VOL. 105 | NO. 6
JUNE 2024

Eos

SCIENCE NEWS BY AGU

Whither the Anthropocene?

The Source of Swift Quakes

Tatooine, Trisolaris,
and Thessia, Oh My!

ALL ROADS LEAD TO...

Seatbelt Rock
the Order of the Red Nose
luna firma
$13,000 worth of missing acid
Teletubby training
beanbag sampling
cruise hands
stickers and geotags
penguins

SCIENCE

AGU
ADVANCING EARTH
AND SPACE SCIENCES

2017 NASA astronaut candidates (left to right) Kayla Barron, Frank Rubio, Raja Chari, and Jessica Watkins gather during geology training in Arizona. Behind them stands their field instructor. Credit: NASA/Bill Stafford

The Art of Doing Fieldwork on the Moon

By Mark Betancourt

David Kring, call sign EV1, describes a boulder that was ejected from Arizona's Meteor Crater to students listening in from a virtual science operations center. Credit: NASA/SSERVI/Ricky Guest

HOW EARLY-CAREER PLANETARY SCIENTISTS ARE PREPARING TO SUPPORT THE ASTRONAUTS WHO WILL RETURN TO THE LUNAR SURFACE AND BEYOND.

2017 NASA astronaut candidates and their field instructors hike as a team at Meteor Crater in Arizona. Credit: NASA/Bill Stafford

2017 NASA astronaut candidates with their field instructors during geology training in Arizona. Credit: NASA/Bill Stafford

Warren Hoburg conducts fieldwork during Earth and planetary science training in Rio Grande del Norte National Monument's upper Rio Grande Gorge area near Questa, N.M., in 2017. Hoburg was an astronaut candidate in 2017 and has since piloted a SpaceX vehicle as part of a NASA Commercial Crew and is part of the Artemis program. Credit: NASA/Norah Moran

2017 NASA astronaut candidates Kayla Barron (left) and Jessica Watkins (right) examine samples. Credit: NASA/Bill Stafford

Walking to the edge of Meteor Crater, David Kring wore hiking clothes, a day pack, and a wide-brimmed canvas hat. The look fit the traditional image of a field geologist scouring a unique landscape. His earpiece and microphone didn't quite fit the image, but they allowed him to communicate with his support team at Mission Control while keeping his hands free to swing a rock hammer.

Meteor Crater, lying just west of Winslow, Ariz., is possibly the best preserved impact crater on Earth. During a warm week in September, Kring took advantage of its similarity to the craters of the Moon. Over the course of 2 days, he played astronaut to give two groups of graduate students and postdoctoral researchers a sense of what's involved in extraterrestrial fieldwork.

> "If the students in the science operations center work with the astronaut correctly, then some really great science can come out of that."

Kring, a planetary scientist at the Lunar and Planetary Institute in Houston, is a veteran field geologist who specializes in impact craters. Among other discoveries, he helped link the Chicxulub crater in Mexico to the apocalyptic collision that killed off nonavian dinosaurs.

The students, who video conferenced in remotely from their homes and offices all over the world, were tasked with directing Kring's traverse. They were armed with satellite images of the area, along with a list of tools he was carrying, a digital elevation model, and a slope map. A NASA technician followed Kring with a camera, streaming video to the students.

"It was like a third-person video game, watching him walk through this terrain," said Hunter Vannier, a fourth-year planetary science Ph.D. candidate at Purdue University in Indiana who studies volcanism on the Moon. He hopes one day to play a role in lunar exploration, and participating in the first of Kring's two traverses was a step in that direction.

The mock extravehicular activity (EVA) course is just one of several trainings Kring has developed over the past 15 years in anticipation of NASA's return to the Moon. Kring's program supported the short-lived Constellation crew's flight program, as well as its successor, Artemis.

Artemis astronauts will be the first to walk on the Moon since 1972, with a crew expected to touch down as early as 2026. After the half-century hiatus from the lunar surface, researchers, astronauts, and flight engineers are relearning how to explore in the field beyond Earth.

Kring is helping to prepare the next generation of planetary scientists to support crewed missions to the Moon and, one day, to Mars. Handling the Meteor Crater EVA, where the moonwalk is simulated but the geology is real, will get them started. "If the students in the science operations center work with the astronaut correctly, then some really great science can come out of that," Kring said.

ARMCHAIR EXPLORATION

Many of the Meteor Crater EVA students had trained in the field as part of their formal education, but extraterrestrial fieldwork requires a unique skill set not usually taught at university field camps.

Not only must the scientists know how to map and catalog the geology of a landscape by probing, scratching, and occasionally smashing parts of it and making off with the pieces; they also must be able to direct someone else—an astronaut—to do it for them. And they'll have to do it by committee.

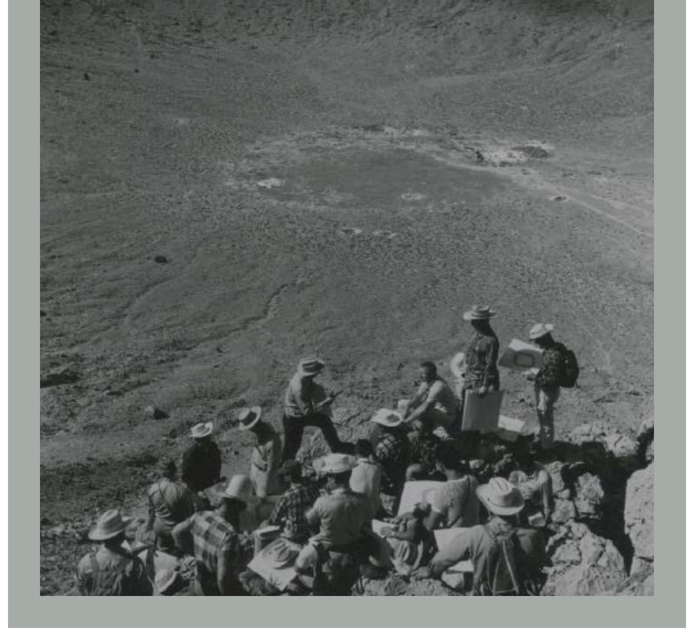
David Kring (right) works with graduate students at his Field Training and Research Program at Meteor Crater in 2011. Credit: David Kring

Rather than having students all chiming in with instructions, Kring's communication system allowed him to hear only one person: the SciCom, in operational parlance. In this case, the role was played by NASA planetary scientist Debra Needham, patched in from Washington, D.C.

The students decided on a course of action for Kring, then typed it into a Discord chat for Needham, who relayed the request to Kring. (Discord is an instant messaging and VoIP social platform.)

Christina Verhagen, a postdoctoral researcher at Michigan Technological University who studies how impact events can make a planetary surface more habitable, logged on from a beanbag chair in her basement while a sitter watched her toddler upstairs. Verhagen was hoping Kring could sample the smaller craters that dot the plain surrounding Meteor Crater, to see whether the rocks there also showed signs of the heat and shock pressures created when a 30- to 50-meter-wide iron asteroid slammed into Earth around 50,000 years ago.

Once Kring's feed came up, he described the landscape from his landing site, then took a "contingency sample" from the area near his feet—a consolation prize in case the rest of the mission had to be scrapped. Then the clock started on his field trip. He had 4 hours—the remainder of his make-believe oxygen and coolant supplies.



Gene Shoemaker (gesturing with a rock hammer) gives a geology lesson to a group of astronauts-in-training at Meteor Crater in the 1960s. Credit: USGS

"Houston, EV1," he said into his headset, using his designated call sign. "Standing by for traverse instructions."

IN THE FOOTSTEPS OF APOLLO

More than 50 years ago, Apollo astronauts trained at Meteor Crater, too, learning to sample rocks and trying out their Moon buggies on a nearby lava flow. Those outings taught astronauts, most of whom were trained as test pilots, the basics of making scientific observations in the field.

Their teachers were all "bona fide" field geologists, Kring said; the legendary pioneer of astrogeology Gene Shoemaker, who helmed the astronauts' geological education, had mapped Meteor Crater itself. The instructors all had rigorous careers studying rocks on Earth, and they were learning on the fly how to take the enterprise elsewhere.

"There was no planetary science," Kring said, until humans sallied forth into the cosmos to collect samples and firsthand observations. "Apollo created the need for a field of planetary geology and planetary science."

Later, after the last crewed Moon landing, the field became all about remote observations made by robots and orbiting instruments.

"Rather than, you know, hiking through the dirt and stubbing your toe on rocks," Kring said, "you suddenly had people simply looking at pictures or looking at spectra of a surface, and that drew talent from other fields." Writing code and handling large amounts of data became key skills. Physicists and astronomers came into the fold, as did atmospheric scientists who studied the spectroscopic makeup of distant bodies.

FIELDWORK FOR ACADEMICS AND ASTRONAUTS

Kring's trainings are meant to help recenter geological field expertise within the planetary science community. In addition to the mock moonwalk, the trainings include an intensive course on spaceflight operations at NASA's Johnson Space Center in Houston and an 8-day field camp at Meteor Crater or another lunar-analogue site. Hundreds of students from across disciplines have participated in the trainings since Kring began the program in 2008, and several have gone on to work for NASA.

> "It takes years to learn a language, and we consider geology something of a language here."

Kring offers similar courses to the new generation of astronauts, who must learn not only to conduct fieldwork but also to act as an extension of the collective will of a roomful of researchers back in Houston. Because the science team at Mission Control will be able to see only so much through remote cameras, the astronauts must learn how to describe what they're seeing in a running commentary that's rich with scientific information.

"It takes years to learn a language, and we consider geology something of a language here," said Cynthia Evans, a field scientist at Johnson Space Center.

Evans directs NASA's multiyear Artemis geology training program. It involves a traditional "field camp" where astronauts learn how to make geological observations and collect samples (often intersecting with Kring's trainings, which are conducted through the Lunar and Planetary Institute), as well as mock exercises designed to give astronauts practice doing fieldwork with the equipment they'll use on a real mission.

The program is developing basic geology courses for operational managers and engineers, who may not have a background in geology, so they can develop an appreciation for the scientific goals and challenges of the Artemis program.

Wishing to give astronauts a unique look at the Moon's layered rocks, mission planners might prepare to send astronauts into underground lava tubes, for example. But basic geological training would help them realize that lava coats the inside of those tubes as it flows through them and cools, obscuring the layers from view. An engineer may suggest sending astronauts out with expensive instruments to identify rocks, but a bit of field training would show them that most rocks can be identified by sight or brought back for further study in a lab.

Evans pointed out that it's a two-way street, with scientists also learning about the operational constraints of conducting fieldwork in an airless environment almost 400,000 kilometers from home. "There's just a lot of logistics involved in putting one step ahead of the next," she said.

"It's humbling."

Meteor Crater, in Arizona, played the part of the Moon in a recent exercise simulating moonwalks for students and early-career planetary scientists. Credit: National Map Seamless Server

SEEING THE BIG PICTURE

As Kring set out on his second mock EVA, some of his students got a small taste of that humility right away.

"We actually had a bit of a challenge finding him," Verhagen said. There are no lunar satellites to guide a GPS, and a compass is useless in the Moon's spotty magnetic fields, so Kring carried neither. The team asked him to walk toward a nearby outcrop to give them a known starting place for his traverse, but they got turned around on the way.

At times, Kring stood still while they deliberated, waiting for instructions. In his debriefing afterward, he advised the students to keep the astronaut moving because time is so precious, and it will be a long time, if ever, before anyone can return to a given site. "Traverses are linear," he said. "If you do not capture it then, it is forever lost."

That time constraint was novel to Vannier, who noted that he can take as long as he wants gleaning observations from orbital imagery. With a crew of astronauts putting their lives on the line for science, a support team can't afford to waffle about which samples to take.

"Decisions need to be made much faster than planetary scientists are used to," Vannier said.

That means science support teams need to be well versed both in what astronauts are describing to them and in the challenges the crew is facing.

Before studying as a postdoc with Kring, most of Amy Fagan's field experience was in the verdant mountains of western Virginia, and she hadn't yet considered how challenging fieldwork can be at a site like Meteor Crater. "It's a fairly small impact crater," said Fagan, who is now an associate professor of geology at Western Carolina University, "but you stand on the rim and it's huge, and imagining trying to get down to the bottom is very difficult. And it's certainly not anything you would want your crew to do." (Meteor Crater is a little more than 1 kilometer from rim to rim—some craters on the Moon are hundreds of kilometers wide.)

The experience also placed the Apollo samples she'd been analyzing in the lab into an entirely new context. She could see how the rocks were formed and why they ended up where they did. Being there, she could visualize the complete story of a meteor impact for the first time.

Kring talks about this kind of moment in a crescendo of zealous excitement. "Field geology is when you go into a mountain range and you find a 100-meter-thick sliver of ultramafic rock and you realize, 'Oh, my God, I'm looking at the ocean floor that's been obducted onto the continent,'" he said. "It's a completely different level of vision; three-dimensional vision and fourth dimensional, in terms of time."

The art of field science is often about noticing patterns or things that stand out, even if you don't yet know why they might be important.

To illustrate this, Kring often tells his students the story of Seatbelt Rock. During the 1971 Apollo 15 mission, astronauts David Scott and James Irwin had just wrapped up an EVA and were driving their rover back to the lander. Scott spotted a vesicular, low-titanium and olivine-bearing piece of basalt that looked different from everything else around it. Knowing that Mission Control might not approve a detour, he pretended to have trouble with his seatbelt. While he and Irwin were "sorting it out," Scott dashed over to collect the rock.

And beyond understanding what scientists expect them to find on the Moon, astronauts must also prepare for those expectations to be completely wrong.

Apollo 16, which landed on the Moon in 1972, said Kring, was a perfect example. The geologists back on Earth said, "'You're going to land and there's going to be two volcanic terrains there.' John Young and Charlie Duke landed, and they said—cryptically, because they knew they were on an open mic and the world was listening—'Houston, there's no volcanic rocks here.' It was 100% impact crater terrain."

HUMAN LIMITS

After Kring got sidetracked on his EVA, the student science team pushed him toward the main crater to make up time. He started to sweat. He reminded them that he was using up more of his imaginary space suit's coolant. As he worked his muscles harder, he was also burning through more of his oxygen supply. And the terrain itself was getting dicey. Knowing the slope of a crater wall is one thing, Kring said later; actually climbing down it is another. As he approached the crater rim, he advised the team that it didn't look safe for him to keep going.

The trick is to "maximize the unexpected."

The exercise was eye-opening for Vannier. Though he's done fieldwork in Iceland and Hawai'i, he hadn't developed an appreciation for the challenges of moving around a landscape like the ones he studies in orbital images of the Moon. "I can't get nearly enough fine-resolution detail from just remote sensing data to allow me to have an appreciation of how difficult this is," he said.

As time ticked by, Kring began to worry about his remaining life support. "I can't see my lander," he told the team. As they discussed their next move, he said it again.

For Verhagen, the concern in Kring's voice, however simulated, invoked memories of narrowly escaping lightning storms or getting lost while conducting her own terrestrial research. The danger on a lunar mission will be incomparably greater, but so will the reward, and the potential thrill of being surprised when an astronaut describes—and brings back—something truly new. Rather than be a setback, Verhagen said, surprises can open up new paths, and new discoveries. That's the nature of fieldwork. The trick, she said, is to "maximize the unexpected."

Though the second team managed to get Kring back to his "lander" before his "oxygen" ran out, he didn't have time to properly sample much of the area. What they needed to do from the outset, Kring said, was to direct him to head straight for the crater in a radial line, along the way collecting from every rock type that was excavated by the meteor's collision with the surface. By eating up time getting oriented, the students lost their chance to capture a complete picture of the impact event.

But the samples themselves weren't the goal of this particular mission. "It also made it evident to most of the students that if they wanted to proceed down this path, if this is an area of science and exploration that they want to participate in, [then] they have some learning to do," Kring said. "In that sense, it was a home run."

AUTHOR INFORMATION

Mark Betancourt (@markbetancourt), Science Writer

Read the article at Eos.org

ENGAGE with *Eos*!

Eos

Connecting students to the latest geoscience research can be cumbersome, but *Eos* makes it easy with ENGAGE (*Eos* News: Geoscience and Global Events). During this webinar, educators will learn about ENGAGE, identify and review articles that fit their curricula, and develop effective methodologies for integrating the articles into their instruction.

6 JUNE 2024
6 pm Eastern (3 pm Pacific

Register for free at bit.ly/ENGAGEwebinar
Visit **Eos.org/ENGAGE**