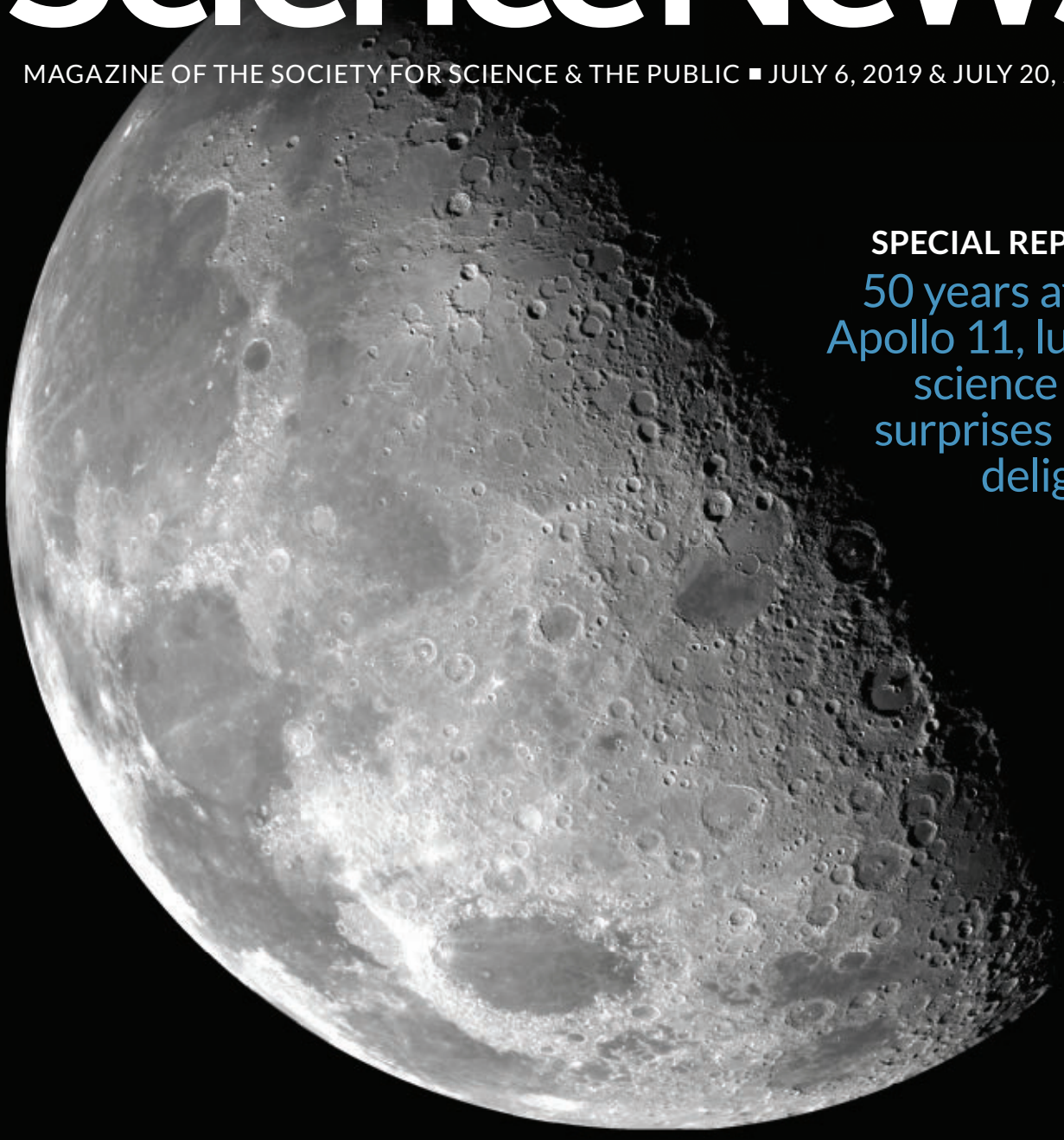
A Dent in the Common Cold's Armor | Ocean Plastic Goes Deep

ScienceNews

MAGAZINE OF THE SOCIETY FOR SCIENCE & THE PUBLIC ■ JULY 6, 2019 & JULY 20, 2019



SPECIAL REPORT

50 years after Apollo 11, lunar science still surprises and delights

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Special Report

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Departments

SOCIETY UPDATE
Society Advocates named

COVER The moon (shown in a composite image) continues to capture the imagination of scientists and civilians alike. *JPL/NASA*

FROM TOP: NASA; G. URTON

After all this time, the moon still manages to surprise us

"Look at the moon!" How many times have I said that when it surprised me, rising huge and orange at the end of the street, scudding behind icy winter clouds or floating serenely in the evening sky? I know I'm not alone in the joy I feel each time its nocturnal show stops me in my tracks. How something so constant and predictable continues to enchant us is an enduring mystery. In the course of our work to create this special issue commemorating the 50th anniversary of the Apollo 11 moon landing, I learned that the moon has many more surprises in store.

For starters, scientists are still discovering new things from the rocks that astronauts scooped from the lunar surface so many years ago. Astronomy writer Lisa Grossman traveled to NASA's Johnson Space Center in Houston, suited up and entered the laboratory that protects the lunar samples (Page 18). She reports on recent discoveries including that the moon, contrary to its parched appearance, is actually wet.

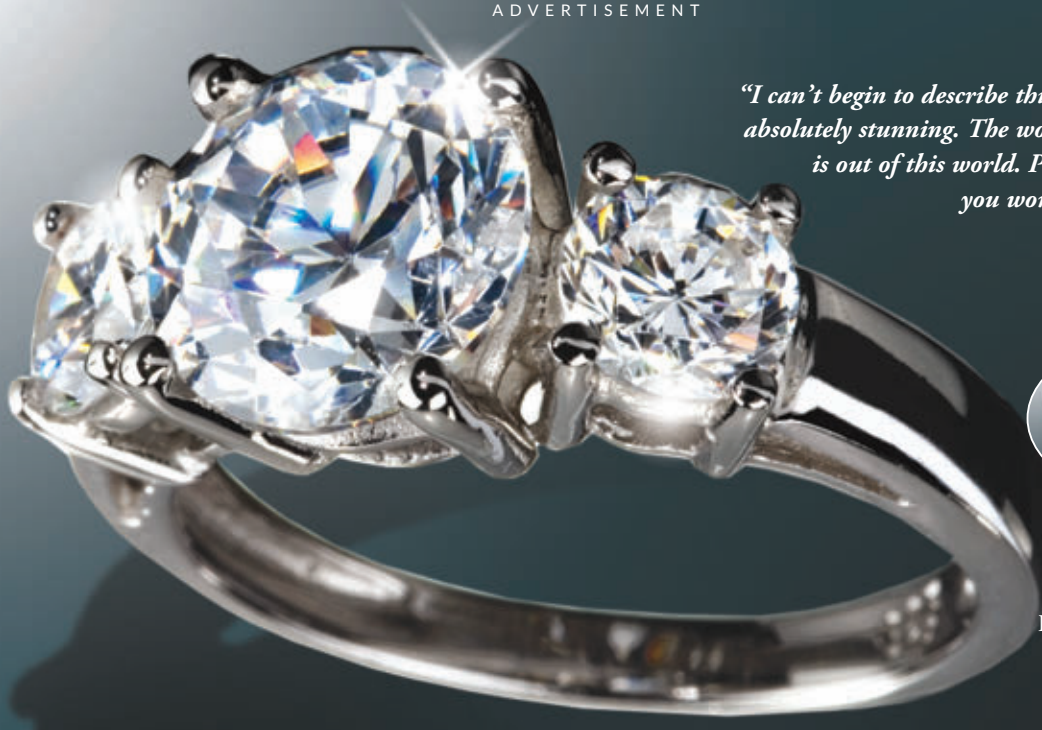
Astronauts also left a lot of stuff behind on the moon. Some was abandoned by the necessity of hauling heavy rocks back to Earth, and some was placed by intent, including astronauts' mementos and messages for potential future visitors. And, of course, the astronauts set up scientific experiments on the lunar surface, as staff writer Maria Temming reports (Page 26). One of those experiments is still in good working order, and researchers are using it to test a key aspect of Einstein's general theory of relativity. And we're not the only creatures under the moon's spell. Managing editor Erin Wayman explores moonlight's sway on Earth's creatures (Page 32).

And in Science Visualized (Page 46), we look at how humans' renderings of the moon have evolved. My favorite was drawn by William Gilbert, physician to Queen Elizabeth I, who sketched what he could see with the naked eye. He thought lighter areas were water, which is incorrect. But we still call some darker areas seas, including Apollo 11's landing spot in the Sea of Tranquility.

There's personal history here, too. *Science News* covered the space race obsessively (Page 38), from the Soviet Union's launch of the Sputnik satellite in 1957 (*SN: 10/19/57, p. 243*) to the tragic loss of astronauts Gus Grissom, Ed White and Roger Chaffee during a simulated launch in 1967 (*SN: 2/4/67, p. 112*) and then on to the historic landing on July 20, 1969 (*SN: 7/26/69, p. 72*). The goal of our reporting then was to resist hyperbole, explain the science and provide context. We remain true to that mission today.

Back in the 1960s, the Apollo program was not without controversy; critics questioned spending billions getting to the moon when the United States was beset with social unrest and the Vietnam War. In 1972, then-editor Kendrick Frazier wrote of his hopes that "in a future and less buffeted age," those critiques would be forgotten (*SN: 10/21/72, p. 259*). Our age may not feel any less contentious, but there's no question that our trips to the moon endure as extraordinary achievements of science and technology. —*Nancy Shute, Editor in Chief*

Note to subscribers: This is one of our four double issues, which feature special coverage. The next issue of the magazine will be heading your way on August 3.



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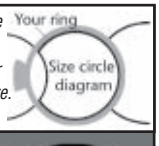

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Excerpt from the July 5, 1969 issue of *Science News*

50 YEARS AGO

Watching the unborn

An artificial womb has been used to keep some 35 fetal lambs alive for up to 55 hours ... researchers [still] have to show that a fetus can actually grow, not just survive, in their man-made womb.... Eventually, it might be possible to place extremely premature infants into such a womb ... to support them until they can survive on their own.

UPDATE: Artificial wombs that bring preemie babies to term could help save thousands of babies born before 28 weeks in the United States each year. In 2017, researchers reported tests on a different kind of womb device on premature lambs. Unlike scientists in the 1960s, who submerged lambs in synthetic amniotic fluid in a fish tank–style setup, the recent group placed lambs in fluid-filled bags, sealed to reduce the risk of infection (*SN: 5/27/17, p. 6*). Those lambs developed normally during the four-week experiment. That was far better than the average 40 hours the lambs in the '60s survived before succumbing to infection. Scientists hope to make such technology ready for humans within a few years.

Soprano pipistrelle bats migrate from Northern to Central Europe every August. Scientists are trying to learn how the bats find their way.

THE SCIENCE LIFE

Chalk in a box shows how bats migrate by sunsets

In migration science, birds rule. And scientists know far less about how the many migrating mammals, including antelopes, whales and bats, make their journeys. So animal navigation researcher Oliver Lindecke invented a device to reveal how bats find their way.

Lindecke, of Leibniz Institute for Zoo and Wildlife Research in Berlin, has studied bat migration since 2011. He started by analyzing forms of hydrogen atoms, or isotopes, in wild bats to infer from where the animals had flown. Figuring out how bats knew where to go was trickier.

Lindecke needed a field setup to test what possible cues from nature help bats navigate vast distances. The first step was studying the direction in which bats take flight. Such experiments on birds usually involve confining the birds to small spaces and studying their attempts to escape. But that doesn't work for bats, which tend to fall asleep in tight spaces. "My challenge was to build a box that bats won't sleep in, but will show me how they take off," Lindecke says.

So he invented what he calls a "circular release box": a flat-bottomed, funnel-shaped container topped by a wide lid. To escape, the bat crawls up an incline and takes off from the edge. Experiments in 2016 had shown that adult bats flew straight in the direction in which they took off, Lindecke and colleagues reported in the May *Journal of Zoology*.

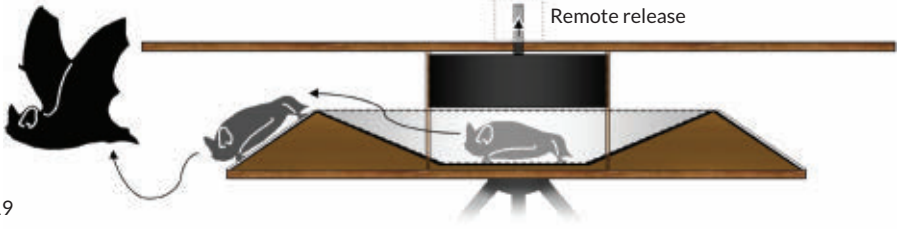
In another experiment in August 2017, Lindecke captured 54 soprano pipistrelle bats (*Pipistrellus pygmaeus*) at the Pape Ornithological Station in Latvia, as the animals were migrating south along the Baltic coast toward Central Europe. But this time, Lindecke added a layer of chalk on the inside of the box; bat tracks in the chalk indicate the precise location at the edge from which the bat took off.

Lindecke also found that bats use the setting sun to orient their nighttime flights. Some bats were given a view of a sunset, while others were shown a mirror reflection of the same sunset. The bats were then moved inland and released from Lindecke's box. The bats that saw the natural sunset flew west — back toward their coastal, migratory route. Those that watched the mirrored sunset flew east, Lindecke and colleagues reported in the April 22 *Current Biology*. Juvenile bats took off in random directions, though. That suggests that navigation skills are not innate, and younger bats must learn them from their elders.

Lindecke's easy-to-build device could inspire more studies on how bats negotiate migration routes, he says. Some of his colleagues have already dubbed the box a "Lindecke funnel" — playing off the cone-shaped Emlen funnel used in bird studies.

"I am not one to call it that," Lindecke says, a little sheepishly. "It's a stupidly simple design." — *Yao-Hua Law*

On the move This cross section of a new device for studying bat migration illustrates how the box works. After being placed in the device, a bat crawls up the sloped wall and takes off in the direction of its flight. A layer of chalk in the box marks the bat's tracks.



FROM TOP: CHRISTIAN GIESE; O. LINDECKE *ET AL*/*CURRENT BIOLOGY* 2019

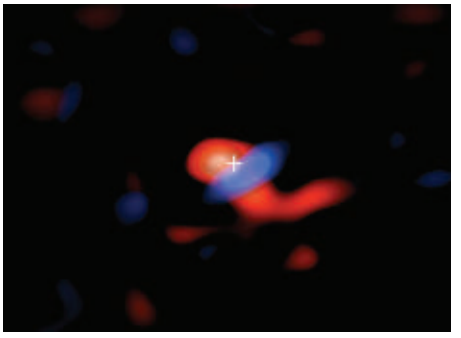
FIRST

Spotted: the disk around our galaxy's black hole

Astronomers have sighted the glowing disk of hot gas orbiting the supermassive black hole in the middle of the Milky Way.

The black hole, Sagittarius A*, is huge, at about 4 million solar masses. But it is still considered "underfed" because it doesn't gobble gas and dust as voraciously as other black holes do. Underfed black holes "don't have enough food" for their accretion disks to glow brightly, says astrophysicist Elena Murchikova of the Institute for Advanced Study in Princeton, N.J. That diminished glow could help to explain why scientists recently managed to capture a picture of the more distant black hole in the galaxy M87 but not yet Sgr A* (*SN: 4/27/19, p. 6*).

Previously, hot gas (around 10 million kelvins) emitting high-energy X-rays had been spotted around Sgr A*. But that gas didn't seem organized into a neat, orbiting disk. So Murchikova and her colleagues searched for cooler gases (about 10,000 kelvins) near Sgr A* by observing particles of light in a particular wavelength emitted when electrons and protons combine to form hydrogen.



This image shows that some gas orbiting the Milky Way's black hole moves toward Earth (blue) and some moves away (red), indicating the disk of gas spins. The plus sign shows the black hole's position.

The photon distribution showed an oblong disk. On one side of the disk, the light wavelength was squished, or blue-shifted. On the other side, the light was stretched, or redshifted. That finding, reported in the June 6 *Nature*, means that one side of the disk is moving toward Earth, and the other is moving away — a sign that the disk is rotating. — *Lisa Grossman*

PICTURE THIS

Fossil captures an ancient school of swimming fish

Fossilized fish caught midswim give a rare glimpse into extinct animal behavior — and suggest swimming in schools arose around 50 million years ago.

It's unclear what killed the fish. But a sand dune collapse, for example, could have buried them in place. The orientation of the 257 extinct, thimble-sized fish called *Erismatopterus levatus* suggests that they coordinated their motion similarly to fish in groups today: Fish are repelled from neighbors to avoid collisions, but track with farther away fish to stick with the group, researchers report in the May 22 *Proceedings of the Royal Society B*.

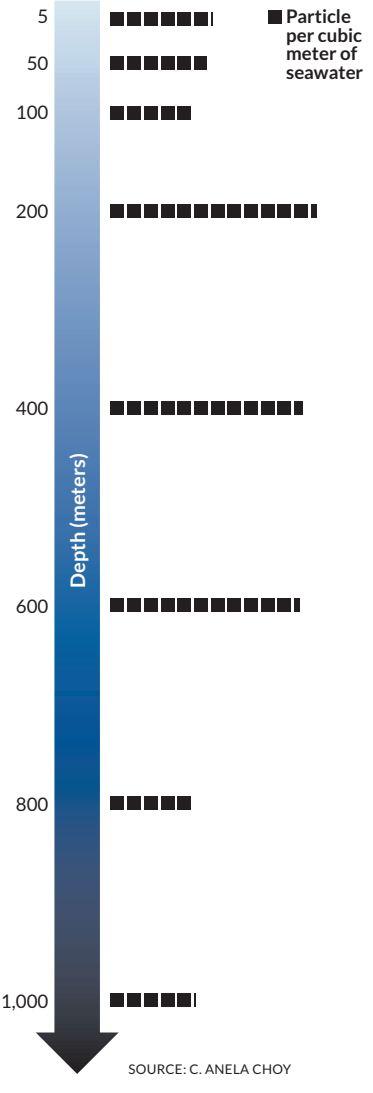
Though collective behavior, such as bird flocking or insect swarming, likely evolved long ago, there has been scant evidence in extinct species. This fossil, housed in a Japanese museum, came from sediments in the Green River Formation in the western United States. — *Carolyn Wilke*

SCIENCE STATS

Ocean plastic is plentiful in the deep

Swathes of floating ocean litter, such as the Great Pacific Garbage Patch, may just be the tip of the trash heap. A survey conducted off California suggests that large amounts of microplastics lurk far beneath the sea surface. This graph shows the average plastic particle concentrations at various depths in Monterey Bay, based on samples collected in 2017 and reported June 6 in *Scientific Reports*. — *Maria Temming*

Average microplastic particle concentrations in seawater



SOURCE: C. ANELA CHOY

CLOCKWISE FROM TOP: E.M. MURCHIKOVA, S. DAGNELLO, ALMA, ESO, NAOJ, NRAO, AUI, NSF; E. OTWELL; N. MIZUMOTO, S. MIYATA AND S.C. PRATT/*PROC. R. SOC. LONDON B* 2019

HUMANS & SOCIETY

Sharpened tools' origins debated

Contested finds point to shift in technology by early *Homo*

BY BRUCE BOWER

Discoveries in East Africa of what may be the oldest expertly sharpened stone implements suggest that early members of the human genus, *Homo*, invented these tools by about 2.6 million years ago, researchers say. But their conclusions are controversial.

New finds at a site in Ethiopia called Ledi-Geraru fit a scenario in which various early *Homo* groups devised ways to sharpen handheld stones, assert David Braun, an archaeologist at George Washington University in Washington, D.C., and colleagues. Ledi-Geraru artifacts date to between 2.61 million and 2.58 million years ago, the team reports in the June 11 *Proceedings of the National Academy of Sciences*.

Until now, stone tools from a nearby site called Gona that date to between 2.58 million and 2.55 million years ago were the oldest examples of cutting and digging devices with systematically sharpened edges (*SN: 4/17/04, p. 254*). These types of artifacts are referred to as Oldowan tools because the first examples were found at Tanzania's Olduvai Gorge.

Age estimates for Ledi-Geraru artifacts were determined by where they were found, between a dated layer of volcanic ash and sediment preserving a known reversal of Earth's magnetic field. These stone tools "are probably at least 50,000 years older, but could be up to 100,000 years older than Gona artifacts," Braun says. His team recovered 300 stone artifacts, including sharp-edged rocks and larger rocks from which those implements were struck. Those finds were strewn among 330 fossilized bones of nonhuman animals.

Older stone tools have been found. For instance, at the Lomekwi 3 site in Kenya, large stone implements, many perhaps best suited for pounding objects, may date to 3.3 million years ago (*SN: 6/13/15, p. 6*). Contested evidence, based on possible stone-tool incisions on two 3.4-million-year-old animal bones, suggests that *Australopithecus afarensis*, ancient hominids best known by Lucy's partial skeleton, butchered animals before the *Homo* genus appeared (*SN: 9/11/10, p. 8*). And chimpanzees and monkeys crack open nuts with stones, a sign that tool use extends far back in primate evolution (*SN: 11/26/16, p. 16*).

But the Ledi-Geraru artifacts indicate that *Homo*, which possibly originated about 2.8 million years ago based on a jaw previously found at Ledi-Geraru (*SN: 4/4/15, p. 8*), took stone-tool making to a new level characterized by skilled edge sharpening, Braun's group argues.

Archaeologist Ignacio de la Torre of University College London agrees. "The association of Oldowan tools with early *Homo* may be best explained by shifts in diet and access to animal meat through scavenging," he says.

Animal bones unearthed with the artifacts came from creatures such as gazelles that would have lived in open grasslands, Braun's team says. That landscape probably presented frequent scavenging opportunities, the researchers suspect. Lucy's species would have spied fewer fresh carcasses, the team contends, because the same part of East Africa featured shrubs with occasional stands of trees and forested areas during her time.

No stone tools dating to between 3.3 million and 2.6 million years ago have been found, so it's unclear if Ledi-Geraru artifacts represented a rapid change in toolmaking or an elaboration of earlier techniques, says archaeologist Sonia Harmand of Stony Brook University in New York. Sharp-edged flakes struck from larger rocks have been found at Kenya's Lomekwi 3, so precursors of Oldowan techniques might have started developing as early as 3.3 million years ago, says Harmand, who directed Lomekwi 3 excavations.

This stone tool, found in Ethiopia and shown from different angles, is one of the oldest known sharpened tools, researchers contend.

Other researchers doubt both Braun's and Harmand's conclusions. Until a detailed analysis of sediment formation at the Ledi-Geraru site is published, archaeologist Manuel Domínguez-Rodrigo says he is skeptical of the claim that the artifacts were found where they originally were deposited or are as old as reported. Domínguez-Rodrigo, of Complutense University in Madrid, also suspects that the Lomekwi 3 artifacts originally lay in much younger sediment before erosion and water moved them down a slope to 3.3-million-year-old sediment. And animal trampling likely created the reported incisions on animal bones from Lucy's time, he argues.

Ledi-Geraru artifacts were also found on a slope where they originally could have lain in sediment younger than 2.6 million years, says Yonatan Sahle, an archaeologist at the University of Tübingen in Germany. Sahle participated in previous fieldwork at Ledi-Geraru with Braun's group, but isn't part of the new study. It's "simply unwarranted" to tag tools from Ledi-Geraru as the earliest Oldowan specimens without a more thorough sediment analysis, Sahle contends. Even the evolutionary identity and age of the Ledi-Geraru jaw initially assigned to *Homo* are up for grabs, he says.

Microscopic study of Ledi-Geraru sediment indicates that stone artifacts were dropped at the edge of a lake and quickly covered by earth that held the finds in their original positions, Braun contends.

For now, scientists' clashing positions on the reliability and implications of ancient toolmaking evidence also appear held in place, if not etched in stone. ■

COURTESY OF D. BRAUN

EARTH & ENVIRONMENT

Food containers may pollute compost

Health effects of PFAS leached into the soil remain unknown

BY CAROLYN WILKE

Composting biodegradable food containers cuts the amount of trash that gets sent to a landfill. But the practice may serve up some unintended consequences for human health.

That's because the items often contain per- and polyfluoroalkyl substances, or PFAS, to help repel water and oil. These persistent chemicals can leach out of the packaging and end up in compost, researchers report in the June 11 *Environmental Science & Technology Letters*. When that compost is used, PFAS could be taken up by plants and ultimately accumulate in people's bodies, though the health effects are unclear.

Microbes can usually help break down chemicals, but for this persistent bunch, the organisms typically transform the compounds into other PFAS.

Environmental chemist Linda Lee of Purdue University in West Lafayette, Ind., and colleagues measured some of those by-products called perfluoroalkyl acids, or PFAAs, in compost from nine commercial facilities and one backyard bin. Seven of the facilities accepted compostable food containers. When those containers were in the mix, the team measured PFAAs at concentrations of about 29 to 76 micrograms per kilogram of compost. Compost with no containers had less than 8 micrograms of PFAAs per kilogram of compost.

"There was a huge difference in the PFAS levels between those two groups," says Laurel Schaider, an environmental chemist and public health researcher at Silent Spring Institute in Newton, Mass., who was not involved in the study. People expect the things they compost to break down entirely and become a sustainable source of nutrients for plants, so it's concerning that chemicals in compostable items can persist, she says.

As a class, PFAS include thousands of compounds. They show up in flame-retardant carpets, in nonstick coatings on cookware and myriad other places. "Everybody's happy to have all those conveniences, but the trade-off ... is pretty huge because [the compounds] don't go away," Lee says.

A chain of carbon forms the backbone of PFAS to which fluorine atoms attach. Lee's group found that most of the PFAS in compost samples were shorter-chain ones rather than the better-known, longer-chain perfluorooctanoic acid and perfluorooctanesulfonic acid, which have been largely phased out in the United States. Shorter-chain PFAS don't hang out as long in the body as their longer cousins, but they can more easily move from organic material in soil to water and be taken up by plants.

Studies have linked PFAS to negative health effects, such as high cholesterol, lowered fertility and low birth weight, as well as testicular and kidney cancers, Schaider says. But only a handful of PFAS have been thoroughly investigated for potential health effects. Little is known about how most of those detected in the compost samples affect human health.

The researchers analyzed the compost because Washington state officials were concerned that it might have been a mistake to allow composting of food containers. In part because of the team's results, the state passed the Healthy Food Packaging Act, which bans PFAS in paper food packaging beginning in 2022 if a replacement can be found.

With this information on which PFAS show up in compost, scientists can start to figure out what health risks might be associated with those chemicals, and if the chemicals should be used in this type of packaging at all, says Jennifer Guelfo, an environmental engineer at Texas Tech University in Lubbock. "Now is the time to look at the uses of these compounds ... and limit their uses to those scenarios where they are absolutely needed." ■

AUDREY VELASCO

LIFE & EVOLUTION

Vanishing act of fish's teeth explained

In the deep sea, dragonfish lure prey to their gaping jaws with beardlike attachments capped with a light. But the teeth of the pencil-length fish (one shown) don't gleam in the glow, which could alert prey. Instead, the teeth are transparent, thanks to nanoscale structures that reduce light scattered by the teeth, scientists report in the July 10 *Matter*.

Like most other animal teeth, dragonfish teeth are made of a hard tissue called dentin that's coated in a layer of enamel-like material. Transmission electron microscopy of one dragonfish species's teeth revealed tiny crystals of the mineral hydroxyapatite in the enamel plus nano-sized rods of collagen coated with hydroxyapatite in the dentin. Such structures would normally scatter light. But because of their small size, the light passes by with less being deflected, the scientists say. The teeth are also very thin, which also helps transmit light. — *Carolyn Wilke*

BODY & BRAIN

Stricter climate goal would save lives

Heat-related deaths predicted for different warming scenarios

BY AIMEE CUNNINGHAM

Meeting a more stringent worldwide goal to limit global warming may prevent thousands of heat-related deaths in 15 major U.S. cities, a study shows. The projections illustrate the high risk urban populations face from climate change.

Under the Paris Agreement, participating countries have pledged to curb greenhouse gas emissions with the aim of limiting warming to no more than 2 degrees Celsius over preindustrial times by 2100 (*SN: 1/9/16, p. 6*). Depending on the city, keeping warming to 2 degrees could mean 75 to 1,980 fewer deaths in an especially warm year, compared with a scenario in which the world warms by 3 degrees, researchers report June 5 in *Science Advances*.

Limiting warming to a more stringent 1.5 degrees, however, could spare 114 to 2,716 more city dwellers from dying in an especially warm year than the 3-degree scenario, the researchers report.

The study is the latest to suggest that, without additional efforts to help people adapt to higher temperatures, "heat-related mortality is likely to increase in the coming decades," says David Hondula, a climatologist at Arizona State University in Tempe who wasn't involved in the study.

> "Heat-related mortality is likely to increase in the coming decades."
>
> DAVID HONDULA

The 2-degree goal doesn't go far enough in many respects, according to the Intergovernmental Panel on Climate Change. Holding warming to 1.5 degrees would further reduce the risk of extreme heat waves, droughts, sea level rise and habitat loss (*SN: 10/27/18, p. 7*).

Excessive heat can kill (*SN: 4/14/18, p. 18*), most directly via heat stroke. Heat is risky for everyone, but some groups are more vulnerable than others, especially older adults, outdoor laborers and people in low-income neighborhoods lacking air conditioning.

In the new study, climate scientist Eunice Lo of the University of Bristol in England and colleagues explored how possible warming scenarios might impact heat-related deaths.

The researchers used mortality and temperature data from 1987 to 2000 for 15 U.S. cities combined with computer modeling to simulate conditions in different warming scenarios. The group projected heat-related deaths during an especially warm year — one expected to occur once in 30 years under each of the scenarios. Among the cities studied were New York, Chicago, Miami, Houston, Phoenix and Los Angeles.

Limiting warming to 1.5 degrees "makes a huge difference in terms of human lives across cities" in the United States, Lo says. "Immediate and drastic emission cuts would be substantially beneficial to public health." ■

GENES & CELLS

Tiny dent could be viruses' downfall

Potential drug target found for common cold, other diseases

BY AIMEE CUNNINGHAM

A newly discovered indentation on the surface of viruses that cause many illnesses, including the common cold, could be an Achilles' heel — and a possible target for effective drugs.

When scientists tested antiviral compounds in cells grown in the lab, the team found one that blocked the replication of an enterovirus. Cryo-electron microscopy revealed that the compound binds to and appears to jam a previously unknown pocket on the virus's protein shell, the researchers report June 11 in *PLOS Biology*.

Additional testing suggests that the pocket is widespread among picornaviruses. That's the viral family that includes enteroviruses — which cause hand, foot and mouth disease, as well as more dangerous infections — and rhinoviruses, responsible for the common cold. No antiviral medications are available to treat those pathogens.

The pocket "is an excellent target for antivirals" that may be effective against many of these types of viruses, says Susan Hafenstein, a structural virologist at Penn State College of Medicine who was not involved in the study.

These viruses mutate frequently, making it "easier for them to escape a drug," she says. To identify drug targets in the viruses, "it is essential to identify key working components" that these pathogens need to survive.

During an infection, viruses inject their genetic material into cells and take over the cellular machinery to make more viral particles. In picornaviruses, a protein shell surrounds the virus's inner core of genetic material. Previous research suggested that the shell changes shape when these viruses are ready to expel their genetic payload during an infection.

But a chemical compound, identified by structural virologist Sarah Butcher of the University of Helsinki, virologist Johan Neyts of the University of Leuven in Belgium and colleagues, binds to the newly discovered pocket in the protein shell and appears to lock the pocket in place. "This locking prevents the virus from infecting cells," Butcher says, because the shell can't change its shape and release its genetic material.

In tests, similar compounds were able to block many other picornaviruses, an indication that the pocket is a shared feature throughout the family with a crucial role in the viral life cycle, Butcher says.

The team is now altering those compounds to enhance their properties for use as drugs, Neyts says. ■

Actual size is 30.6 mm

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EARTH & ENVIRONMENT

New weather forecasting tool goes live

Experts hope upgraded U.S. model improves hurricane tracking

BY CAROLYN GRAMLING

The National Weather Service has launched a powerful new weather forecasting model. But whether the model is ready for prime time is an open question.

Over the last two years, the weather service has tested the tool, using it to do retrospective forecasts of three hurricane seasons and three seasons of winter storms. Scientists compared those forecasts with those of the previous model: the Global Forecast System, or GFS.

Scientists hope that the new model, GFS-FV3, for Finite-Volume Cubed-Sphere Dynamical Core, will improve the accuracy of U.S. weather predictions, currently in third place behind those of two European weather agencies. It's the first big upgrade to the GFS in about 40 years. So far, the tests suggest that the FV3 model has more accurate five-day forecasts and better predictions of hurricane tracks and intensification than the GFS or the models from the European agencies.

A dynamical core is the engine of a weather model, solving equations that describe the many complex physical interactions between the atmosphere and ocean, so that they can be incorporated into the model. Launched June 12, the new model produces more detailed images faster than the previous one, which means that it can incorporate more weather processes that might otherwise be missed, the weather service says. FV3 also simulates vertical movements such as updrafts, a key component of severe weather, at very high resolution.

When it comes to forecasting hurricane tracks, the FV3 model showed some promise during the 2018 storm season. Its prediction of the track of Hurricane Lane, which struck Hawaii last August, had fewer errors than any other system.

But some hitches appeared last winter. The model had an apparent "cold bias in the lower atmosphere," as a memo from the weather service noted in February, which caused it to dramatically overpredict snow amounts in the Northeast.

On April 4, government scientists released a new configuration of the model that they said removed the cold bias and "showed a clear improvement" in excessive snowfall predictions. But the model still predicted somewhat more snowfall than was observed in some test cases.

"That's one of the problems we will continue to work on," said Brian Gross, director of the National Oceanic and Atmospheric Administration's Environmental Modeling Center, during a news conference June 12.

Another problem: FV3 tends to predict that weather patterns in the midlatitudes will move a bit faster than they do, Gross said. "It's something to look out for as we continue to work on that."

For now, scientists are reserving judgment. "I believe that most of the overprediction of snow has been taken care of," says Cliff Mass, an atmospheric scientist at the University of Washington in Seattle. Whether the model will prove to be a meaningful improvement over the previous version remains unclear, he says. "The microphysics in FV3 is superior to GFS," so the new model will likely be better at predicting where and how much rain will fall, for example, he says. ■

ATOM & COSMOS

Magnetism seen in cosmic web

Finding comes from thread connecting 2 galaxy clusters

BY MARIA TEMMING

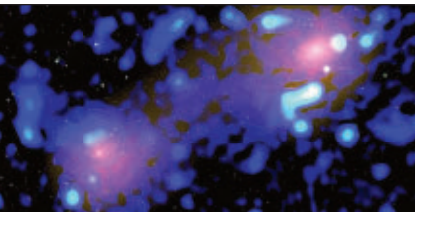
Astronomers have sighted magnetic fields between two galaxy clusters — a find suggesting that some of the universe's largest-scale structures are magnetized.

The fields run between the galaxy clusters Abell 0399 and Abell 0401, which are beginning to merge about 1 billion light-years from Earth, researchers report in the June 7 *Science*. Radiation from electrons zipping through the magnetic fields revealed this magnetism inside the gaseous filament that connects the clusters in the cosmic web.

"So far, magnetic fields have been measured in [specific] objects, like in clusters, or in galaxies," says Nabila Aghanim, a cosmologist at the Institute for Space Astrophysics in Orsay, France, who wasn't involved in the study. In the cosmic web, filaments stretch between clusters to form a celestial mesh full of voids. If magnetic fields pervade the gaseous throughways, the fields may have influenced the properties and evolution of gas throughout the cosmos, Aghanim says.

Scientists examined the gap between Abell 0399 and Abel 0401 using the Low-Frequency Array of radio telescopes in Europe. Observations of the 10 million light-years between the clusters revealed a band of radiation called synchrotron emission, made by high-speed electrons spiraling around magnetic field lines.

Computer simulations indicate that weak shock waves from the early stages of this galaxy cluster merger can't accelerate normal electrons in the filament enough to generate that synchrotron emission. Instead, the filament must already have contained high-energy electrons.



Two galaxy clusters (pink) are connected by magnetic fields that have high-energy electrons zipping through. Radio emissions from that bridge form the blue-toned smear in between.

The source of the high-speed electrons is unknown, says study coauthor Federica Govoni, a radio astronomer at the Cagliari Observatory in Selargius, Italy. "They may have been ejected in the past by [nearby] galaxies or by explosions of supernovae." ■

DSS, PAN-STARRS1, XMM-NEWTON, PLANCK SATELLITE, F. GOVONI AND M. MURGIA/INAF, CJBEARDS, ASTRON

GEOLOGIC ROAD TRIP OF THE MONTH

Though it has gone by many names, including Kings Peak and Tower Mountain, Chief Mountain was derived from the Blackfeet Indians' name for this peak.

CHIEF MOUNTAIN, MONTANA

The high prairie of northern Montana rolls westward in an unfolding panorama of speckled sage and open sky, defined by a slowly rising but otherwise benign landscape. Along Montana 17 a few miles southeast of the Canadian border, topographic change is finally realized by the haughty appearance of Chief Mountain, a sentinel that identifies the Rocky Mountain Front, the eastern border of Glacier National Park, and the location of one of the world's classic—albeit enigmatic—geologic structures.

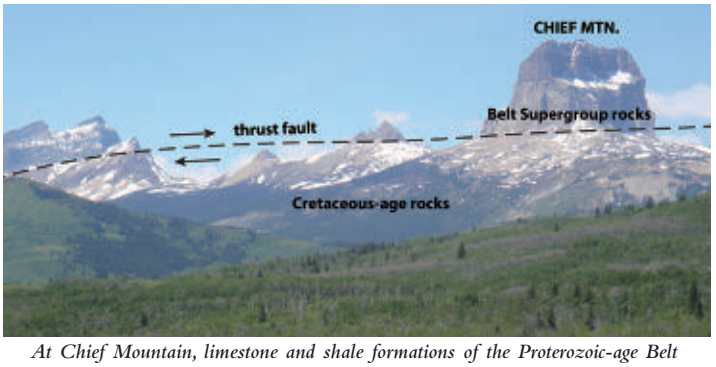
A model klippe—an outcrop isolated by faulting and erosion—standing 9,006 feet high with 1,500 feet of relief, Chief Mountain is constructed of sedimentary rocks that are of a different age and environment than the rocks of the underlying terrain. A well drilled from the mountain's crest would first engage 1,300-million-year-old green shale of the Appekunny Formation and then 1,450-million-year-old tan and red strata of the Altyn limestone. These two formations make up a significant portion of the Belt Supergroup, perhaps the best-preserved sequence of middle Proterozoic–age rock in the world. Close examination of these layers uncovers beautifully preserved ripple marks, mud cracks, raindrop impressions, and fossils of several species of algae. The fossils and preserved sedimentary features are evidence that the strata were deposited in both playa and perennial lake-basin environments that periodically were connected to the open ocean. Finally, the drill bit would penetrate sandstone and shale beds deposited under marine conditions a mere 100 million years ago, during the Cretaceous period.

The enigma of Chief Mountain has nothing to do with either the different depositional conditions or the 1,350-million-year age difference between these two suites of rocks. Instead, it is the age relationship of these juxtaposed formations. In Chief Mountain, ancient rocks overlie much younger strata, contrary to the logic of a basic geologic axiom. As mentioned in the introduction, according to the principle of superposition, in an undisturbed sequence of strata the oldest beds are positioned on the bottom. How is this deviation from the venerated principle explained?

Answers became available when geologists recognized that the northern Rocky Mountain terrain is composed of thick sequences of faulted and stacked sedimentary rocks. The nature of the faults suggests that as the forces compressing the crust in this region increased in intensity, the faults became overthrusted upon each other, much like the arrangement of cedar shakes covering a roof. This fracturing and subsequent stacking of strata effectively reversed the age relationship of the rocks—older rocks were placed over younger ones.

The rocks of Chief Mountain were thrust up and over younger rocks sometime between 170 million years ago, during the construction of the ancestral Rocky Mountains, and 70 million years ago, when the modern Rocky Mountains were forming. During this 100-million-year time frame the Lewis Overthrust slab formed. Measuring 200 miles long and more than 2 miles thick, this massive slab of rock was transported eastward an amazing 50 miles along one of the largest thrust faults in the world. Since then, erosion has altered the slab so that today Chief Mountain stands completely isolated—but no longer an enigma.

Because the chapter and verse of its geologic history are so beautifully preserved, the Chief Mountain klippe is widely recognized as an ancient and revealing window through which the process of modern mountain building, such as that underway today in the Himalaya Range of southern Asia, can be better understood.



At Chief Mountain, limestone and shale formations of the Proterozoic-age Belt Supergroup overly much younger Cretaceous-age rocks, a textbook example of a thrust fault. Arrows indicate relative rock movement along the fault plane.

HUMANS & SOCIETY

Knotted strings may record Inca taxes

Researchers make progress in unraveling khipu mysteries

BY BRUCE BOWER

While excavating an Inca outpost in Peru, Alejandro Chu and colleagues uncovered some twisted surprises.

In 2013, the archaeologists were digging in one of the rooms at the entrance to what had been a storage structure and found knotted strings poking through the ground. Known as khipus, these cords recorded census totals, astronomical events and other matters of state interest. In a society without a writing system, khipus also told stories about Inca rulers.

At least, that is what Spanish chroniclers wrote about khipus in the decades after toppling the Inca empire in 1532. But these accounts provide only general descriptions. Researchers have yet to decipher khipus from various parts of the Inca empire, and it's a mystery what any particular cord array meant to its makers.

Just finding khipus at Inkawasi, an imposing military and administrative site, was a big deal. But Inkawasi's khipus were unlike any found before, covered by the remains of regional crops, mainly peanuts or chili peppers. In two years of work, Chu's team found 29 khipus. Most lay underneath scattered edibles.

Chu, of the Universidad Nacional Mayor de San Marcos in Lima, Peru, couldn't explain what he had uncovered. When Harvard University archaeologist Gary Urton heard about the discoveries, he headed to Peru. "I had never seen produce placed on khipus," Urton says of his 2014 visit.

Urton and Chu think they have untangled the meaning of the crop-topped cords. These khipus recorded a fixed amount, or tax, deducted from food that surrounding communities deposited at the state-run storage center, the researchers reported in the March *Latin American Antiquity*. This is the first evidence, the pair says, that the Inca devised a way to tax goods.

That conclusion is only one small piece of a larger puzzle. About 1,000 khipus are held in museums and private collections worldwide. While the knotted cords are receiving increasing research scrutiny, most remain mysterious. To enable more research, Urton and colleagues have assembled khipu information into a digital database, which investigators from Lima to London can consult as they try to untangle the code, or codes, of the cords.

Research on how numbers were recorded on khipus goes back nearly a century. A series of thin, twisted cords arranged in tiers typically hang from one or more thick, horizontal cords. Knots in the bottom tier record ones, knots in the next highest level record tens and successively higher levels record greater powers of 10 (hundreds, thousands and so on).

Inkawasi khipus express a code unlike anything seen on other khipus, Urton and Chu conclude. The storehouse cords contain what amount to simple numerical equations, represented as a = b + c, with any of four fixed values assigned to b.

Either of two fixed values, 10 or 15, appear on khipus found under chili peppers. Either of two other fixed values, 47 or 208, appear on peanut-covered khipus.

Knotted string values signified units of produce, not individual peppers or nuts, Urton and Chu argue. Several rectangular, roughly 30-meter-long rooms in the storage facility may have been receiving areas for crops. Each room's floor was covered in a grid of about 3,510 squares. Incoming produce was spread across these surfaces, and each square was one unit, the researchers say.

In analyzing 100 presumed chili pepper and peanut deposits recorded on four khipus, the team found that fixed values on three of the khipus equaled about 2 percent of an average deposit's size in units. One chili pepper khipu contained a fixed value equal to about 11 percent of an average deposit. "These khipus contain all the earmarks of the first known Inca taxation system," Urton says.

Inkawasi's size and complexity may have prompted knot readers to invent a way to deduct set amounts of state-owned produce being stored there as a kind of maintenance fee. Workers at the site needed to eat and would have left for their family farms if not supplied with crop levies, Urton says.

It's not clear why fixed values of chili peppers were lower than those for peanuts, he says. If officials valued peppers more than nuts, then fewer units of chili peppers may have met their tax demands. Reasons for two chili pepper values and two peanut values are also unknown.

Scientists have long thought that Inca rulers required their subjects to farm lands run by the state on a rotating basis. But unlike other early civilizations, the Inca were not thought to have taxed household goods and produce. Until

A pair of stringed devices called khipus were found covered with chili peppers at an Inca site. Researchers say these khipus recorded taxes on stored quantities of those vegetables.

G. URTON

now, no evidence of taxation in the ancient empire had come to light.

Had the Spanish not invaded, the taxation innovation might eventually have inspired levies imposed on all subjects of the empire, a practice typical of other early states.

Social anthropologist and khipu researcher Sabine Hyland says there's another plausible explanation: The khipus could have referred to crop amounts set aside as seeds for the next year's planting. In the 1600s, Spanish hacienda owners near the former Inca capital of Cuzco withdrew relatively fixed amounts from their annual maize harvests for seed. Ledgers of one owner show that he took between 40 and 42 llama loads of maize from harvest totals every year from 1604 to 1613, says Hyland, of the University of St. Andrews in Fife, Scotland. Fixed values on Inkawasi knotted cords may have reflected much the same practice.

Urton and Chu emphasize that fixed numbers in Inkawasi calculations always stayed the same rather than varying from one year to the next, as might be expected if they represented seeds to set aside.

At the ruins of Inkawasi, an Inca administrative and military center, archaeologists found what they say is the first evidence of Inca taxation.

Even if the knots do show that taxes were as inevitable as death at Inkawasi, that still leaves a lot to explain about other khipus. Consider knotted cords found at Inkawasi in 2016 that include entwined strings dyed in pairs of either light or dark colors. These cords may represent credit and debit calculations for communities that stored produce at Inkawasi, says archaeologist Jon Clindaniel, a recent graduate student of Urton's now at the University of Chicago.

Light-colored cords denoted addition, Clindaniel suspects; dark-colored cords stood for subtraction. Knotted devices with both colors could represent a math operation such as "+90, –15 = 75." Accountants could have used such a system to record credits and debits, simultaneously tracking what communities had paid in crop taxes and what was still owed. That practice has yet to be confirmed, though.

Accounting documents that track credits and debits side by side go back 1,000 years or more in Europe, long considered the birthplace of "double entry" bookkeeping, Urton says. At many Inca sites, pairs of khipus are connected by cords, possibly as a way to form a kind of ledger with credits on one side and debits on the other, he suspects. Studies of those khipus are in the early stages.

Other khipus may record stories. Both Hyland and Urton are trying to figure out how to read what appear to be stories or historical accounts on khipus fashioned by the Inca after Spanish conquest. ■

G. URTON

EARTH & ENVIRONMENT

Glaciers greased plate tectonics

Erosion may have kick-started Earth's recycling system

BY CAROLYN GRAMLING

Vast amounts of sediment eroded from Earth's continents were necessary to lubricate the wheel of plate tectonics, scientists propose.

The idea offers a new angle on long-standing riddles about the origin and evolution of the planet's global surface recycling system, one that is unique in the solar system.

Earth's interior holds a lot of heat, even today, 4.6 billion years after the planet formed. For the first 1 billion to 1.5 billion years of Earth's history, the planet's insides were still too hot for the lithosphere — Earth's crust and upper mantle — to cool and thicken (*SN Online: 9/21/17*). That cooling is one necessary ingredient for modern plate tectonics, the ongoing collisions and separations of large "plates," the jigsaw puzzle pieces that make up the lithosphere.

Eventually the planet cooled enough for the crust to form. And then, around 3 billion years ago, Earth's first continents arose. The arrival of those continents ultimately added another key ingredient that allowed plate tectonics to get under way, geophysicist Stephan Sobolev and geologist Michael Brown argue in the June 6 *Nature*. Massive amounts of sediment scraped by glaciers off the continents were essential to kick off the lithospheric dance, the researchers contend: That soft sediment was slowly deposited in deep ocean trenches, where it reduced the amount of friction between a sinking, or subducting, plate and the overlying plate, speeding up plate tectonics.

Giant influxes of sediment to the oceans, related to worldwide glaciation events such as one that lasted from about 750 million to 630 million years ago, could explain why plate tectonics has sometimes kicked into a higher gear, Sobolev and Brown say. And a dearth of such sediments in the geologic record could also explain periods of sluggish tectonic movement, including the "boring billion," a period of tectonic and evolutionary stability between about 1.8 billion and 800 million years ago (*SN: 11/14/15, p. 18*).

Sobolev, of the University of Potsdam in Germany, and Brown, of the University of Maryland in College Park, combined data on how sediments reduce friction at subduction zones in modern times with geologic records of glaciation and the growth of mountains. The team also looked at geochemical data as a stand-in for ancient subduction speeds. From these datasets, the team created a unified picture of when plate tectonics has sped up or slowed down during the last 4 billion years of Earth's history.

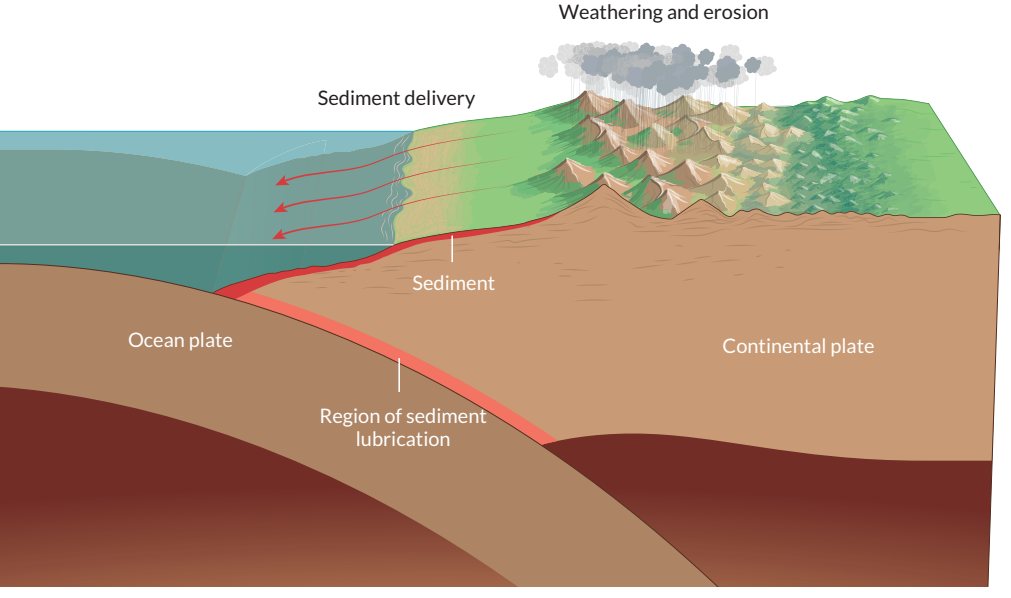
The cycle sped up three times, Sobolev and Brown found, with each period lasting at least several hundred million years. The first began about 2.8 billion years ago, the second about 2.3 billion years ago and the third about 750 million years ago. Each period corresponds to a time when the erosion of the continents would have also increased, delivering larger loads of sediment to the oceans that could then have lubricated subducting slabs.

The earliest period followed the initial uplift of continents out of the oceans. And all three periods followed major glaciation events. Glaciers are efficient eroders of land, bulldozing sediment ahead of them and ultimately to the sea. One of the largest surface erosion events in Earth's history, known as the Great Unconformity, followed Snowball Earth glaciation some 750 million to 630 million years ago. That glaciation event, the researchers say, kick-started the modern era of active, continuous plate tectonics.

The hypothesis is "intriguing," but there is a lot more work to be done to test it, says Whitney Behr, a geologist at ETH Zurich who wrote a commentary in the same issue of *Nature*.

For example, she notes, there are the competing influences of higher mountain topography — which produces more sediment — and the increase in friction that the extra mass can create. And because Earth's lithosphere and climate are different today than they were in the past, she says, more work is needed to determine the lubricating power of ancient sediments. ■

Lubricated slab Three periods of global glaciation leading to intense continental erosion in the last 3 billion years coincided with times of increased activity of plate tectonics, a study finds. Eroded sediment helped speed up subduction — where one tectonic plate sinks beneath another — by reducing friction at the interface between plates, researchers propose.



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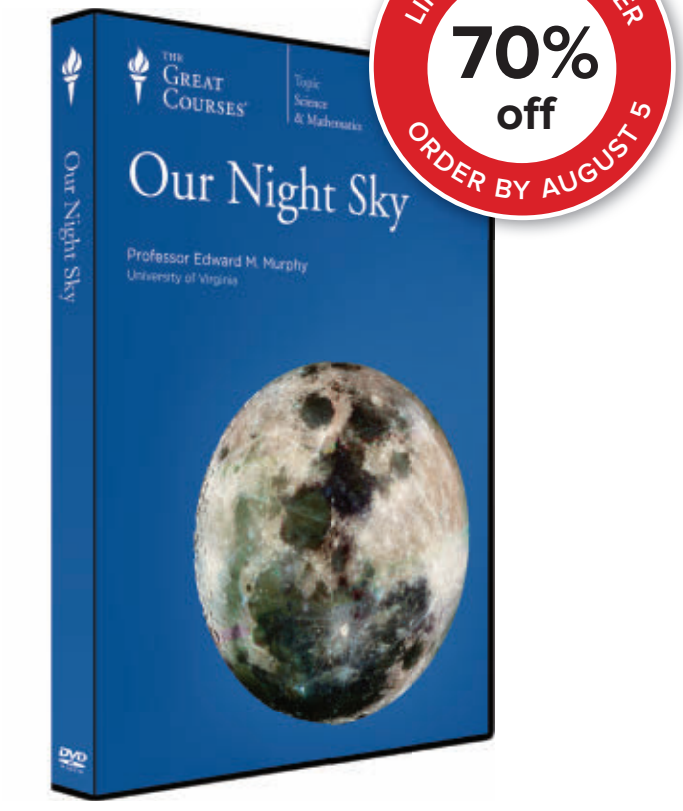

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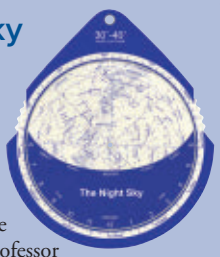

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BODY & BRAIN

An extra finger can come in handy

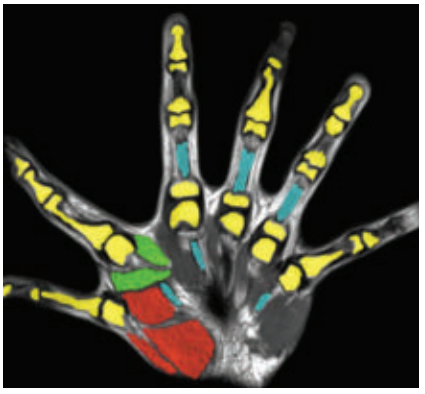
Two people born with six fingers per hand can tie their shoes, adroitly manage phones and play a complicated video game — all with a single hand, a study shows.

That superior dexterity, described June 3 in *Nature Communications*, suggests that instead of being seen as aberrations that ought to be surgically removed, extra fingers can bring benefits. The findings also highlight how flexible the human brain can be, a feature that will be central to the design of brain-controlled robotic appendages.

Bioengineer Etienne Burdet of Imperial College London and colleagues worked with a 52-year-old woman and her 17-year-old son, both born with six fingers on each hand. The extra finger, positioned between the thumb and index finger, resembles a thumb in the versatile ways that it moves.

Brain and hand MRI scans revealed that the extra fingers are controlled by a dedicated brain system, along with their own muscles and tendons. That means that these extra fingers aren't just along for the ride, controlled by the muscles that move the other fingers.

The results may not extend to other people with extra digits, Burdet says. In some cases, extra fingers may be less well-developed. — *Laura Sanders*



An extra finger on the right hand of a boy is controlled by its own muscles (red and green) and tendons (blue; bones are shown in yellow).

BODY & BRAIN

Bats are the main cause of rabies deaths in the United States

In the United States, the landscape of rabies transmission has shifted over the last 70 years.

Following a massive campaign to vaccinate dogs starting in 1947, rabies deaths linked to dog bites and scratches dropped, and those from wild animals now carry a greater share of the blame. Since 1960, bats have caused about 70 percent of the 89 deaths from rabies exposure that occurred in the United States, the U.S. Centers for Disease Control and Prevention reported June 12. About two people die from rabies in the United States every year.

In 2015, the CDC noticed that bats had surpassed raccoons to become the animal with the most number of positive tests for rabies. The agency also noticed an uptick in the number of mass bat exposures, where 10 or more people are exposed to a possibly rabid bat. This happens most often where bats are found living in homes, dorms or campgrounds. The vast majority of bats tested, about 94 percent, do not have rabies, and the CDC estimates that less than 1 percent of bats overall are infected. — *Carolyn Wilke*

GENES & CELLS

Almost all healthy people harbor patches of mutated cells

Normal isn't always normal. A study finds that large groups of cells in healthy tissues carry mutations.

About 95 percent of healthy people had patches of cells with genetic mutations in at least one of the 29 tissues examined, including kidney, muscle and liver, researchers report in the June 7 *Science*. Most mutations found in 467 of the 488 people in the study are harmless, but some have been tied to cancer.

About 40 percent of tissues had at least one big patch of mutated cells, and about 5 percent of study samples had five or more mutant patches, Keren Yizhak of the Broad Institute of MIT and Harvard and colleagues discovered.

Skin, esophagus and lung tissues had more of these mutant patches than other tissues. Those three tissue types are exposed to more ultraviolet light, pollution, smoke and other environmental factors that may cause mutations than other internal organs are. Age also affected the number of mutations, with mutations popping up more often after age 45 in tissues with actively dividing cells. Tissues with nondividing cells didn't tend to build up age-related mutations.

It's not yet possible to tell how close a tissue is to becoming cancerous, but the study is a step toward answering that question, Cristian Tomasetti, a cancer researcher at Johns Hopkins School of Medicine wrote in a commentary in the same issue of *Science*. — *Tina Hesman Saey*

ATOM & COSMOS

Physicists have finally figured out how pentaquarks are built

Exotic subatomic particles called pentaquarks contain five smaller particles called quarks and antiquarks. But those particles aren't a simple clump of five constituents rattling around. Instead, the pentaquarks are molecule-like agglomerations of a pair of smaller particles, each of which consists of either three quarks or a quark and an antiquark, scientists report in the June 7 *Physical Review Letters*.

First spotted in 2015 at the Large Hadron Collider near Geneva, pentaquarks were unlike anything seen before (*SN: 8/8/15, p. 8*). All previous known quark-containing particles were either baryons — particles such as protons and neutrons, which contain three quarks — or mesons, which consist of one quark and one antiquark. Pentaquarks, with their five component particles, didn't fit into either of those categories.

Some scientists thought that a pentaquark's five constituents could mingle on equal footing. But measurements from the LHCb experiment reveal that a pentaquark is made from a baryon and a meson stuck together. That finding makes the particle a bit less exotic than had been speculated.

Still, before this result, it wasn't clear that baryons and mesons could glom on to one another at all, says study coauthor Tomasz Skwarnicki, a particle physicist at Syracuse University in New York. — *Emily Conover*

C. MEHRING *ET AL*/*NATURE COMMUNICATIONS* 2019

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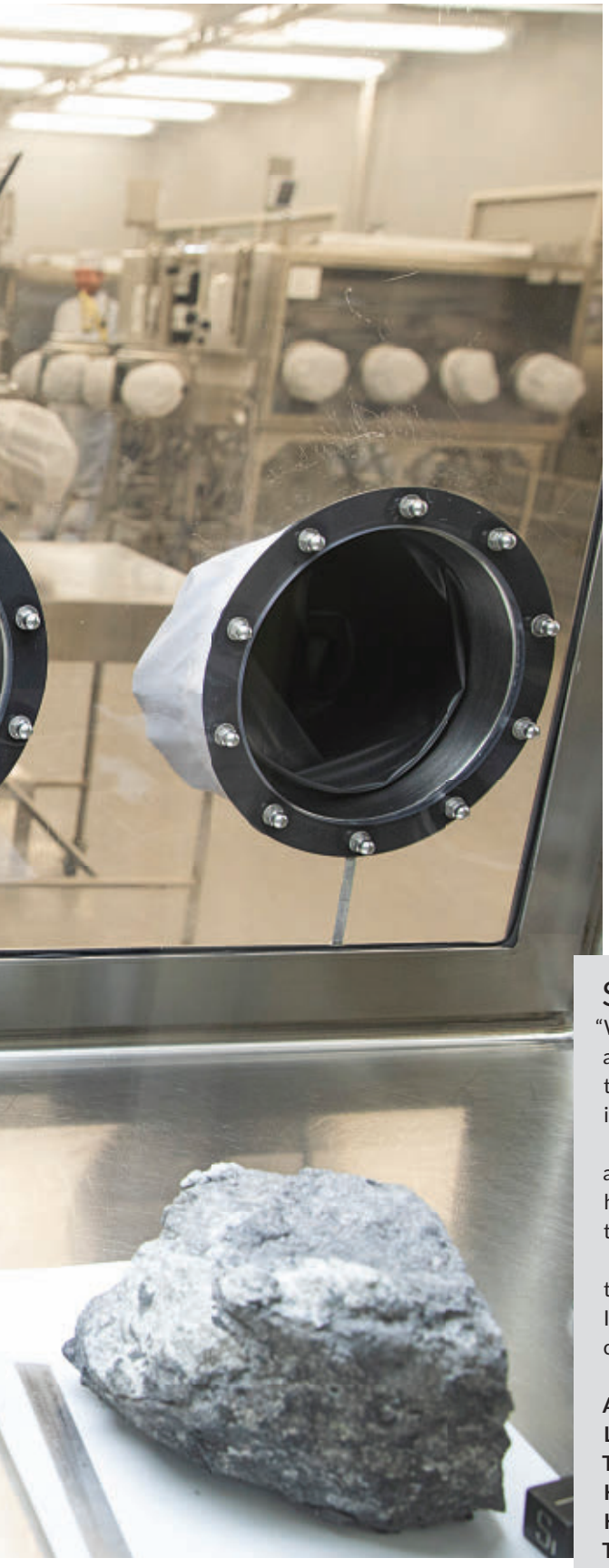
Science News astronomy reporter Lisa Grossman visits the pristine sample lab at NASA's Johnson Space Center in Houston in March. The display case holds rocks collected during Apollo 15 and 16. The 1.5-kilogram chunk of volcanic basalt in the center is 3.4 billion years old.

FELIX SANCHEZ



A Visit to Moon Rock Central

Curators treat the Apollo samples as more precious than gold

By Lisa Grossman

I'm not allowed to touch the moon rocks.

In the room where NASA stores the samples that Apollo astronauts brought to Earth decades ago, I peer at rocks and trays of dirt through glass. But my tour guides are firm: Nobody touches the moon rocks.

This is the pristine sample lab at NASA's Johnson Space Center in Houston. Being here is a big deal for me. I've spent years looking at cosmic rocks from a distance — my childhood involved lots of stargazing through a telescope, and in my college lab job, I processed pictures of Mars. I've been itching to scoop up a handful of alien sand and let it run through my fingers. Today, the

Special Report: Moonstruck

"We choose to go to the moon." In September 1962, President John F. Kennedy affirmed the United States' commitment to reaching the moon: "We have vowed that we shall not see space filled with weapons of mass destruction, but with instruments of knowledge and understanding."

Less than seven years later, on July 20, 1969, U.S. astronauts Neil Armstrong and Buzz Aldrin strode onto the moon's surface. By 1972, the Apollo program had ended, but not before six missions had put astronauts on the moon, where they ran experiments, collected rocks and left more than a few things behind.

As we celebrate the 50th anniversary of those first steps, nations including the United States, China, India and Israel are eyeing that nearby orb once again. In this special issue, we celebrate humans' enduring fascination with that radiant chunk of rock and explore the many ways it affects life on Earth.

Left: Lunar sample processors Charis Krysher (left) and Lacey Costello (center) show Grossman (right) how to don a protective bunny suit before entering the pristine sample lab. Right: The air pressure inside the sealed cabinets that house the moon rocks is higher than in the surrounding room. That difference sweeps any debris away from the moon rocks and inflates the gloves that processors put their arms through to handle the samples.

BOTH: FELIX SANCHEZ

opportunity feels as close as it is unlikely.

Before entering this clean room, I remove all my jewelry, including my wedding ring. My guides and I cover our shoes with blue paper booties and step into full-body jumpsuits with zippers from navel to neck and snaps at the ankles, wrists and throat. Once in the white bunny suits, we put on neoprene gloves, a hair cover, plus a pair of knee-high boots pulled over the blue booties. Finally, we spend a full minute standing in a phone booth–sized air shower, under a steady breeze blowing from ceiling to floor to clear us of any lingering dust.

Inside the clean room, I face another barrier: The rocks are stored in secure, pressurized cabinets — like big terrariums — filled with pure nitrogen. The only way to reach the samples is by sticking already-gloved hands into another set of gloves that wave from the cabinets like zombie arms.

Only five people in the world get to routinely handle these precious pebbles, sample processor Charis Krysher tells me. She's one of them. But even Krysher and the lucky few can't touch the samples directly. To pick up an Apollo rock, Krysher must either use stainless steel tweezers or slide her fingers into a third set of gloves made of Teflon.

"You do lose quite a bit of dexterity," she says. "You get used to it, but it takes practice."

All this effort is to protect the 382 kilograms of rocks, core samples, pebbles, sand and dust lifted from the moon during the six Apollo landings from 1969 through 1972. Those priceless samples are still offering fresh details about how the moon — and the entire solar system — formed and evolved. The rocks have revealed the rough ages of all the rocky planets' surfaces and informed debate about whether an ancient reshuffling of the outer planets caused a bombardment of meteorites on Earth (*SN Online: 9/12/16*).

"One of the biggest misconceptions is that the Apollo samples aren't being studied anymore, and that the Apollo samples only tell us about the moon," says Ryan Zeigler, Apollo sample curator at the Johnson Space Center. "Neither of those is true."

In fact, NASA is opening a cache of untouched samples for new studies on this 50th anniversary of the July 20, 1969 Apollo 11 moon landing.

Lunar science takes off

Since those first bits of moon arrived, NASA has sent about 50,000 individual samples to 500 research labs in more than 15 countries. Even with all that sharing, upward of 80 percent of the original haul is still untouched. Keeping with NASA's hypercareful approach, nearly 15 percent of that lot is stored in a vault at the White Sands Test Facility near Las Cruces, N.M., a roughly 1,300-kilometer drive from Houston.

Designers also constructed this boxy, beige building in Houston, which opened in 1979, with certain disasters in mind. The structure is hurricane-resistant, and the pristine sample lab is one story above ground level to avoid flooding.

When the lunar samples first arrived on Earth, they were flown to Houston and quarantined for weeks (as were the astronauts). Researchers

wanted to keep the samples safe from earthly contamination and keep Earth life safe from the samples. No one knew whether anything lived on the moon, or if potential moon life would be toxic to earthlings.

Those early samples were collected by Apollo 11 astronauts Neil Armstrong and Buzz Aldrin, who scooped about 21.5 kilograms of moon rocks and dirt into storage boxes.

From that first collection, about 700 grams went to a biological test lab. There, samples were placed into secure chambers with mice, fish, birds, oysters, shrimp, cockroaches, houseflies, flatworms and single-celled organisms, plus 33 species of plants and seedlings. Scientists watched to make sure that none of the test species died or developed mutations, and that nothing grew in the moon grains themselves.

When nothing happened, seven kilograms or so of the Apollo 11 rocks were parceled out to laboratories around the world, as far from Houston as Tokyo and Canberra, Australia. Researchers studying those rocks agreed not to publish their findings before getting together to discuss them at the first Lunar Science Conference, which was held in Houston in January 1970.

"No other set of geologic samples has ever been investigated so extensively," geologist (and later Apollo 17 astronaut) Harrison Schmitt and colleagues wrote in the introduction to the conference proceedings.

Those studies, which launched the discipline "lunar science," almost immediately led to a new understanding of the moon's origin. That theory is still the leading theory today: The moon formed, hot and molten, from the congealing debris of a giant impact between the young Earth and some other early planet (*SN: 4/15/17, p. 18*).

"What a beaut"

The fact that scientists had the right samples to reveal that the moon was once hot and gooey was a stroke of luck.

At the end of the first moonwalk, "the very last thing that happened was Neil Armstrong looked in the rock box and thought, this looks a little empty," Zeigler says. So Armstrong shoveled in nine scoops of soil to keep the large samples from bouncing around. "It was an afterthought."

That extra soil contained a treasure: tiny white and light gray rocks called anorthosites. These rocks stood out against the dark volcanic basalts that formed most of the landing site.

"The anorthosites were totally unexpected," geologist John Wood and colleagues at the Smithsonian Astrophysical Observatory in Cambridge, Mass., wrote in 1970 in *Science*. The rocks' low density suggested that they formed part of an ancient crust after rising to the surface of a lunar magma ocean, Wood's team reasoned. If a large portion of the moon was once liquid magma, heavier stuff would sink in the goo, and lighter stuff like the anorthosites would rise. An independent team led by mineralogist Joseph Smith of the University of Chicago came up with a similar picture.

Left: Astronauts from Apollo 16 used this rake to collect samples of the moon's surface in 1972. Right: When the very first samples were brought to Earth with Apollo 11 in 1969, quarantine control officers transported the samples directly to a pristine lab to make sure they posed no threat.

BOTH: NASA

Our modern understanding of that lunar magma ocean is more complex, says planetary scientist Steve Elardo of the University of Florida in Gainesville. The moon must have gone through distinct stages to morph from that melted mass to today's solid rock: first separating into light crust and dense mantle, and then cooling over time.

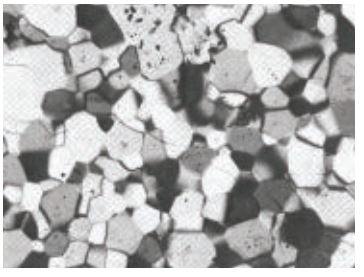
But when researchers measure the ages of rocks that should have come from those different eras, they all seem to be roughly the same: 4.35 billion years old.

The result "has thrown geochemists for a loop," Elardo says. Either their measurements were wrong, or everything happened very quickly.

Still, the main idea that the whole moon was once liquid rock has held steady. In fact, geologists now think that's the life cycle for most young planetlike bodies.

"We even talk about magma oceans, little ones, for asteroids," Elardo says.

Those groups in 1970 had less than six months to study the samples, discover the anorthosites and figure out what it all meant. "And they basically got it right," Elardo says. "That always kind of blows my mind a little bit."



Under a microscope, anorthosites, the distinctive white rock that made up the moon's ancient crust, stand out from darker volcanic basalt.

In 1971, NASA told Apollo 15 astronauts David Scott and James Irwin to look out for bright white rocks that could confirm this idea with more study. The mission transcript shows their excitement when they found one during a moonwalk.

"It's about — *oh, boy!*" Scott said. "Guess what we just found.... What a beaut." Irwin chimed in: "I think we found what we came for."

Krysher shows me portions of both Armstrong's and Scott's samples, displayed in separate cabinets. The Apollo 11 soils fill what looks like two metal cupcake wrappers. Among a layer of dark grains, I can spot a few white flecks, the anorthosites. Scott's rock is nicknamed the Genesis Rock because at the time, it was among the oldest moon rocks known. I can see why it stood out: It's a brilliant, chalky white. The remnant on display is smaller than I expected, about the size of a lime. It could easily fit in my hand.

"May I hold it?" I ask Krysher. No dice. I had to ask, even though Zeigler had warned me in an e-mail before I arrived: "We have pretty strict rules about people putting their (gloved) hands in the cabinets to touch samples. Basically, it's an only-if-you-walked-on-the-moon rule."

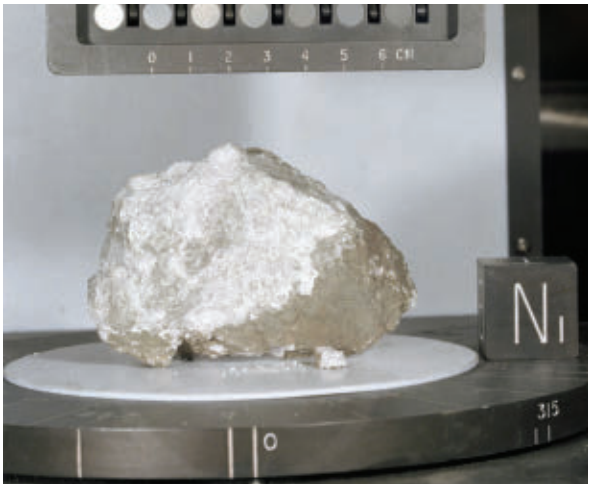
A wet world

Keeping pristine samples away from curious fingers allowed scientists to make one of the most surprising lunar discoveries of the last 50 years: The moon is wet. Over the last decade, scientists have found hundreds of times more water in lunar samples than researchers in the Apollo era realized existed.

The first studies of Apollo samples suggested that the moon was bone-dry, with less than 1 part per billion of water. That made sense: If the moon was born hot, water and other easily vaporized molecules would have boiled away quickly.

But in the late 2000s, researchers began to find hints of ancient moisture trapped in lunar samples. Alberto Saal of Brown University and

Left: Lunar sample processor Jeremy Kent demonstrates how to handle a lunar sample safely. Right: The Genesis Rock, shown here before processing, is a piece of the moon's primordial crust that was picked up in 1971 by Apollo 15 astronauts. It is white because it contains anorthosites.



CLOCKWISE FROM TOP: J. WOOD *ET AL./PROC. APOLLO 11 LUNAR SCI. CONF.* 1970; NASA; FELIX SANCHEZ

colleagues used an ion microprobe to find water molecules deep within tiny volcanic glass beads from lunar soils, the team reported in *Nature* in 2008 (*SN: 8/2/08, p. 12*).

Based on the amount of water in the beads, the researchers estimated that the magma beneath the moon's crust could have had up to 750 parts per million water. Then later studies found water in the moon's deeper mantle, perhaps as much as Earth's: tens to hundreds of parts per million, planetary scientist Francis McCubbin of NASA Johnson said in March at the Lunar and Planetary Science Conference in The Woodlands, Texas.

There's still a lot of disagreement about exactly how much water the moon contains, McCubbin said. But keeping lunar samples under pristine conditions was crucial for discovering water 40 years after the rocks were brought to Earth. "Making sure we curate those samples in a way that our grandchildren and their grandchildren can keep making discoveries is critically important," he said.

This, I realize, is one reason why I can't touch the moon rocks. I'm too full of water. So is the air.

Unsung heroes

That's the whole point of sample curation, says processor Lacey Costello. "Research gets all the glory." But curation is crucial.

Processors preserve and prepare the samples, making sure there's no contamination. Without that effort, Costello says, the data that researchers get wouldn't be accurate. "How could you trust it if the samples might have been contaminated?"

Curation involves more than just three sets of gloves. Processors maintain a detailed database of every sample ever taken from the moon, plus every chip and slice that was ever divided from the original sample. These specialists photograph and record the mass of every subsample before filing it away in a vault, behind the same kind of door that protects the U.S. gold reserves at Fort Knox. The processors even maintain the north-south and up-down orientation that the rocks had on the moon.

"We do have extensive procedures," says processor Andrea Mosie, a Houston native who has worked in the lunar samples lab for 43 years. She was a high school intern at the Manned Spacecraft Center — the Johnson Space Center's original name — in July 1969 when the first rocks came in.

Her supervisor let her sit in on lunar mission planning meetings. "I actually did more than I was supposed to do, which was really encouraging," she says. "And I was in the same building with the astronauts, so that was great."

Top: Lunar sample processor Andrea Mosie wears three pairs of gloves, the outermost of which is Teflon, to handle a moon rock. Left: Shown here in 1976, Mosie has been at NASA's pristine sample lab in Houston for 43 years.

After earning degrees in chemistry and math, Mosie returned to NASA. "The clean room has been the perfect place for me ... because I'm a very picky person," she said in a talk at the Lunar and Planetary Science Conference. "Everything has a procedure. I probably get on a lot of people's nerves."

Mosie trained Krysher, Costello and other processors who joined the lab. "She's our moon goddess," Krysher jokes. Krysher started in the lunar lab about five years ago, after spending the better part of a decade as an aerospace engineer.

Costello also switched from aerospace engineering to geology after a lecture on meteorites sparked a passion for planets. She's the newbie, having joined the lab in January. She soon realized that a big part of her job is helping researchers identify the best sample for their studies.

"Curators acquire the most intimate knowledge

FROM TOP: THE WASHINGTON POST/GETTY IMAGES; COURTESY OF A. MOSIE/NASA

of the samples," Costello says. "A lot of times researchers know what they want. But there are times where they think they know what they want, and they maybe don't."

Once the right moon rock is chosen, processors break off a tiny piece of the main sample. A typical subsample sent to a research group weighs between half a gram and a gram, and could fill maybe a quarter of a teaspoon.

"Over the years, the scientists have been able to do more with a lot less," Krysher says. That's why so much of the collection is still pristine.

There are procedures to account for human foibles, too. To minimize contamination, only three materials may come into direct contact with the samples: aluminum, stainless steel and Teflon. Hence the tweezers and extra gloves. And if dust or a piece of a rock breaks off during sampling, that bit becomes a new sample.

I finally get my chance to play processor. I see an empty cabinet, and to my delight, my guides let me put my double-gloved hands in and pretend to process a sample.

I struggle to stretch my fingers into the gloves, which wave like balloons from the higher pressure inside the cabinet. The rubber wraps tightly around my arms: I almost feel like I'm pushing my arms into a thick liquid. I clumsily pick up a stainless steel hammer and a chisel inside the cabinet. I mimic chipping a corner off of an imaginary sample. Even without a real moon rock, I find myself laughing with joy.

For the curators, "that excitement lasts forever," Mosie tells me. "Every time you handle a sample, you ... realize that you're one of the few who will ever be doing this.... That's a special opportunity, and it's an awesome responsibility."

Geologist Beck Strauss remembers that feeling. While a postdoc at Rutgers University in Piscataway, N.J., Strauss got to open a pristine sample from Apollo 12.

"That was one of the coolest things I've gotten to do — to be the first person to hold a piece of this rock," says Strauss, now at the National Institute of Standards and Technology in Gaithersburg, Md.

At Rutgers, Strauss and colleagues studied magnetic fields preserved in lunar rocks to figure out how the moon's interior has changed over time. Churning liquid rock in the moon's core, or at the boundary between the core and mantle, could have driven a magnetic field that weakened as the moon cooled and solidified.

Strauss presented work at the March Lunar and Planetary Science Conference suggesting that the early moon had a strong magnetic field that faded by 3 billion years ago. The moon maintained a weaker magnetic field for another 1 billion to 2 billion years before the field dropped to essentially nothing today.

With advances over the last 50 years, geologists can measure smaller and smaller magnetic fields in the moon rocks, Strauss says, that "let us get at information that was just physically inaccessible during the Apollo era."

And Strauss feels all that history in the work. "For me to do the experiments I'm doing and collect the data I have, we basically had to invent spaceflight," Strauss says. Nearly 50 years after

Left: Grossman reaches into an empty cabinet through rubber gloves to pretend-touch a moon rock. Right: Of these two soil scoops collected during Apollo 11, the one on the right contains visible white anorthosite flecks, fragments of the moon's ancient crust.

FROM LEFT: FELIX SANCHEZ; THE WASHINGTON POST/GETTY IMAGES

Top: Grossman holds an acrylic trophy with a chip of rock from the 1971 Apollo 15 mission. Bottom: Other samples are on display around the world, including this one under Grossman's thumb at the Smithsonian National Air and Space Museum in Washington, D.C.

Apollo, Strauss got to walk into the lab, open a safe, "and take out these incredible little pieces of our moon and learn all sorts of really cool things about them. I think that's awesome."

When NASA sends samples to research labs, no special government courier service is used, just the regular mail, FedEx or UPS. To deter thieves, the curators make the packages inconspicuous. "We obviously don't write: 'This is a moon rock in here,'" Mosie says. She admits that a few samples have been lost in the mail. But there's no point insuring them. "They're priceless," she says. No amount of money can replace them.

Hidden treasures

But there are ways to find new samples in the same old rocks. A lot of the Apollo rocks are cementlike aggregates called breccias, which can hide rocks on the inside that aren't visible from the outside. Until recently, the only way to find those hidden rocks was to break the breccias open with a chisel. But in 2017, the pristine sample lab got a CT scanner to take a look inside the rocks without breaking them. That will let curators know where to cut the rocks to extract unseen bits.

Some untouched samples are about to come out of storage. Three tubes of soil pulled from the lunar surface during Apollo 15, 16 and 17 have been sealed since the 1970s. In March, NASA announced that nine research teams will receive precious bits from those tubes.

And new missions are on the horizon. In April, NASA Administrator Jim Bridenstine announced a proposal to land U.S. astronauts on the moon again as early as 2024. China plans to launch a sample-return mission to the farside of the moon later this year (*SN: 11/24/18, p. 14*). Those moon rocks will be the first samples from that region of the moon and the first returned at all since 1976.

"Getting samples from another part of the moon would revolutionize our understanding of the moon and of the solar system, just like the Apollo samples did," Zeigler says.

I thought I might have to apply to be an astronaut to finally get my hands on a moon rock. But I found an easier way. The Smithsonian National Air and Space Museum in Washington, D.C., has a slice of basalt, called the Touch Rock, from Apollo 17 on display. Anyone can walk right up and touch it.

I can't suppress a smile when I run my fingers over it. The stone is cool and smooth, like a river rock. But instead of being worn down by water and time, this piece of our moon has been polished by millions of human hands. ■

Explore more

- Ryan A. Zeigler *et al.* "The Apollo sample collection: 50 years of solar system insight." 50th Lunar and Planetary Science Conference. The Woodlands, Texas, March 21, 2019.

FROM TOP: FELIX SANCHEZ; C. VANCHIERI

Lunar Leftovers

50 years on, the Apollo landing spots still generate fervent interest from scientists and historians

By Maria Temming

Astronauts, like those who touched down in the Apollo 15 lunar module (shown) in July 1971, left a lot on the moon's surface, from scientific instruments to trash.

Once on the moon, Apollo astronauts had two major goals: get themselves and the moon rocks home safe.

To make space on the cramped lunar modules for the hundreds of kilograms of moon samples, the astronauts had to go full Marie Kondo. Anything that wasn't essential for the ride home got tossed: cameras, hammocks, boots and trash. Downsizing also meant abandoning big stuff, like moon buggies and the descent stage that served as a launchpad for a module's lunar liftoff.

But the astronauts left more than castoffs. Starting with the Apollo 11 mission, which touched down on July 20, 1969, astronauts left six American flags and plenty of personal and political mementos. Importantly, the crews also left behind instruments for about a dozen experiments to keep tabs on lunar conditions (*SN: 8/2/69, p. 95*); one is still running today.

These devices "were really important parts of Apollo," says Noah Petro, project scientist for the Lunar Reconnaissance Orbiter mission. Back then, the experiments didn't get much time in the limelight, "because humans on the surface are obviously the big story," says Petro, who is based at NASA's Goddard Space Flight Center in Greenbelt, Md.

When we think of Apollo's 50-year legacy, most of us probably aren't picturing the scattered remnants of astronaut outposts gathering space dust. But as nations plan new ventures to the moon, preservationists are fighting to protect these historic sites so that future lunar visitors don't erase the marks of humans' first steps beyond Earth.

Solving old mysteries

By December 1972, six Apollo crews had collectively spent nearly 80 hours exploring the moon's surface (*SN: 12/23/72, p. 404*). They gathered rocks, photographed the landscape and performed all manner of experiments — from unfurling metal foil to catch solar wind particles to setting off explosives and measuring the resulting seismic tremors.

Apollo 11 left behind solar-powered seismometers and a reflector array that could be paired with lasers on Earth to precisely measure the distance between Earth and the moon. On five later missions, Apollo 12 through 17 (Apollo 13 returned home without landing on the moon), astronauts left more elaborate setups powered by nuclear batteries that generated electricity through radioactive decay (*SN: 11/8/69, p. 434*). Some of those instruments collected data through 1977, when NASA decided to focus on other projects and pulled the plug on the whole operation (*SN: 10/1/77, p. 213*).

"There was this period of time where the data languished," Petro says. But within the last decade or so, a new generation of scientists has taken up the torch, analyzing Apollo

NASA

observations to answer questions lingering from early studies. Unfortunately, this isn't nearly as simple as picking up where 1970s scientists left off, as geophysicist Seiichi Nagihara discovered when he set out to solve a decades-old puzzle about the moon's underground temperature.

On Apollo 15 and 17, astronauts installed thermometers in the lunar surface, which took the moon's temperature at various depths and sent the data back to Earth (*SN: 9/11/71, p. 167*). When Apollo-era scientists reviewed data collected through 1974, the results revealed something odd: The moon's temperature just beneath the surface appeared to be slowly rising.

"We're talking about very minor warming," just a couple degrees, says Nagihara, of Texas Tech University in Lubbock. But researchers at the time couldn't figure out why. Nagihara decided to examine all the temperature data collected through 1977 to figure out what was going on. Unfortunately, the tapes that recorded these measurements were missing. This is a common problem, because during the Apollo era, data were housed at the individual labs of scientists working on each experiment and many measurements were never properly archived.

"A group of us decided to ... try to hunt down the tapes," Nagihara says. After scouring thousands of documents at NASA's Johnson Space Flight Center in Houston, the researchers traced 440 tapes to an archive in Suitland, Md. But even those covered only about three months of observations. At the Lunar and Planetary Institute in Houston, Nagihara and colleagues discovered more temperature measurements noted by Apollo-era scientists in weekly memos. Between the recovered tapes and the memos, Nagihara's team pieced together a picture of the moon's temperature from 1971 through 1977.

The slow warming under the surface continued through the end of data collection, the researchers reported in April 2018 in the *Journal of Geophysical Research: Planets*. In search of a source for the heat, Nagihara and colleagues turned to pictures taken by the Lunar Reconnaissance Orbiter, which has been orbiting the moon since 2009 (*SN: 6/11/16, p. 10*). The images showed that soil stirred up by astronaut activity was slightly darker than other lunar terrain. Perhaps it was dark enough to absorb more sunlight and warm the underlying ground.

Computer simulations confirmed that the moon wasn't heating up from internal processes. Astronauts trekking around the Apollo sites probably caused an increase in surface temperature of about 2 to 3 degrees Celsius, and the extra heat slowly spread more than a meter into the ground — causing the gradual warming detected by Apollo instruments. Turns out that astronaut footsteps left marks on the moon far deeper than those iconic boot prints.

Keeping vigil over gravity

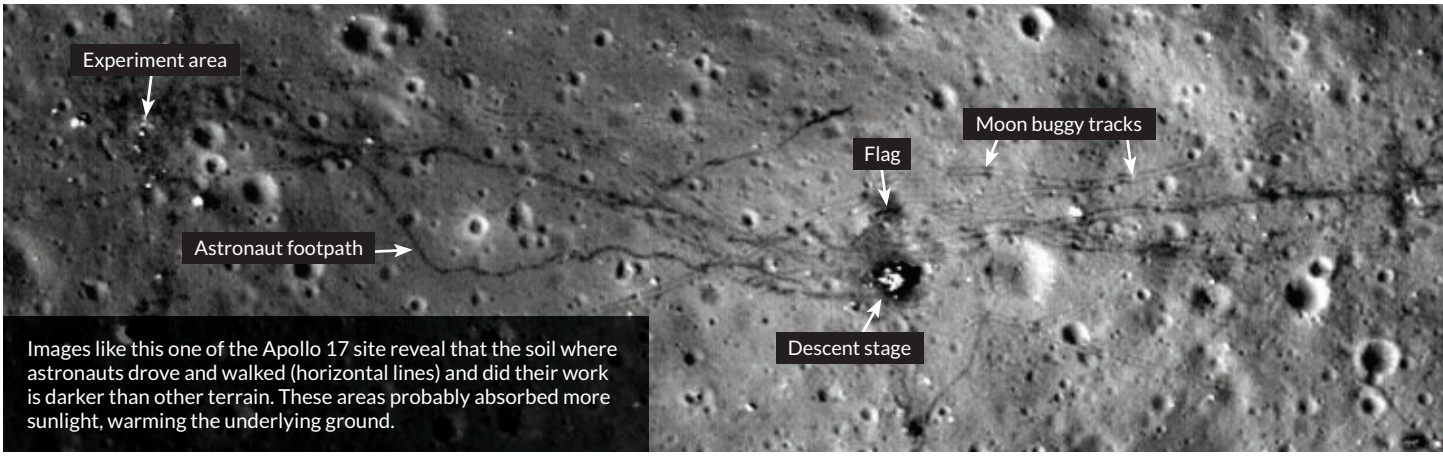
While Nagihara and other researchers are digging up old Apollo data for new analyses, one lone project is still in full swing: the laser ranging retroreflector experiment.

This experiment uses arrays of reflectors placed on the moon by Apollo 11, 14 and 15 astronauts and anchored on two rovers left behind by the Soviets (*SN: 5/20/78, p. 326*). These arrays consist of special mirrors, each with three sides in the shape of a cube's corner, which always reflect light in the exact direction from which it came. By shooting a laser beam at a corner-cube array from a telescope on Earth and clocking the time it takes for the light to return, researchers can measure the exact distance between different spots on the moon and Earth.

Laser ranging retroreflector measurements have offered several insights — like the fact that the moon is withdrawing from Earth at about 3.8 centimeters per year. Plus, slight variations in the moon's rotation suggest that the orb has a relatively small core.

Physicist Tom Murphy of the University of California, San Diego is using the corner-cube arrays to probe a question much bigger than the moon. He's testing whether a key part of Einstein's general theory of relativity, called the equivalence principle, holds up.

The equivalence principle states that any two objects in the same gravitational field should fall at the same rate (*SN: 1/20/18, p. 9*). Just like a bowling ball and a golf ball should hit the ground simultaneously, the Earth and moon should fall around the sun (that is, orbit the sun) at exactly the same rate. "You're sensitive to any difference in how they're

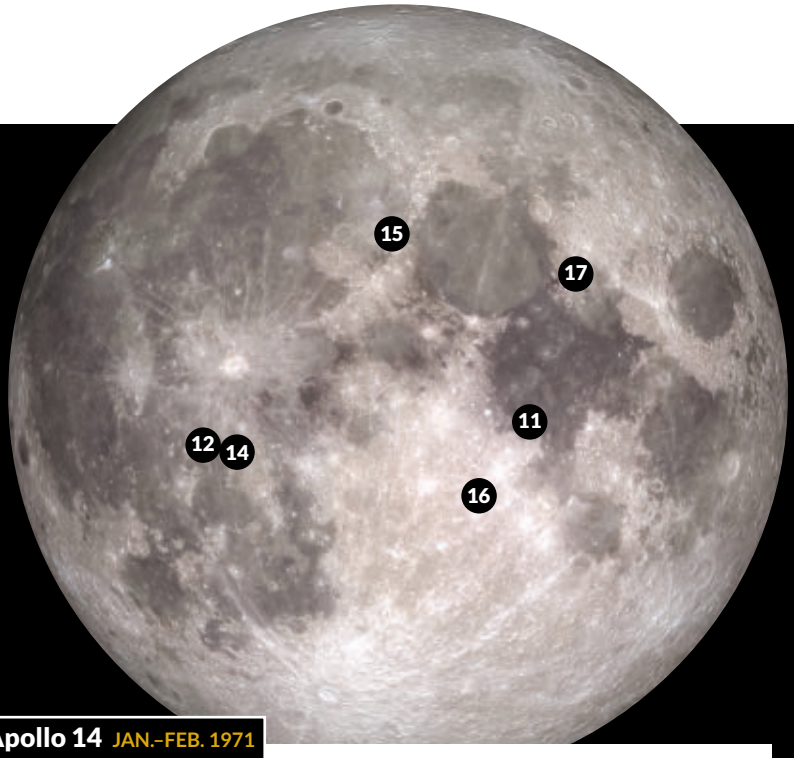


Images like this one of the Apollo 17 site reveal that the soil where astronauts drove and walked (horizontal lines) and did their work is darker than other terrain. These areas probably absorbed more sunlight, warming the underlying ground.

GSFC/NASA, ASU

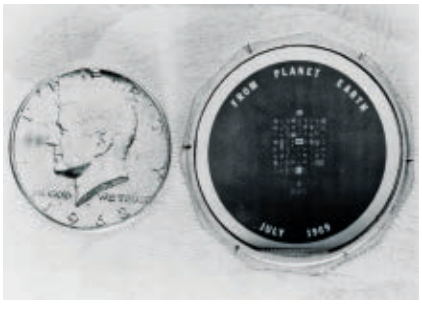
Memories and markers

Astronauts left a slew of equipment and mementos on the moon. Here are some of the artifacts that future lunar visitors might see if they are ever lucky enough to tour the six Apollo landing sites, locations shown on the moon at right.



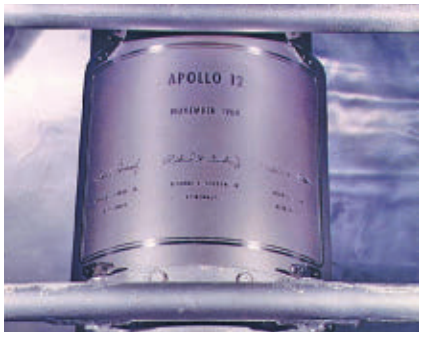
Apollo 11
JULY 1969

This medal commemorates the life of Russian cosmonaut Yuri Gagarin, who became the first man in space in 1961.



Slightly larger than a half-dollar coin, this silicon disk carried goodwill statements from 74 countries, including four from U.S. presidents.

Apollo 12 NOV. 1969



A plaque like this replica, with signatures of mission astronauts, was attached to the descent stage of the Apollo 12 lunar module, which stayed on the moon. Other missions left similar plaques.

Apollo 14 JAN.–FEB. 1971

After affixing a golf club head to the handle of a sample collection device, astronaut Alan Shepard hit two golf balls on the moon.

Astronaut Ed Mitchell hurled the handle of a sampling instrument javelin-style (shown here where it landed). Astronaut Alan Shepard declared the throw, "beautiful!"

Apollo 15 JULY–AUG. 1971

This plaque, along with the statuette representing a fallen astronaut, was placed on the moon in 1971 to honor 14 deceased U.S. astronauts and Soviet cosmonauts.

Astronaut David Scott dropped a feather (in his left hand) and a hammer (in his right) to show that objects, regardless of mass, fall at the same rate in a vacuum.

MOON: GSFC/NASA, ASU; APOLLO 11, FROM TOP: SMITHSONIAN NATIONAL AIR AND SPACE MUSEUM (NASM TMS A20020464000CP01); NASA; APOLLO 12, 14 AND 15, ALL: NASA

Apollo 16 APRIL 1972

The first telescope to make observations from the surface of another planetary body was a gold-plated far ultraviolet camera/spectrograph, shown at left with astronaut John Young.

In 1972, astronaut Charlie Duke left this shrink-wrapped family photo, signed by his wife and kids, on the lunar surface.

Astronauts put this moon buggy to the test with a "Grand Prix" of winding routes, hairpin turns and hard stops.

Apollo 17 DEC. 1972

This rudimentary gravitational wave detector, had it worked, would have searched for spacetime ripples predicted by Einstein's general theory of relativity.

ALL: NASA

[orbiting] the sun by measuring the distance between the Earth and moon as they weave around each other," Murphy says. If the Earth-moon distance ultimately breaks with the equivalence principle, that would reveal a shortcoming of general relativity. And that, in turn, could inform the creation of a theory of quantum gravity that resolves the tension between general relativity and quantum mechanics (*SN: 10/17/15, p. 28*).

So far, laser ranging retroreflector measurements with centimeter-level precision haven't shown any difference in how quickly the Earth and moon are falling around the sun. But in 2006, Murphy started collecting data with millimeter-scale precision using improved laser technology and a larger telescope at the Apache Point Observatory in New Mexico.

Amassing enough data will require several more years of observation and researchers will need more sophisticated computer models to analyze the observations, Murphy says. Luckily, since the reflectors on the moon don't require any power, he can collect data into the foreseeable future. Eventually, those observations — at the millimeter level or even smaller scales — could reveal a crack in the equivalence principle.

Since general relativity is fundamentally incompatible with quantum mechanics, something eventually has to give. The equivalence principle might be one of those things, Murphy says. "We have to turn over every rock and see where the bugs are."

One astronaut's trash

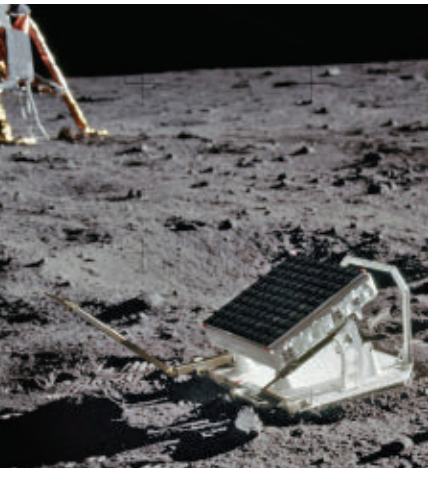
Thermometers and reflectors were among about a dozen types of instruments installed on the moon. Other devices measured the moon's magnetic field and sniffed out chemical components of the moon's tenuous atmosphere. NASA's Lunar Data Project is restoring data from these and other Apollo experiments, so that scientists can continue to pore over the observations for years to come.

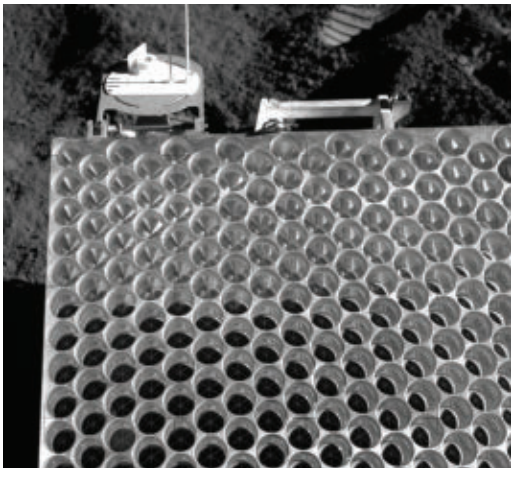
"When you have this incredibly rare resource, you can't not keep working on it," says planetary scientist Renee Weber of NASA's Marshall Space Flight Center in Huntsville, Ala., who studies lunar seismic data. "There are always new techniques to try" and better computer processing to tease out previously missed signals.

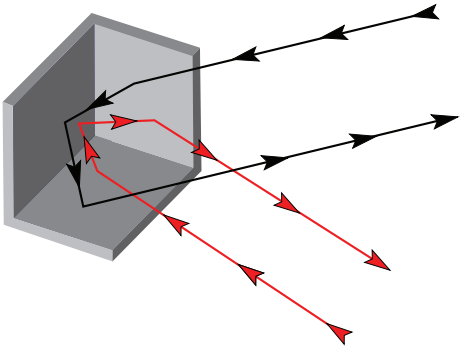
Based on moonquakes sensed by Apollo seismometers, Weber and colleagues reported in May that the moon may still be tectonically active, as revealed by young faults on the lunar surface called lobate scarps (*SN: 6/8/19, p. 7*). Understanding moonquakes could help NASA and other agencies decide where to land future spacecraft or construct buildings on the moon, Weber says. If these lobate scarps truly mark sites of tectonic activity, future lunar visitors may want to avoid them, she says.

There's also plenty to learn by testing how well the Apollo instruments, as well as the nonscientific paraphernalia strewn across the lunar surface, have held up. All of that stuff has been exposed to the lunar elements for decades. Future expeditions could sample the detritus to get a sense of how human communities might one day fare on the moon.

"Every single thing at the sites would be a completely priceless







Still running To measure the Earth-moon distance, arrays of "corner-cube" mirrors were set up at Apollo sites (left). Inside each circle (center) is a corner cube that reflects laser light back to Earth in the exact direction it came from (illustrated, right).

scientific investigation," says planetary scientist Philip Metzger of the University of Central Florida in Orlando. He can imagine scrutinizing the effects of ultraviolet radiation, solar wind and other factors on everything from batteries to camera lenses to towels and earplugs.

Metzger sees value in everything left behind on the moon, including the astronauts' discarded bags of excrement. "We have studies of microbes lasting in space over very short amounts of time on the International Space Station," he says, but testing whether microbes in astronaut waste have survived or mutated over the last 50 years could help determine whether life is up to the challenge of hopping between planets or even solar systems. These are "really important questions about the position of life in the cosmos," he says.

Protecting Apollo

While Metzger and other space scientists are hoping Apollo remnants can teach us more about how humans would fare on the moon, Beth O'Leary and other archaeologists are hoping to preserve these items as testaments to the human endeavor of getting there.

"Space is not a vacuum. We carry our culture into it," says O'Leary, of New Mexico State University in Las Cruces. The remnants of Apollo sites are important relics of a singular time in human history. Astronaut memorials, messages of peace and commemorative plaques on the moon are obvious pieces of heritage. But "even the scientific stuff has cultural importance," she says. More than 400,000 space-age Americans at over 20,000 companies and universities across the country teamed up to put Apollo astronauts on the moon. That kind of mass collaboration, in itself, was "a cultural act, as well as a scientific or engineering feat," O'Leary says.

Unfortunately, securing legal protections for the historical preservation of Apollo sites isn't easy. Don't expect the United States to establish an Apollo National Park on the moon any time soon. As fun as that sounds, it would violate the Outer Space Treaty of 1967, which states that no nation can claim sovereignty over the moon's surface.

NASA has published guidelines on how to avoid ruining Apollo artifacts in preparation for the many countries and companies that are vying for parking spots on the moon (*SN: 11/24/18, p. 14*). This rulebook includes policies such as the distance a future lunar spacecraft should land from Apollo sites so that the rocket exhaust doesn't wipe Neil Armstrong's first boot print off the face of the moon. These guidelines aren't legally binding, Metzger says, but "no company is going to want to be known as the company that ruined one of the Apollo sites."

Michelle Hanlon, who specializes in space law at the University of Mississippi in Oxford, has her sights on a much broader agreement to protect Apollo sites. Her nonprofit, For All Moonkind, is seeking United Nations protections for relics on the moon. The U.N. Committee on the Peaceful Uses of Outer Space is "the ideal place to negotiate a new treaty on heritage in space," Hanlon says, though she suspects it may take decades to reach such an international deal.

By then, many more people than professional astronauts may be walking the moon, fueling concerns about visitors making off with Apollo artifacts. In 2015, a lunar sample bag used by Armstrong was mistakenly sold at a government auction for $995 and later resold for $1.8 million. Other space-age memorabilia has sold for similarly astronomical prices.

"If NASA can lose [Armstrong's] bag, how can they keep track of all the artifacts" once people begin making regular round trips to the moon? Hanlon asks. "You can imagine [looters] going up and just grabbing artifacts and bringing them back to sell."

It's not just Apollo artifacts Hanlon wants to see preserved. Earlier this year, China let the first rover loose on the farside of the moon (*SN: 2/2/19, p. 5*), and Israel crash-landed its first spacecraft on the lunar surface (*SN Online: 4/11/19*). "These are all wildly important milestones" in humankind's quest to touch the stars that deserve to be preserved, Hanlon says. ■

Explore more

- NASA History Program Office. Catalogue of manmade material on the moon. https://go.nasa.gov/2CprmZB

FROM LEFT: NASA; NSSDC; CHETVORNO/WIKIMEDIA COMMONS (CC0)

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The Moon Lights The Way

Animals move, grow and even sing differently when the moon is full

By Erin Wayman

During winter, the moon is the main source of light for life in the Arctic.

Crowds of people gather to watch an evening spectacle on beaches in Southern California: Twice a month, typically from March through August, the sand becomes carpeted with hundreds or thousands of California grunion. Writhing, flopping, silvery sardine look-alikes lunge as far onto shore as possible. As the female fish dig their tails into the sand and release eggs, males wrap around females and release sperm to fertilize those eggs. About 10 days later, the eggs hatch and the little grunion get washed out to sea.

This mating ritual is set to the tides, with hatching timed to the arrival of the peak high tide every two weeks. But the ultimate force choreographing this dance is the moon.

Many people know that the moon's gravitational tug on the Earth drives the tides, and with them, the life cycles of coastal creatures. Yet the moon also influences life with its light.

For people living in cities ablaze with artificial lights, it can be hard to imagine how dramatically moonlight can change the nocturnal landscape. Out in the wild, far from any artificial light, the difference between a full moon and a new moon (when the moon appears invisible to us) can be the difference between being able to walk outside without a flashlight and not being able to see the hand in front of your face.

And animals respond. The presence or absence of moonlight, along with the predictable changes in brightness across the lunar cycle, can shape reproduction, foraging, communication and other aspects of an animal's world. "Light is possibly, maybe just after the availability of resources in terms of food, the most important environmental driver of changes in behavior and physiology," says ecologist Davide Dominoni of the University of Glasgow in Scotland.

Researchers have been cataloging moonlight's effects on animals for decades and continue to mark new connections. Several recently discovered examples reveal how lunar light influences lion prey behavior, dung beetle navigation, fish growth, mass migrations and even birdsong.

Beware the new moon

Lions of the Serengeti in Tanzania are night stalkers. They're most successful at ambushing animals (including humans) during the darker phases of the lunar cycle. But how the cats' prey respond to changing predator threats as the moon waxes and wanes has been a dark mystery.

Meredith Palmer, an ecologist at Princeton University, and colleagues spied on four of the lions' favorite prey species for several years with 225 camera traps installed across an area almost as big as Los Angeles. Volunteers with the citizen science project Snapshot Serengeti analyzed thousands of images of these animals.

The prey — wildebeests, zebras, gazelles and buffalo — are all plant eaters that need to frequently forage to meet their food needs, even throughout the riskier nighttime. The candid snapshots revealed that these species respond to changing risks across the lunar cycle in different ways, Palmer's team reported in *Ecology Letters* in 2017.

Common wildebeests (*Connochaetes taurinus*), which make up a third of the lion diet, were the most attuned to the lunar cycle. The animals appeared to set their plans for the entire night based on the moon's phase. During the darkest parts of the month, Palmer says, "they'd park themselves in a safe area." But as nights got brighter, wildebeests were more willing to venture into dangerous places where run-ins with lions were likely.

Weighing as much as 900 kilograms, African buffalo (*Syncerus caffer*) are lions' most formidable prey and were least responsive to changing predation risks. "They just sort of went where the food was," Palmer says. But as nights got darker, the buffalo were more likely to form herds.

Lions hunt (top) most successfully during the darkest nights of the lunar month. The big cats' favorite meal, wildebeests (middle), avoid places where lions congregate when it's dark, camera traps show. The larger African buffalo (bottom), another lion prey, tend to form herds, maybe for safety in numbers.

OPPOSITE: GEIR JOHNSEN/NTNU AND UNIS; THIS PAGE: M. PALMER, SNAPSHOT SERENGETI/SERENGETI LION PROJECT

Researchers placed dung beetles in this arena to test how well the insects could orient themselves under different nighttime skylight scenarios.

Grazing in groups might offer safety in numbers.

The routines of plains zebras (*Equus quagga*) and Thomson's gazelles (*Eudorcas thomsonii*) also changed with the lunar cycle. But unlike the other prey, these animals reacted more directly to changing light levels across the evening, Palmer says. Gazelles were more active after the moon had come up. Zebras "were sometimes up and about and doing things before the moon had risen," she says. That may seem like risky behavior, but being unpredictable could be a zebra defense strategy to keep lions guessing, she says.

These scenarios playing out in the Serengeti really demonstrate the wide-reaching effects of moonlight, Dominoni says. "It's a beautiful story, a very clear example, of how the presence or absence of the moon can have fundamental, ecosystem-level impacts."

Nighttime navigators

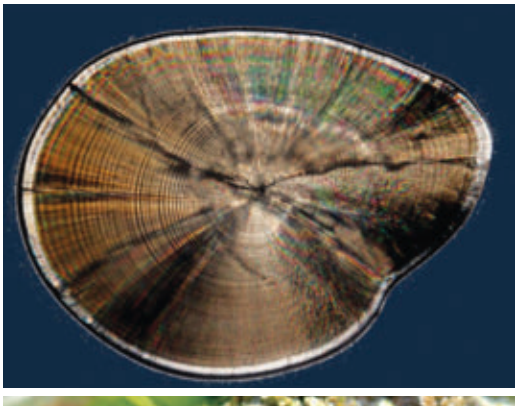
For nocturnal dung beetles, moonlight is a compass. How well the insects navigate depends on the phases of the moon.

In South African grasslands, a dung pat is like an oasis, providing scarce nutrients and water that draw a crowd of dung beetles. *Escarabaeus satyrus* beetles come out at night to grab and go, sculpting dung into a ball that's often bigger than the beetle itself and rolling the ball away from other hungry beetles. The beetle then buries the ball and itself in the ground.

The most efficient getaway is a straight line to a suitable burial spot, often many meters away, says James Foster, a vision scientist at Lund University in Sweden. To avoid going in circles or landing back at the feeding frenzy, beetles look to polarized moonlight (*SN: 7/5/03, p. 4*). Some lunar light scatters off gas molecules in the atmosphere and becomes polarized — meaning the light waves tend to vibrate in the same plane. This scattering produces a pattern of polarized light in the sky that human eyes can't see. But beetles may use this sky pattern to orient themselves, inferring where the moon is without even having to see the orb directly.

In recent field tests, Foster and colleagues evaluated the strength of the polarization signal in the night sky over dung beetle territory. The proportion of light in the night sky that's polarized during a nearly full moon is similar to that of polarized sunlight during the day, which many daytime insects such as honeybees use to navigate. As the moon gets darker across the lunar cycle, the signal weakens. By the crescent moon, beetles have trouble staying on course, the researchers reported in January in the *Journal of Experimental Biology*. Polarized light during this lunar phase may be at the limit of what the dung harvesters can detect.

At this threshold, light pollution could become a problem, as artificial light interferes with patterns of polarized moonlight, Foster says. He is conducting experiments in Johannesburg to see if city lights affect dung beetle navigation. Although rural African grasslands may not yet be bathed in an artificial glow, dung beetles are probably not the only nocturnal invertebrates that use polarized



Researchers determined that moonlight enhances the growth of young common triplefin fish (an adult shown, bottom) by studying the tree ring–like growth of an inner ear structure called an otolith (a roughly 0.5-millimeter-wide cross section is shown under a light microscope).

FROM TOP: CHRIS COLLINGRIDGE; DANIEL MCNAUGHTAN; BECKY FOCHT

moonlight to find their way, Foster says. "Even if [light pollution is] not a problem for this particular species, it could be a problem for many others."

Like a grow lamp

In the open ocean, moonlight helps baby fish grow.

Many reef fish spend their infancy at sea — maybe because the deeper waters make for a safer nursery than the predator-packed reef. But that's just a guess, because these larvae are too tiny to track, so scientists don't know a lot about them, says Jeff Shima, a marine ecologist at Victoria University of Wellington in New Zealand. He's recently figured out a way to observe the moon's influence on these fish.

Larvae of the common triplefin (*Forsterygion lapillum*) — a small fish that inhabits New Zealand's shallow rocky reefs — spend about 52 days at sea before getting big enough to go back to the reef. Fortunately for Shima, adults carry an archive of their youth within the inner ear. Calcium carbonate structures called otoliths, or ear stones, grow a new layer every day. So, much like tree rings, ear stones record patterns of growth, with a layer's width indicating how much growth occurred that day.

By matching otoliths from more than 300 triplefins with a calendar and weather data, Shima and marine biologist Stephen Swearer of the University of Melbourne in Australia found that larvae grow faster during bright, moonlit nights than on dark nights. If the moon is out but covered by clouds, larvae don't grow as much.

The moon's effect isn't trivial. It's on par with the effect of water temperature, a known driver of larval growth: The advantage of a full moon relative to a new moon is similar to that of a 1-degree Celsius increase in water temperature, the researchers estimated in the January *Ecology*.

Shima suspects that bright nights enable larvae to better see and hunt plankton. And like a child's reassuring night-light, the moon's glow may allow larvae to "relax a bit," he says. Likely predators, such as lantern fish, shy away from moonlight to avoid the bigger fish that hunt them by light. With nothing chasing them, larvae may be able to focus on foraging.

But when young fish are ready to return to the reef, moonlight may become a hindrance. In a different study, more than half of over 1,000 young sixbar wrasses (*Thalassoma hardwicke*) observed arriving at coral reefs in French Polynesia over 11 months did so during the darkness of a new moon. Only 15 percent came during a full moon, Shima and colleagues reported in *Ecology* in 2018.

Because many predators in coral reefs hunt by sight, a cover of darkness may give young sixbar wrasses the best chance of settling into a reef undetected. In fact, Shima has shown that some of these fish appear to stay at sea several days longer than normal to avoid a homecoming during the full moon.

Moonlight might similarly influence larvae of many kinds of reef fish and affect many aspects of the life cycle, Shima says.

Bad moon rising

Moonlight may flip the switch in the daily migration of some of the ocean's tiniest creatures.

K. LAST

Arctic zooplankton such as these copepods, which can grow up to a few millimeters long, make daily trips up and down in the ocean, timed to a solar schedule. In winter, when the sun is absent, these journeys follow a lunar schedule.

The moon's power over us

We all know the full moon doesn't turn people into hairy, scary werewolves (unless some Hollywood magic is involved). But if other animals respond to the moon, why not people?

Scientists have investigated possible connections between the moon and a broad mix of human experiences, such as conceptions, births, emergency room visits, cardiac events, psychiatric episodes, sports injuries, aggression and crime, and even the ups and downs of the stock market. Much of the evidence is inconclusive or contradictory. For every study that finds, for instance, that people lose sleep during a full moon (*SN: 8/24/13, p. 15*), there's another study that says, hold on, there's no connection. One thing that does seem clear: It's just a coincidence that the average length of a menstrual cycle, 28 days, nearly matches the 29.5-day lunar cycle.

"It's really hard to find definitive answers because most of the studies are correlational," says ecologist Davide Dominoni of the University of Glasgow in Scotland. Any uncovered effect could be real, or due to some other factor.

In reality, much research has relied on data from studies that weren't looking for moon effects in the first place. What's needed, researchers have argued, are experiments with clear hypotheses on how the moon might sway our behavior or physiology. Until then, it's hard to say if the moon's hold over us is fact or fiction. — *Erin Wayman*

In the seasons when the sun rises and sets in the Arctic, zooplankton plunge into the depths each morning to avoid predators that hunt by sight. But many scientists had assumed that, in the heart of winter when the sun is absent, zooplankton take a break from the up and down.

"People generally had thought that there was nothing really going on at that time of year," says Kim Last, a marine behavioral ecologist at the Scottish Association for Marine Science in Oban. But the light of the moon appears to take over and direct the migrations, Last and colleagues suggested in 2016 in *Current Biology*.

Last's group discovered these winter migrations all across the Arctic by analyzing data from acoustic instruments stationed off Canada, Greenland and Norway, and near the North Pole. The instruments record the echoes of sound waves bouncing off swarms of zooplankton as the critters move up and down in the ocean.

Normally, migrations follow a 24-hour rhythm, with zooplankton, including krill and copepods, descending many centimeters to tens of meters into the ocean around dawn and moving back toward the surface at night to graze on phytoplankton. But winter trips follow a slightly longer 24.8-hour schedule (*SN Online: 1/11/16*). That timing coincides exactly with the length of a lunar day, the time it takes for the moon to rise, set and rise again. And for about six days around a full moon, the zooplankton hide especially deep, down to 50 meters or so.

Zooplankton seem to have an internal circadian clock that sets their sun-based, 24-hour migrations. Whether the swimmers also have a lunar-based biological clock that sets their winter journeys is unknown, Last says. But laboratory tests show that krill and copepods have sensitive visual systems that can detect very low levels of light, he says.

Male white-browed sparrow weavers (left) sing solos at dawn. Behavioral ecologist Jenny York, shown here trying to catch a sparrow weaver from a roost in South Africa, learned that these performances begin earlier and last longer when there's a full moon in the sky.

FROM LEFT: J. YORK; DOMINIC CRAM

Moonlight sonata

The light of the moon also influences animals that are active in daytime. That's what behavioral ecologist Jenny York learned while studying white-browed sparrow weavers (*Plocepasser mahali*) in South Africa's Kalahari Desert.

These brown and white sparrow-sized birds live in family groups. Year-round, family members sing as a chorus to defend territory. But during the breeding season, males also perform solos, waking up at dawn to sing their own tune. These dawn songs are what brought York, now at the University of Cambridge, to the Kalahari.

She awoke at 3 or 4 a.m. to get to her field site before a performance began. But on one bright, moonlit morning, males were already singing when she arrived. "I missed my data points for the day," she recalls. "That was a bit annoying."

So she wouldn't miss out again, York got herself up and out earlier and found that the birds' early start time was not an isolated incident. Over seven months, she discovered that when a full moon was visible in the sky, males started singing about 10 minutes earlier on average than when there was a new moon, York and colleagues reported in *Biology Letters* in 2014.

The extra light, rather than some other aspect of the lunar phase, kick-starts the singing, the team concluded, because on days when the full moon is already below the horizon at dawn, sparrow weavers start crooning on their normal schedule. Some North American songbirds seem to have the same moon reaction.

The earlier start time lengthens the males' average song period by 67 percent, with a lot of variation. Some devote just a few minutes to dawn singing; others go on for 40 minutes to an hour. Whether there's a benefit of singing earlier or longer is unclear. Although sparrow weavers mate in pairs, they aren't always faithful. "Shenanigans" go on in the twilight hours, York says. Something about dawn songs may help females evaluate potential mates. A longer performance may very well help the females tell "the men from the boys," as York puts it. ■

Explore more

- Snapshot Serengeti: www.snapshotserengeti.org

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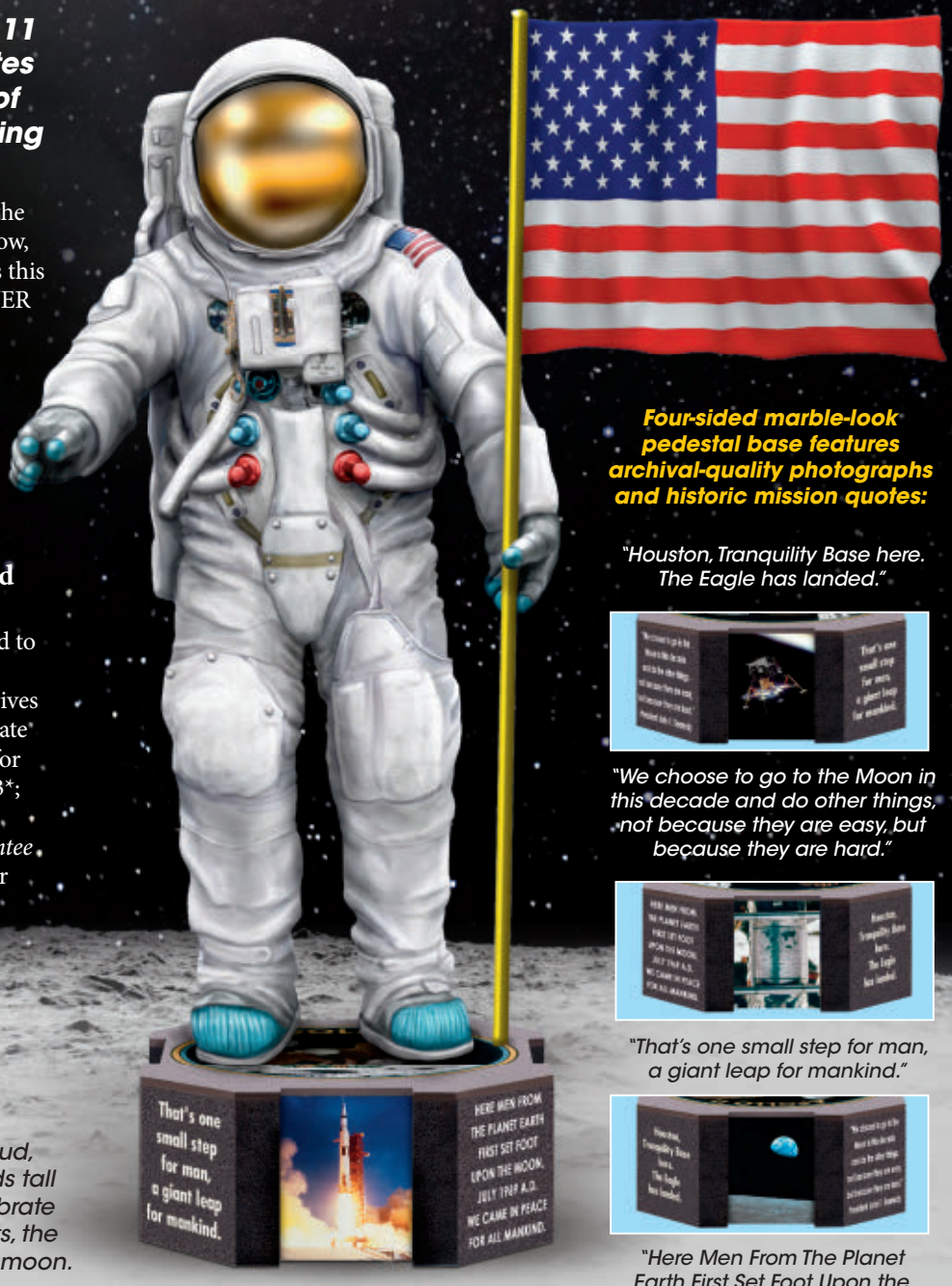

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How *Science News* covered the Apollo missions

There are two astronauts in this 1969 photo. Buzz Aldrin stands on the moon near the Apollo 11 lunar lander while Neil Armstrong, reflected in Aldrin's visor, takes the picture.

NASA

The magazine reported on every facet of this scientific feat

By Christopher Crockett

To cover humankind's first steps on the moon, *Science News* needed a backup plan.

"We didn't know what kind of pictures we'd get, when we would get them, who we would get them from," says Kendrick Frazier, who joined *Science News* as a writer just two months before Apollo 11 touched down on lunar soil. So the staff took pictures of their home television screens during the July 20, 1969 broadcast of the moon landing. "It didn't work out very well," he says.

Fortunately, images from NASA sufficed. On the cover of the July 26, 1969 issue — just 25 cents! — the words "At last the moon" ran atop a raw, black-and-white image of two blurry forms standing on desolate terrain, with the spidery outline of the lunar lander in the background. A description of the photo — Frazier's one contribution to the coverage — captured the scene: "Ghostly they were, those two figures gliding over the surface of the moon. But, with all the world watching, it was certain. The dream of the ages had been fulfilled: Man was on the moon."

Throughout the Apollo program, *Science News* kept a watchful eye, reporting on the successes, setbacks and skepticism. From 1967 to 1973, the magazine published more than 100 stories about the United States' quest to reach the moon, from the Apollo 1 launchpad fire that killed three astronauts (*SN: 2/4/67, p. 112*) to the splashdown of the final mission, Apollo 17 (*SN: 12/23/72, p. 404*), plus later findings of moon-based experiments.

"Apollo was an epic achievement. We all were super excited," Frazier says. Yet the magazine never went overboard, he adds. "We managed to cover all the other things going on in science." The July 26 issue devoted just five of its 24 pages to the Apollo 11 landing. Other stories included advances in predicting the sex of an unborn child and urban influences on precipitation.

The job of covering Apollo 11 fell to staff writer Jonathan Eberhart. He most likely traveled to Cape Kennedy (now called Cape Canaveral) in Florida for the launch and then to Houston for the rest of the mission, Frazier suspects, filing stories by phone or telegram. In describing the mission, Eberhart's prose soared: "Now the moon is man's.

The incredible accomplishments of Apollo 11 have changed it irretrievably in the eyes of humankind." Then he quickly got to work recounting the well-rehearsed descent, the harrowing landing, the hesitant first steps — before spending much of his time, of course, on the science.

Eberhart, who covered space exploration for *Science News* for three decades, painstakingly described three experiments installed by the Apollo 11 astronauts: a metal foil for snagging solar particles, a seismometer for tracking moonquakes and a mirror array for reflecting lasers back to Earth (see Page 26).

Some geologists, he noted, were miffed about the sample collection: The astronauts didn't know precisely where they landed and were snatching soil from areas where they had already trod, thus collecting samples from potentially disturbed terrain (*SN: 7/26/69, p. 72*).

But Eberhart's coverage wasn't just about timelines and equipment. In a sidebar tucked in the corner of a page of Apollo 11 coverage, Eberhart asked: "What has happened to awe?" He expresses the challenges of a writer conveying the enormity of the moment while pleading with readers to contemplate what humans had just accomplished.

"Try, briefly, to ignore the flashy rockets and the heroic astronauts. Try to feel the smallness of man and the vastness of what he is doing," Eberhart wrote. "After two million years, man has stepped out of this world onto another. And, by incredible fortune, we are alive at the instant he did it."

Eberhart can't explain what he was thinking; he died in 2003 (*SN: 3/1/03, p. 134*). But Frazier says that this sidebar captured "Jonathan's sense of wonder and awe amidst all of his professionalism."

Early on, magazine editor Warren Kornberg pondered the value of this adventure amid the heavy challenges of the time (*SN: 7/26/69, p. 71*). "Nothing can mar the glory earned by the astronauts," Kornberg wrote in a special commentary. But "[t]he verdict of history may well be that, while the world erupted, we ignored the real challenge and chased a rocket trail to the moon." It's a sobering note. But Apollo's achievements overlapped with assassinations, race riots and the unpopular Vietnam War, a truth that *Science News* had to acknowledge.

"We felt we had a special role of reporting on the science part of the ... mission as well as putting it into the broader context," says Frazier, who became the magazine's editor in 1971. Kornberg's editorial, he says, reflected widespread "antipathy about spending this money to go to the moon while the whole country was falling apart socially and politically."

The July 26, 1969 cover of *Science News* showed an image — taken from a video feed about 40 minutes after the historic first step — of Neil Armstrong (right) walking toward Buzz Aldrin (left). Aldrin is inserting a solar wind collector into the ground.

Letters to the editor published that September echoed Kornberg's concern (*SN: 9/13/69, p. 194*). "We are frustrated and ashamed," wrote one reader.

Three years later, in his own — more optimistic — editorial as Apollo 17 drew near, Frazier wrote: "The misfortune of Apollo is that it was conceived in one era of American history and fulfilled in another.... [I]n a future and less buffeted age, the tarnish will have disappeared, and the Apollo landings on the moon will stand as an unambiguous and unparalleled human achievement" (*SN: 10/21/72, p. 259*).

Despite the public misgivings, Frazier says it was an incredible time to be writing about science. At his home in Albuquerque, he keeps a memento from his tenure at *Science News*: the engraving plate used to print the cover of the moon landing issue. He plans to display it in his home office this summer, a nod to the 50th anniversary of Apollo 11. "It is, to me, the greatest souvenir of that time," he says. ■

Christopher Crockett, formerly at Science News, *is a freelance science writer and editor based in Arlington, Va.*

"After two million years, man has stepped out of this world onto another. And, by incredible fortune, we are alive at the instant he did it."

JONATHAN EBERHART

The Venus of Laussel holds a horn carved with 13 notches, which may represent lunar cycles and fertility.

Keeping Time With the Moon

When ancient humans used the crescent as a calendar in the sky

By Rebecca Boyle

The sun's rhythm may have set the pace of each day, but when early humans needed a way to keep time beyond a single day and night, they looked to a second light in the sky. The moon was one of humankind's first timepieces long before the first written language, before the earliest organized cities and well before structured religions. The moon's face changes nightly and with the regularity of the seasons, making it a reliable marker of time.

"It's an obvious timepiece," Anthony Aveni says of the moon. Aveni is a professor emeritus of astronomy and anthropology at Colgate University in Hamilton, N.Y., and a founder of the field of archaeoastronomy. "There is good evidence that [lunar timekeeping] was around as early as 25,000, 30,000, 35,000 years before the present."

When people began depicting what they saw in the natural world, two common motifs were animals and the night sky. One of the earliest known cave paintings, dated to at least 40,000 years ago in a cave on the island of Borneo, includes a wild bull with horns. European cave art dating to about 37,000 years ago depicts wild cattle too, as well as geometric shapes that some researchers interpret as star patterns and the moon.

For decades, prehistorians and other archaeologists believed that ancient humans were portraying what they saw in the natural world because of an innate creative streak.

The modern idea that Paleolithic people were depicting nature for more than artistic reasons gained traction at the end of the 19th century and was further developed in the early 20th century by Abbé Henri Breuil, a French Catholic priest and archaeologist. He interpreted the stylistic bison and lions in the cave paintings and carvings of southern France as ritual art designed to bring luck to the hunt.

In the 1960s, a journalist–turned–amateur anthropologist proposed even more practical purposes for these drawings and other artifacts: They were created for telling time.

In the early days of the Apollo space missions, the journalist, Alexander Marshack, was writing a book about how the course of human history culminated in the moon shot. He delved into prehistory, trying to understand the earliest concepts of timekeeping and agriculture (*SN: 4/14/79, p. 252*).

"I had a profound sense of something missing," Marshack wrote in his 1972 book, *The Roots of Civilization*. Formal science, including astronomy and math, apparently had begun "suddenly," he noted. Same with writing, agriculture, art and the calendar. But surely these cognitive leaps took thousands of years of preparation, Marshack reasoned: "How many thousands was the question."

To find out, he examined ancient bone carvings and wall art from locations including caves in Western Europe and fishing villages of equatorial Africa. He interpreted what was seen by some as simple dots and dashes or depictions of animals and people as sophisticated tools for keeping track of time — via the moon. Today, some experts support his thesis; others remain unconvinced.

Early almanacs

It's easy enough to keep track of the seasons just by paying attention to the environment, of course. Throughout the world, animals like deer and cattle are pregnant through the winter's dark privation; they give birth when the leaves appear on trees and when grasses grow tall.

Early humans of 30,000 years ago frequently connected the changes in these "phenophases," the seasonal stages of flora and fauna, with the appearance of certain stars and the phases of the moon, says science historian and astronomer Michael Rappenglück of the Adult Education Center and Observatory in Gilching, Germany. He refers to early cave depictions as "paleo-almanacs" because they combined time-reckoning with information related to the cycles of life.

As Rappenglück puts it, simply noting the spinning of the seasons would not be enough to keep time. For one thing, flora and fauna change from place to place, and even 30,000 years

MUSEUM COLLECTION OF AQUITAINE–FRANCE PHOTO J-M ARNAUD, BORDEAUX CITY HALL

ago, humans were traveling great distances in search of food. They needed something more constant to help them tell time.

"People carefully watched the course of the moon, noting its position over the natural horizon and the change of its phases," Rappenglück wrote in the 2015 *Handbook of Archaeoastronomy and Ethnoastronomy*.

In the 1960s, Marshack, the first to argue that Paleolithic people were connecting the moon with time, sifted through dusty cabinets in French museums, retrieving bone and antler pieces that had been worked by humans. Others had interpreted the etchings on these objects as the by-product of point-sharpening, or maybe, as most before Breuil thought, abstract artworks made by idle hands.

But Marshack saw the earliest examples of sky almanacs. The etchings were numerical and notational, he argued. On a bone shard from a prehistoric settlement called Abri Blanchard in France, dating to 28,000 years ago, he found a pattern of pits, some with commalike curves and some round. He viewed it as a record of lunar cycles.

Deeply excited by the find, Marshack soon brought his conclusions to archaeologists and anthropologists throughout Europe and the United States. Some of these experts were impressed, according to accounts at the time.

Hunters who could figure out when the night would be illuminated by moonlight would have had an "adaptive advantage," Aveni says. "That is so much what the cave paintings are about," he says, referring to the tally marks near the animals on the walls of the Chauvet Cave in France and elsewhere.

Regarding Marshack's speculations about the Blanchard bone shard, paleoanthropologist Ian Tattersall is still unsure. "We know Ice Age European art was highly symbolic, and there is no doubt that [ancient people] perceived symbols all around them in nature. And it is pretty certain that the moon played a huge role in their cosmology, and that they were fully aware of its cycle," says Tattersall, curator emeritus of human origins at the American Museum of Natural History in New York City. "Beyond that, all bets are off."

Thirteen notches

In the decades after Marshack published his findings, historians and anthropologists began noticing similar lunar motifs throughout the archaeological record of this time period and afterward, Aveni notes. "There are more than one of these items that have markings on them that might relate to the moon," he says.

The Venus of Laussel is one extraordinary example. It is a carving of a voluptuous woman, one hand resting on her abdomen, the other raised and holding a bison horn etched with 13 notches. Her face is turned toward the horn. The figure was carved between 22,000 and 27,000 years ago, in a rock-shelter in the Dordogne region of southwestern France.

Some archaeologists now think the 13 notches represent the number of lunar cycles in a solar year — and, approximately, the average number of menstrual cycles. Though modern

The Blanchard bone dates to 28,000 years ago, in the Aurignacian period of Western Europe. Alexander Marshack argued that the artifact depicts a lunar calendar.

scientists have debunked any direct connection between the cycles of the moon and human fertility (see Page 32), ancient people would have recognized the parallel timing; the lunar cycle repeats every 29.5 days, roughly the same schedule as the average woman's menstrual cycle. People of 30,000 years ago could have used the moon and stars to plan their pregnancies, Rappenglück speculates.

Cave paintings in the Dordogne region may be depictions of the lunar and menstrual cycles. Specifically, the Lascaux cave paintings, dating to 17,000 years ago, are best known for their curvy, sweeping depictions of horses and bulls. Beyond the cave entrance, past what is called the Hall of Bulls, is a dead-end passage called the Axial Gallery. Red aurochs, an extinct form of cattle, stand in a group. A huge black bull stands apart from them. Across the gallery, a pregnant horse gallops above a row of 26 black dots. The mare is running toward a massive stag, with front legs invisible behind 13 additional evenly spaced dots.

The animals may represent seasons, Rappenglück suggests. In Europe, bovines calve in the spring; horses both foal and mate in the late spring. The deer rut takes place in early autumn, and the wild goats known as ibex mate around the winter solstice.

To Rappenglück, the dots depict the 13 full moons of the lunar cycle. The 26 dots may roughly represent the days of a sidereal month, or the time it takes the moon to return to the same position in the sky relative to the stars. "The striking row of dots is a kind of a time-unit," he wrote in 2004.

Critics have said Marshack's work overinterprets many artifacts from Africa and Europe, some of which contain markings at the limit of naked-eye visibility (*SN: 6/9/90, p. 357*).

"By modern standards of evidence, he is playing with numerological coincidences," art historian James Elkins wrote in 1996 in an article that is part critique and part celebration. Elkins noted that Marshack countered his doubters by throwing their uncertainty back at them, arguing that better explanations were lacking.

"Nights were real nights at that time, and Paleolithic people certainly had deep insights into what was going on in the sky," says Harald Floss, an anthropologist at the University of Tübingen in Germany who studies the origin of art. "But I would not risk saying more." ■

Rebecca Boyle is a science journalist based in St. Louis. She is writing a book about humans' relationship with the moon.

BOOKSHELF

Spend the Apollo 11 anniversary with a good book

Astronomy lovers are not the only ones excited about the 50th anniversary of the moon landing. Publishers are also taking note, serving up a pile of books to mark the occasion. Are you looking for a general overview of the birth of the U.S. space program? Would you rather geek out on the technical details of the Apollo missions? How about flipping through a collection of photographs from the era? *Science News* staff took a look at the offerings and picked out a few favorites to help you decide. There's something for everyone in the list below.

Shoot for the Moon
James Donovan
Little, Brown and Co., $30

WHO SHOULD READ?
History aficionados

This retelling of the space race begins with the launch of the Soviet Union's Sputnik satellite in 1957 and culminates in the historic Apollo 11 mission 12 years later. The book offers insights into the personalities of the astronauts, engineers and others who made the U.S. space program a success.

One Giant Leap
Charles Fishman
Simon & Schuster, $29.99

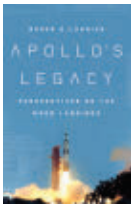
WHO SHOULD READ?
Detail-obsessed NASA fans

Getting to the moon demanded a million hours of work for each hour spent in space, this book argues. Accordingly, the story focuses on the engineers, coders, project managers and others who toiled to get the Apollo program off the ground.

Picturing Apollo 11
J.L. Pickering and John Bisney
Univ. of Florida, $45

WHO SHOULD READ?
Anyone who ever dreamed of being an astronaut

Packed with hundreds of photos, some published for the first time, this coffee-table book reads like a photo album of the Apollo 11 mission. The images focus on candid moments from astronaut training, as well as the excitement of liftoff, the historic landing and the return home of the three men.



Apollo's Legacy
Roger D. Launius
Smithsonian Books, $27.95

WHO SHOULD READ?
Readers ready for a sober view of Apollo

A space historian takes the Apollo program off its pedestal to examine it from multiple angles: as a cog in the Cold War political machine, an engineering endeavor riddled with as many failures as feats of glory and an iconic cultural moment. The book explores both positive and negative viewpoints on the U.S. moonshot project from scientists, politicians, the media and the public during the space race and beyond.

Moonbound
Jonathan Fetter-Vorm
Hill and Wang, $35

WHO SHOULD READ?
Fans of graphic novels

Colorful and detailed, the comic-style illustrations in this book of graphic nonfiction bring the moon landing to life. Much of the astronauts' dialog is based on real recordings, making the book feel particularly authentic.

Moonshot
Richard Wiseman
TarcherPerigee, $26

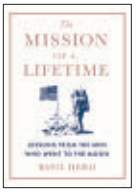
WHO SHOULD READ?
Self-improvement buffs

A psychologist takes practical lessons from the Apollo era and suggests ways to apply them to everyday problems, from changing careers to raising a family.

The Apollo Missions
David Baker
Arcturus Publishing Limited, $19.99

WHO SHOULD READ?
Space enthusiasts

A former NASA engineer uses photographs, illustrations, blueprints and other documents to guide readers through a concise history of the space race and the Apollo program, from the beginnings of rocket science to the successful return home of the Apollo 11 crew.



The Mission of a Lifetime
Basil Hero
Grand Central Publishing, $22

WHO SHOULD READ?
History wonks with a soft spot for psychology

The Apollo astronauts rarely gave personal interviews. But now that they're getting older, the astronauts are starting to get introspective. This book distills conversations with the 12 lunar voyagers still alive into general wisdom on conquering fear and appreciating life.

Hasselblad & the Moon Landing
Deborah Ireland
Ammonite Press, $14.95

WHO SHOULD READ?
Photography lovers

This slim book offers an offbeat take on the mission to the moon, telling the story of the Apollo program through the development of the Hasselblad cameras that Neil Armstrong and Buzz Aldrin used to document their time on the lunar surface.

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SOCIETY NAMES 60 ADVOCATES TO MENTOR UNDERSERVED STUDENTS

Advocate Reny Mathew (far left) and her students volunteered as science fair judges for local elementary schools.

Advocate Patrycja Krakowiak (far right) teaches students how to express a gene in bacteria that glow when exposed to ultraviolet light.

Advocate Merridith Joly's students display their Twin Cities Regional Science Fair awards.

Society for Science & the Public is pleased to announce this year's 60 Advocates who will mentor underrepresented and low-income students and guide them in entering science research competitions.

Through the Advocate Grant Program, educators and scientists expand opportunities for underserved students who have the potential, yet lack the necessary resources, to succeed in STEM fields. Each Advocate will mentor a cohort of three or more students, providing support as they complete science research projects and apply to compete in science research competitions.

2019–2020 Lead Advocates, who will oversee groups of Advocates:

Charmain Brammer, St. George, UT
Jennifer Claudio, San Jose, CA
Andrea Cobb, Manassas, VA
Cynthia Hopkins, Corpus Christi, TX
Vincent Joralemon, New York, NY
Deborah Morgan, Monroe, UT
Lorraine O'Shea, Grand Forks, ND
Heather Overkamp, Portsmouth, VA

2019–2020 Advocates:

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Keri Meador, Louisville, KY
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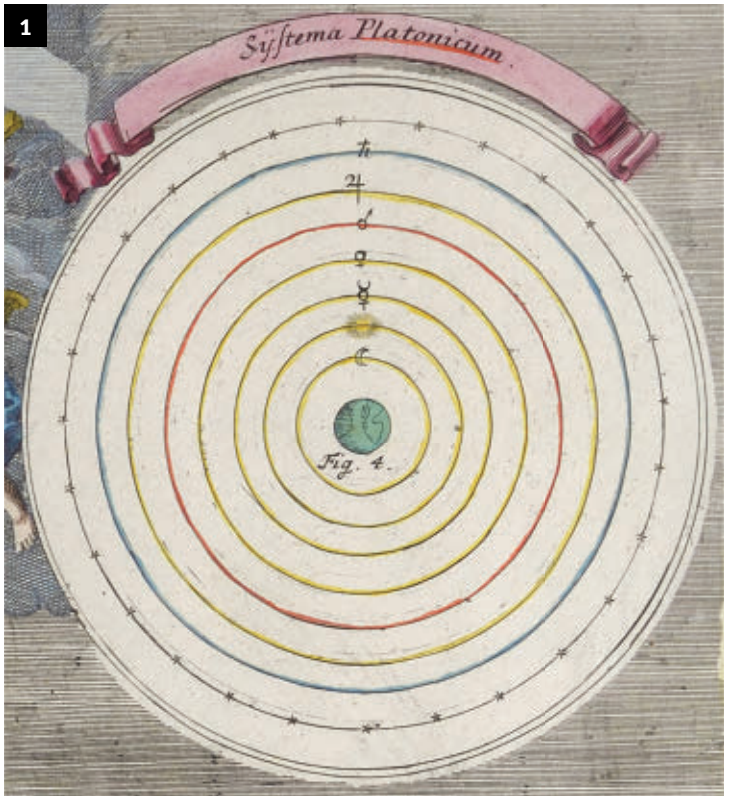
The moon through the ages

Look up at the moon and you'll see roughly the same patterns of light and shadow that Plato saw about 2,500 years ago. But humankind's understanding of Earth's nearest neighbor has changed considerably since then, and so have the ways that scientists and others have visualized the moon.

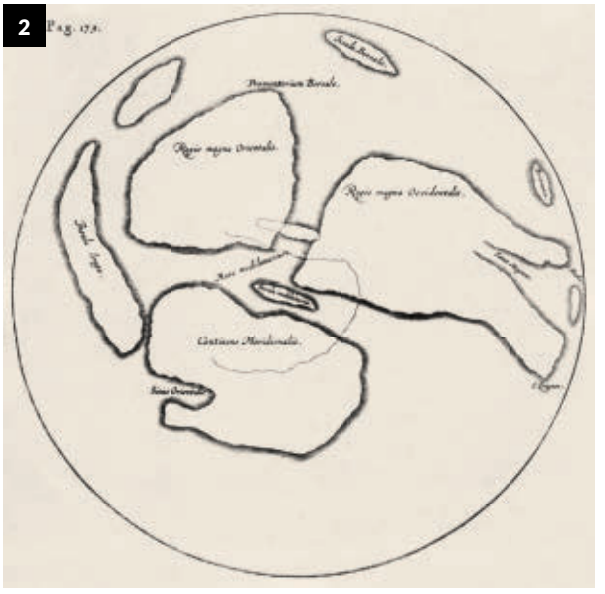
To celebrate the 50th anniversary of the Apollo 11 moon landing, here are a collection of images that give a sense of how the moon has been depicted over time — from hand-drawn illustrations and maps, to early photographs, to highly detailed satellite images made possible by spacecraft such as NASA's Lunar Reconnaissance Orbiter.

The images, compiled with help from Marcy Bidney, curator of the American Geographical Society Library at the University of Wisconsin–Milwaukee, show how developments in technology such as the telescope and camera drove ever more detailed views of Earth's closest celestial companion.

— Cassandra Willyard



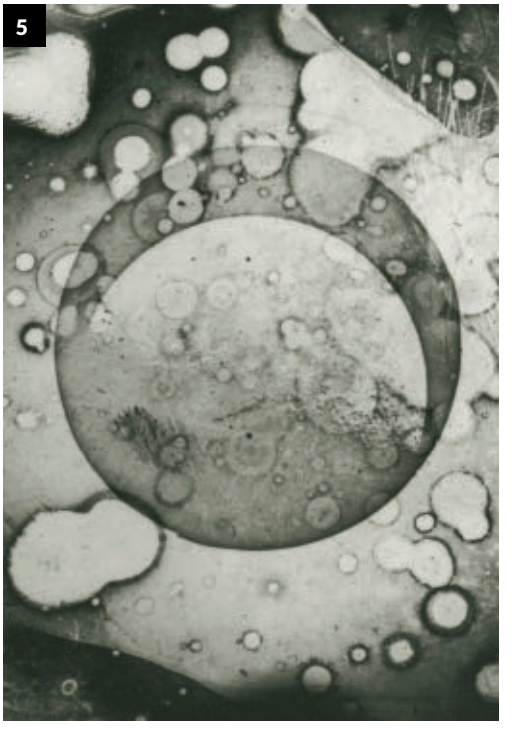
1. Ancient Greek philosophers like Plato thought the moon and other celestial bodies revolved around a fixed Earth. This 1742 diagram by German scientist Johann Gabriel Doppelmayr depicts that idea. The thinkers saw the moon as perfect and struggled to explain its dark marks.



2. Created around 1600, this sketch is the oldest known lunar map and was drawn using the naked eye. William Gilbert, physician to Queen Elizabeth I, imagined that the bright spots were seas and the dark spots land, and gave some features names.

3. The telescope made it far easier to see the moon's topography. By Galileo, these 1610 lunar maps are some of the first published to rely on telescope views. His work supported the Copernican idea that the moon, Earth and other planets revolved around the sun.

CLOCKWISE FROM TOP: SCIENCE HISTORY IMAGES/ALAMY STOCK PHOTO; GALILEO/CUL DIGITAL COLLECTIONS; AMERICAN GEOGRAPHICAL SOCIETY LIBRARY/UW–MILWAUKEE



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4. In 1647, Polish astronomer Johannes Hevelius published the first lunar atlas, *Selenographia*. The book contains more than 40 engravings and drawings (including this one) that show the moon in its phases. Hevelius included a glossary of 275 named surface features.

5. Photography opened a new way to capture the moon. Taken around 1840 by British-born physician John William Draper, this daguerreotype is the first known lunar photo. Spots are from mold and water damage.

6. Lunar photos quickly improved. John William Draper's son Henry shot this image from his Hastings-on-Hudson observatory in New York in 1863. Also a physician, he became a pioneer in astrophotography.

7. This 2018 image, from NASA's Lunar Reconnaissance Orbiter, shows the moon's familiar face in incredible detail. Today we know its marks are evidence of a violent past and include mountains and giant basins full of hardened lava.

MAY 11, 2019 & MAY 25, 2019

Porcine puns

Four hours after pigs died, a sophisticated artificial system restored the animals' brain cell activity, **Laura Sanders** reported in "Dead pig brains show signs of life" (*SN: 5/11/19 & 5/25/19, p. 6*). Online reader **David Campbell** joked about the result. "It's the zombie aporkalypse! If the technique also works to keep pig intestinal cells alive, that would really be a wurst-case scenario."

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Heat keepers

*Long ago, molten iron could have erupted from metal asteroids in a process scientists refer to as ferrovolcanism, **Lisa Grossman** reported in "Metal asteroids maybe had iron volcanoes" (*SN: 5/11/19 & 5/25/19, p. 5*).*
"In the cold vastness of space, how long are these rocks expected to keep their thermal energy?" asked online reader **Bronze Condor**.

It depends on the size of the asteroid and how it solidifies, says planetary scientist **Jacob Abrahams** of the University of California, Santa Cruz.

In general, the cores of big asteroids stay warm longer than the cores of small asteroids. In big enough asteroids, radioactive isotopes that provide heat cluster in the mantle or even the crust. In the case of metal asteroids, though, which are thought to be the exposed cores of large planetary bodies, those warming radioactive isotopes would have been stripped away. "The core ends up pretty empty," **Abrahams** says. "At that point, the heat you have is all the heat you get."

How long metal asteroids preserve that heat depends on whether the objects solidify from the outside in or inside out. An asteroid that solidifies from the inside out loses heat "incredibly quickly," **Abrahams** says. That's because the asteroid has hot material radiating heat on its surface. An asteroid that solidifies from the outside in, however, can keep its heat for millions of years. Such asteroids "form an insulating crust that slows cooling," **Abrahams** says.

Flowing on air

*Mixtures of hot volcanic rock and gas called pyroclastic flows glide on air, **Maria Temming** reported in "Lab study reveals volcanic secret" (*SN: 5/11/19 & 5/25/19, p. 12*). A low-friction, air-rich layer forms underneath the volcanic material due to flow-rate differences, simulations suggest.*
Reader **David Kutzler** thought that another factor may help form the air-rich layer. "Water in the soil and plants in the path of the flow would instantly flash to steam, which would serve to further dilute the bottom layer of the flow," **Kutzler** wrote.

That's an interesting idea, and one that has been around for a while, says volcanologist **Gert Lube** of Massey University in Palmerston North, New Zealand. But there is no direct evidence that this actually occurs.

"Some test experiments that we performed on ... hot experimental flows over small water bodies did not show any signs of increased mobility," **Lube** says. "My opinion is that this idea needs proper investigation in the future."

Lithium life cycle

*The demand for lithium is skyrocketing, thanks in part to the expected boom of electric vehicles, **Carolyn Gramling** reported in "Looking for lithium" (*SN: 5/11/19 & 5/25/19, p. 40*). The element is used to make lightweight batteries.*
Reader **John Jaros** wondered what happens to lithium batteries when electric vehicles are "junked."

Electric-vehicle batteries could be recycled to recover other metals in them such as cobalt, **Gramling** says. "But recycling lithium is trickier and costlier, and that loop has yet to be closed," she says. The European Union requires battery manufacturers to pay for collection, treatment and recycling of lithium batteries. The United States does not. Batteries no longer suitable for powering vehicles might also find second lives storing electricity from wind turbines and solar panels.

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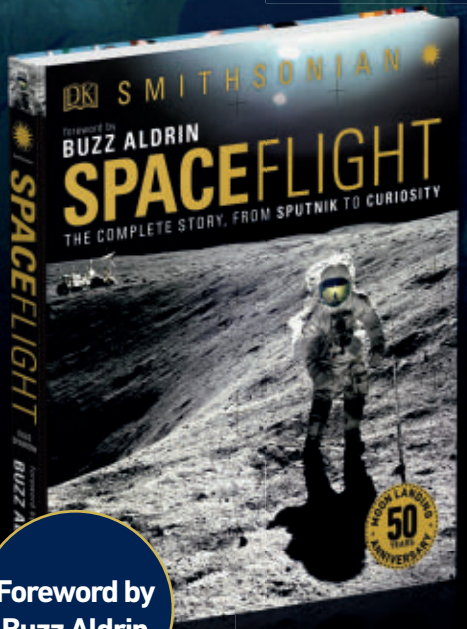
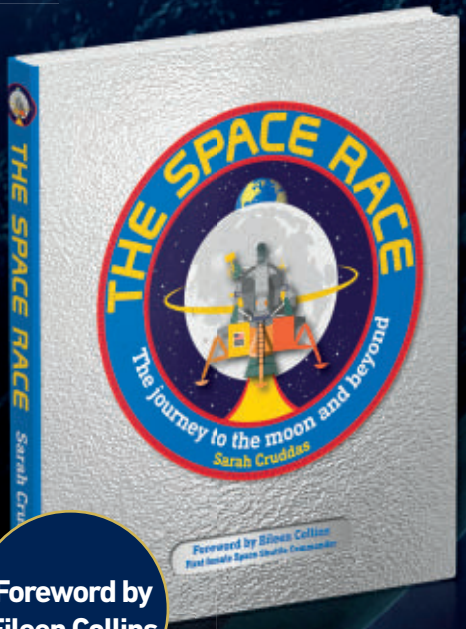


Foreword by Buzz Aldrin



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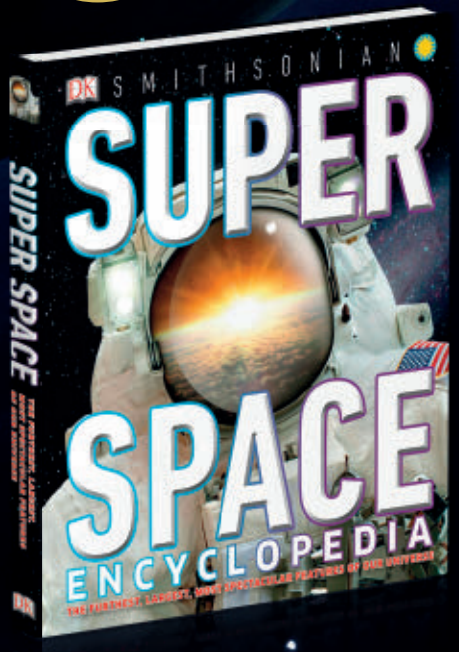

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