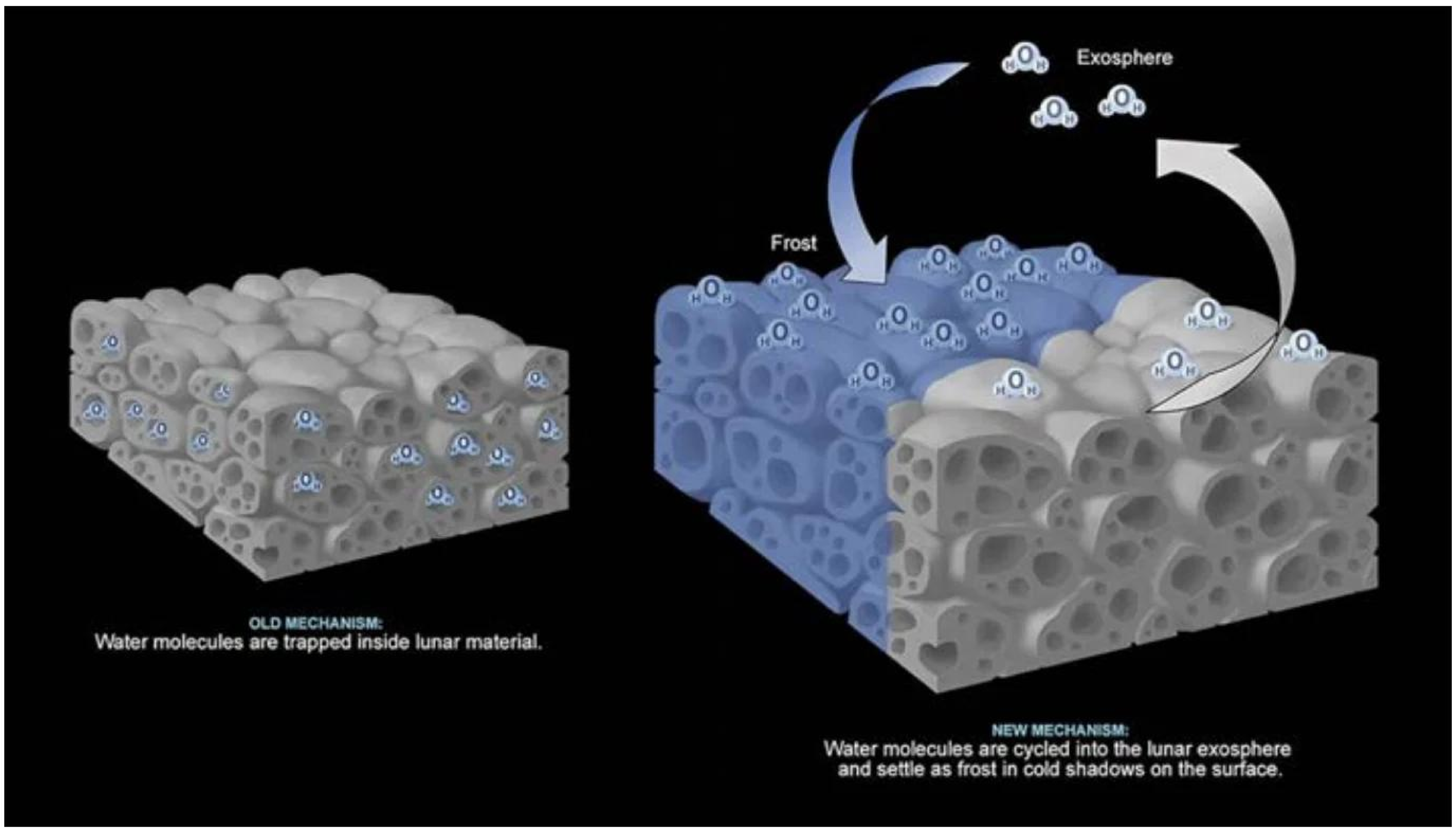
Samples may offer insights into when the Earth became habitable – which cannot be answered any other way



Above: a new study suggests that water on the Moon might remain as frost in shadows and move via the thin exosphere. Below: Artemis II astronauts Reid Wiseman, Victor Glover, Christina Koch and Jeremy Hansen in January

These patches of perpetual darkness should provide a whole new way of looking at the history of the inner solar system over the past few billion years, a record written not just in water ice but in many other types of frozen volatile, too: methane, ammonia, carbon monoxide, carbon dioxide, hydrogen sulphide, and some organic molecules.

The things scientists think they will find out from the laminated layers of ice have them very excited. Chances are, they will also find things that they haven't yet begun to imagine which will excite them more. That's the sort of thing that happens when science comes into contact with previously unseen phenomena.

Surveying the ices, though, is not a matter of pure science; it will also be intensely practical. Having a local source of some or all the volatiles you need makes running a base a much easier proposition. Humans need water and oxygen; the plants with which they feed themselves need water and carbon dioxide. Rockets to get from the lunar surface back into space need oxygen too, as well as hydrogen or methane as propellants. Concretes need sulphur.

Some of these materials can be recycled. Even so, having a source nearby rather than shipping supplies from Earth could be very handy. And rocket fuel really can't be recycled; having the makings of a steady supply close to hand would be an immeasurable asset to a base.

This is why the Moon's South Pole is a target for China and the US alike – and why there's a possibility that conflicts between pure science and resource extraction may well, in time, open up on a second world.

With bases established, more science will follow. For instance, radio astronomers have a keen interest in the far side of the Moon; it is the only place in the solar system where they can be sure that their observations will not be interfered with by radio signals from Earth. Only from the lunar farside can radio astronomers have the perfect peace they need for some of their most ambitious observations of the cosmos and its history.

The most poetic of all the scientific endeavours, though, will be the meteorite hunting. The majority of meteorites are fragments of asteroids, but some are fragments of planets. When a large impactor hits a planet, some of the debris it throws out travels so fast and so far as to be knocked right off the planet. There are meteorites on Earth that come from both the Moon and Mars.

And this means that on the Moon there will also be meteorites from Mars – and from Venus and Earth. That rocks from the Earth might be exciting seems strange: if there is one thing you would think earthbound scientists had enough of without going into space, it is rocks from our own planet. But most rocks on Earth are comparatively young. Though our planet is 4.54 billion years old, rocks older than three billion years old are rare, four billion years effectively unheard of.

This means there are hundreds of millions of years of Earth history of which Earth itself carries no physical record – hundreds of millions of years crucial to how the planet became what it is today; hundreds of millions of years during which, it is quite possible, life first came into being.

But the early Earth, like the early Moon, was being hit by asteroids a lot more than either is today. That means meteorites were being flung off it at a far greater rate. And the most likely place for a rock knocked off the Earth this way to end up, other than back on Earth, would be the Moon.

On the Moon, rocks are safe from the erosional indignities of wind and rain and the exceedingly slow, exceedingly fine grinding provided by the wheels of plate tectonics. For the most part, only fragments may remain. But fragments of such ancient rock would still matter a lot. And larger samples are not inconceivable.

The lunar science of the coming decades has the potential to unravel the early history of the solar system, and the ways in which rocky planets organise their innards as they form. Scientist-astronauts may find all sorts of stories written in exotic ices, and map the resources that allow a human presence on the Moon to continue indefinitely. And they may find extraordinarily rare, extraordinarily precious mementoes of the Earth's own infancy. These aren't the reasons why nations invest huge sums in such exploration. But like rocks thrown from planet to planet by asteroid impacts, they are the most wonderful of side effects.

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NASA/JPL-CALTECH, NASA/KIM SHIFLETT