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NASA's Opportunity Rover Hits 5,000 Sols on Mars *by Alan Fischer*

PSI Senior Scientist R. Aileen Yingst was in the driver's seat Feb. 15, 2018, directing the science activities for NASA's Opportunity Rover as it spent its 5,000th day exploring the Martian surface. Aileen served as Science Operations Working Group chairperson running the group that decided what the rover did that sol, or Martian Day.

The rover's mission has far exceeded the 90 sols for which it was initially scheduled when it landed on Mars Jan. 25, 2004. A Martian "sol" lasts about 40 minutes longer than an Earth day, and a Martian year lasts nearly two Earth years.

"Five thousand sols after the start of our 90-sol mission, this amazing rover is still showing us surprises on Mars," said Opportunity Project Manager John Callas, of NASA's Jet Propulsion Laboratory, Pasadena, Calif.

Aileen said she never imagined the rover would continue to function this long. "Absolutely not, but not because I lacked faith in the engineering. Simply put, rocket science is difficult and risky. Principal Investigator Steve Squyres compared working on a rover to doing geology with a sniper over your shoulder," she said.

"There's no landed mission that compares to NASA's Mars Exploration Rover (MER) program's longevity and resilience, and that's due to the people who work so hard and give up their weekends and off-hours to solve the unsolvable and work around the unworkable," said Aileen, who has worked on MER since 2006.

"I headed up the science planning for what Opportunity did during sol 5,000," said Aileen, who is an Associate Principal Investigator for the rover. "The rover got a nice selfie shot to mark the day. We also imaged a channel in which the rover has been driving. It's another day at the office, but the office is millions of miles away. Science on Mars is always special, amazing, incredible, and different."

Rover on Mars takes a selfie on sol (day) 5,000. *Credit NASA/JPL-Caltech/Univ. of Arizona*

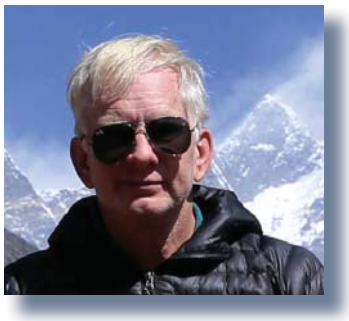
Opportunity has driven more than 28 miles (45 kilometers) from its landing site to its current location about one-third of the way down "Perseverance Valley," a shallow channel cutting from the crest of the crater rim down its inside slope. The rover has returned more than 225,000 images, which may be viewed at https://mars.nasa.gov/mer/gallery/all/opportunity.html

The long-lived rover continues to offer new insights on Mars, including the recent discovery of what are believed to be rock stripes. On some slopes within the Perseverance Valley where the rover is now located, the soil and gravel particles appear to have become organized into narrow rows or corrugations, parallel to the slope, alternating between rows with more gravel and rows with less. The pattern resembles a smudged version of very distinctive stone stripes on some mountain slopes on Earth that result from repeated cycles of freezing and thawing of wet soil. But it might also be due to wind, downhill transport, other processes, or a combination.

Aileen said that Opportunity has seen a broad spectrum of scientific successes. "There isn't just one thing. I think the coolest part is the mission itself — the fact that I wake up every morning and go to work on Mars like it's a normal thing to do. It's crazy amazing that it's that way, but it also should be that way, because humans are capable of it. We stretch the limits of possibility every day, and that's something that our species can be proud of."

Inside this issue:

Jeffrey Kargel, Ice Man

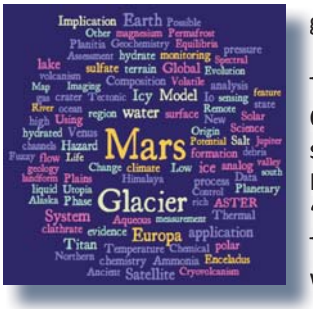


Jeff Kargel, with the Himalayan mountain Lhotse in the background. Lhotse, the fourth highest mountain in the world at 8,516 meters (27,940 ft), is on the border between Nepal and Tibet.

Jeffrey Kargel, a new PSI Senior Scientist, has Bachelor of Science and Master of Science degrees in geological sciences (Ohio State University) and a doctorate in Planetary Sciences (University of Arizona).

Having about 500 scientific articles to his name (over 150 peer reviewed) Jeff has contributed to the understanding of volcanism on Venus and Io, the global composition of Earth, the potential resources of asteroids, glaciers on Mars and Earth, and ices in the outer Solar System. Whereas some of his work pertains to whole-planet geochemistry, most of Jeff's work orients around ice. His current work includes high mountain hazard processes and basic cryospheric science of the High Mountain Asia region, where Jeff has undertaken many field expeditions from the area of Everest, Annapurna, and Makalu, down to the jungles of the Gangetic Plain. Dodging avalanches (by luck) and focusing lately on earthquakes and landslides, his Himalayan world is one of tectonic and erosional turmoil of an active planet.

Jeff's childhood scientific roots were Devonian marine fossils and the Apollo lunar explorations during elementary school. Thus began his interests in geology and planetary science. His family became hosts to over a hundred students and postdocs from Ohio State University, bringing the world into his childhood home. His family's guests included many from India and other Asian as well as African and South American countries, but it was Asia, including the Himalayan region, that was most represented by these foreign emissaries of exotic cultures and dramatic physiographies. The Himalaya again became a key development in Jeff's future career as an undergraduate student.



A word cloud of Jeff's research drawn from titles of his peer-reviewed papers.

Three weeks into Geology 121 at Ohio State, professor Gunter Faure showed a slide of folded rocks in the Himalaya, and Jeff had an epiphany: "Geologists go to amazing places. That's my career choice." And so it was, with 20 seconds' reflection on one slide. Finding mentorship in a geochemist, Ken Foland, and later Vic Baker and Bob Strom in planetary sciences, Jeff found freedom in academia. A month after settling on geology as a career choice and finding geological intrigue in Asian mountains, he met his bride-to-be, now Bay Kargel.

As a Ph.D. student, Jeff was taking a break from his dissertation on cryomagmatism in the outer Solar System and came across a singularly instructive Viking Orbiter image of Mars, showing what at first looked like a spectacular braided channel system. After a second look, it emerged that the features were inverted ridges rather than channels, a finding that led Jeff to consider these features as possible eskers, which are subglacial deposits of sand, gravel, and boulders. That began Jeff's examination of glaciation as a possible contributor to Martian geological and surface evolution. He self-educated on glaciers and glacial landscapes on Earth, hauling his young family to mosquito-ridden places in Canada and Minnesota. Before long, Jeff was directing a 30-nation, 200-researcher consortium called Global Land Ice Measurements from Space, at first from the U.S. Geological Survey's Astrogeology Team, then back at the University of Arizona. Glaciological research led straight to applied research on glacier avalanches, glacial lake outburst floods, and landslides.

Now Jeff's work ranges from studies aimed toward lowering glacial lakes to mitigate against outburst floods to studying Martian oceans and hydrocarbon lakes on Titan with fellow PSI scientists including Alexis Rodriguez and Sugata Tan. Earth analogs of extraterrestrial landscapes and low temperature aqueous and hydrocarbon geochemistry are key areas of work, but Jeff retains an avid interest in applying remote sensing and field studies to helping some of the most vulnerable people in one of the most naturally dangerous places on Earth—villagers in remote places of the Himalaya.

This April in Nepal, Jeff was honored by the Nepal Geographical Society with an Honorary Life Membership "In grateful recognition of distinguished contributions to the mission and activities of the Nepal Geographical Society." It was based on his work on Himalayan natural hazards and geomorphology. Some of that work was of an applied science and humanitarian-science nature, including his response to the 2015 earthquake in Nepal, research that led to the lowering of Imja Lake to reduce its hazard, and several other natural disaster events or hazards. He also works on the basic science examination of lake accelerated melting of glaciers, the mass balance of Himalayan glaciers, and the role of lithology and bedrock geology in controlling landslides.

Jeff was awarded the Nepal National Geographical Society Honorary Life Membership in April 2018.

Photos: Jeff Kargel

As he starts work at PSI, he is emboldened to continue his Earthly work by PSI Director Mark Sykes, who assures Jeff that "Earth is a planet. But, Pluto? Some people aren't sure."

However, PSI *is* sure that we are very glad to have Jeff aboard!

(See Jeff's front page story "Mystery Solved for Mega-Avalanches in Tibet, and perhaps on Mars" in the Spring 2018 issue of the PSI Newsletter.)

Getting to Know Catherine Neish

Catherine Neish joined PSI as a Research Scientist in June 2016. She also works as an Assistant Professor of Earth Sciences at the University of Western Ontario.

Catherine hiking Mt. Whitney in the Sierra Nevadas in 2008.

Catherine is originally from Canada, growing up on Agricultural Research Farms all over the country as she followed her father from site to site. She spent time in Ontario, Alberta, and Saskatchewan before finally settling in British Columbia, where she completed high school and university. An avid fan of The X-Files, she spent many days in Vancouver looking for the former filming locations of that television show.

Catherine as an undergraduate research intern at Arecibo, Puerto Rico, in 2003.

In 1997, Catherine read Carl Sagan's "Contact," and saw the movie of the same name. She was inspired to pursue radio astronomy, and was thrilled to be accepted to Arecibo Observatory's 2003 Research Experience for Undergraduates (REU) program. There, she discovered radar astronomy for the first time. After years of passively observing the universe, she was delighted to discover that humans had the ability to use a radio flashlight a kilometer in diameter to observe asteroids, comets, planets, and moons throughout the Solar System.

Her mentor at Arecibo encouraged Catherine to apply to the University of Arizona for graduate school. She was accepted in 2004, and arrived in Tucson shortly after Cassini arrived at Saturn. When the first images of Titan were beamed back to Earth, she was hooked. Catherine spent the next four years using Cassini RADAR images to understand impact cratering and volcanism on Titan. She also spent time in the mass spectrometry facility in the Department of Chemistry, creating prebiotic molecules under Titan analogue conditions. She would be ecstatic to find an amino acid (or two!) on Titan with the proposed New Frontiers mission Dragonfly, recently selected for Phase A funding.

After completing her Ph.D. in December 2008, Catherine moved to the Applied Physics Lab in Maryland to pursue her radar love on another world, the Moon. As a postdoctoral fellow, she was one of a small team of scientists and engineers working to operate and interpret the data from the Mini-RF instrument on the Lunar Reconnaissance Orbiter. She continued her work at NASA Goddard Space Flight Center before accepting a faculty position at the Florida Institute of Technology. Located on the "space coast," Catherine and her family watched rocket launches from their front porch on a regular basis.

In 2015, life took Catherine back to Ontario to join the Centre for Planetary Science and Exploration at Western. She lives in London, Ontario, with her husband and daughter. Aside from Titan, the Earth is her favorite planet, and she enjoys exploring the world with her family and students. In the past three years, she has conducted field work in Idaho, Iceland, and the Canadian High Arctic. Although she did not realize it as a freshman astrophysics major, it turns out she is a geologist at heart.

Preparing for field work in the Canadian High Arctic in Resolute Bay, Nunavut, in 2016.

Photos: Catherine Neish.

Catherine has been a wonderful addition to PSI!

Catherine is a co-author on a paper about the newly named Elisabetta "Betty" Pierazzo crater entitled, "Lobate impact melt flow within the extended ejecta blanket of Pierazzo crater." See PSI Staff News on page 5 for an article and photos.

Front page banner: Total eclipse of the moon setting behind Picacho Peak, Arizona, taken shortly before sunrise on the morning of January 31, 2018. *Photo by Gil Esquerdo.*

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Chris Holmberg, Editor, Writer, Photographer
Alan Fischer, Writer and Photographer
Special thanks to Dianne Janis, Carol Neese, and Elaine Owens.

Introducing Norbert Schörghofer

Norbert Schörghofer presenting at a workshop.

I grew up on a small farm in the Austrian Alps, and unlike most people in my village, I attended high school. And though I did lack access to books back then, I did have an unbeatable upbringing in a quiet and stable environment where perhaps only two cars per day passed our house. A farm in the Austrian Alps has just about what you might suspect: cows, chickens, cats, a horse, a pig, and a dog.

In 1990, I moved to Vienna to study physics, and I attended as many lectures as would fit in a day. The difference between my home village and Vienna was greater than that between Vienna and any place in the U.S. I lived in thereafter. Sometimes I think I am still traumatized by that move. The availability of almost everything was quite a change for me.

My first trip to the United States was for a student exchange year at the University of California, Berkeley. The return to Vienna to finish my master's degree, awarded in 1995, was followed by graduate school at the University of Chicago, where I worked in Leo Kadanoff's group. Kadanoff was a giant in theoretical physics and he encouraged his students to work in new fields. I owe my entire career to him.

In Chicago, I worked on complex systems and fluid dynamics, but had always wanted to apply these fields to study the environment. This soon led to a transition to geophysics, as a postdoc at the Massachusetts Institute of Technology (MIT) working with Daniel Rothman. From 2000-2002, at the Department of Earth, Atmospheric and Planetary Sciences (EAPS) building at MIT (the tall building with one ball on top), it was clear that Mars exploration was a promising field. Mars Global Surveyor was in orbit and more missions would follow soon. I moved with Oded Aharonson (also now at PSI), whom I met at MIT, to Caltech where we started various projects related to ice and present-day surface processes on Mars. I wrote few papers during my two years at Caltech, but they turned out to be my most influential ones (so far). We took the time to think through various aspects of ice on Mars, and that turned out to be a timely and forward-looking topic.

Although I had never visited Hawaii, I knew I would love it. The move to Hawaii was tied to Karen Meech's new astrobiology group. One of my long-term goals was to develop a theory of ice ages on Mars, just as Milankovitch and others had done for Earth about a century earlier. Well, I am still working on that. The University of Hawaii has a large planetary group dedicated to asteroids, comets, and the Moon, so in part I worked on these subjects, trying to understand why there is ice in some unexpected places and not others. Project after project, I find that ice is everywhere it could be, one just has to crunch the numbers correctly.

By chance I heard about the existence of perennial ice on Hawaii's tallest volcanoes, which led to the bizarre situation of a theoretical physicist conducting fieldwork. I had previously participated in several geology field trips, but never led a field study of my own. But, I realized if I didn't study these interesting places, nobody else would. Five years later, I had—with substantial help from others—conducted the first ever geophysical survey of permafrost in Hawaii, discovered a record low temperature extreme in Hawaii (-20° Celsius), and co-authored the first scientific study of an ice-filled cave in Hawaii, places almost no one knew existed. I am here to tell you that these fairy tale-like places really exist, and I am slowly starting to understand why.

Norbert climbing a cinder cone to study Hawaii's largest permafrost body.

Nevertheless, most of what I do is scientific modeling. Thankfully, the fieldwork pulls me away from the computer once in a while, reducing my chance of acquiring carpal-tunnel syndrome. Right now, I am trying to find out how liquid water could form on Mars, using models of temperatures in the alcoves of Martian gullies that by now have grown rather complex and computationally powerful. To me, the challenge of scientific computing is to not get distracted by scientific computing, so one can stay focused on the science goal.

The obvious but nonetheless great advantage to computer work is that it can be done anywhere. Since my research does not require a laboratory or any observational facility, a switch to PSI seemed natural. PSI has created an online community that is scientifically stimulating. This pioneering approach to research is clearly the way of the future.

Norbert at the Makapu'u tide pools on Oahu, Hawaii. *(Photo credits: Norbert Schörghofer)*

I joined PSI in 2016 as a Senior Scientist, and I hope one day we will have enough PSI members in Hawaii to establish a permanent office on one of the islands. So, consider this an invitation to my PSI colleagues to come visit, and *stay*!

PSI is delighted to have Norbert on our staff!

Director's Note

You have to love "the little rover that could." The Opportunity Rover with a 90-day mission on Mars extends that to more than 14 years! It is a testimony to excellent engineering in this country, and the fact that it has gone through many extended mission reviews where a review board had to assess whether the cost of extending the mission for another year or two was worth the science being returned.

I have served on these kinds of boards and the case made must be compelling. Part of that compelling case is the excellent and unique science that has been and is being done by PSI scientists Aileen Yingst, Jim Rice, Cathy Weitz, Oded Aharanson, Eldar Noe Dobrea and their Opportunity colleagues, and their dedication to this project. This is how we maximize the return on investment in all of our NASA missions.

I have to give a shout out to JunoCam at Jupiter. It is managed by PSI Senior Scientist Candy Hansen and was designed to engage the public by letting them decide what pictures to take of the giant planet. It was not a priority instrument of the Juno mission. Juno was designed to investigate Jupiter's composition, magnetospheric environment, and interior structure. When thinking of how the Jupiter atmosphere looked from earlier missions, it frankly seemed kind of boring (sorry). However, the public processing of images returned from JunoCam has radically changed that perception. Jupiter is spectacular! It is beautiful (something I never thought I would say), and the detail of its atmospheric dynamics is fascinating.

The most fun and inspiring part of our business is when we are confronted with the unexpected. The returns from Opportunity on Mars and JunoCam at Jupiter provide continuing surprises and excitement —and great science.

Mark V. Sykes
June 2018

PSI Staff News

PSI Senior Scientist **Amara Graps** has been awarded the 2018 Europlanet Prize for Public Engagement with Planetary Science. This prize recognizes achievements in engaging European citizens with planetary science and raising the profile of outreach within the scientific community. "It is awarded to individuals or groups who have developed innovative practices in planetary science communication and whose efforts have significantly contributed to a wider public engagement with planetary science."

The prize will be presented in Berlin on September 16 at the European Planetary Science Congress where Amara will be giving a talk on her style of outreach.

PSI Education Specialist **Sanlyn Buxner** has had an asteroid named for her. Here is the official citation:

16702 Buxner

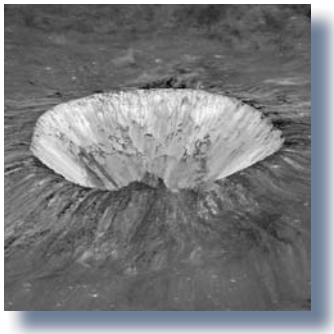
Discovered 1995 Feb. 24 by Spacewatch at Kitt Peak.

Sanlyn R. Buxner (b. 1978) is known for her work in space science education and public outreach, including curriculum development, teacher workshops, and program evaluation. Her focus is on how science research experiences empower teachers and students and improve their science understanding.

On April 21, 2018**,** while in Nepal doing fieldwork PSI Senior Scientist **Jeff Kargel** was honored by the Nepal Geographical Society with an Honorary Life Membership "In grateful recognition of distinguished contributions to the mission and activities of the Nepal Geographical Society!

(See page 2 for more information and a photo of Jeff receiving this award.)

Elisabetta "Betty" Pierazzo has been honored with an impact crater named for her on the Moon. She was an expert in the study of impact modeling throughout the Solar System, as well as an expert on the astrobiological and environmental effects of impacts on Earth and Mars. At the time of her death in 2011, Betty was a Senior Scientist at PSI.



The Elisabetta "Betty" Pierazzo Crater on the Moon.
Credit:NASA/GSFC/Arizona State University.

The 9.3-kilometer diameter crater is located on the far side of the Moon. Bright rays of ejected material extend more than 450 kilometers from the crater rim, suggesting that the crater was formed by a relatively recent impact event. Furthermore, new high-resolution images obtained from the Lunar Reconnaissance Orbiter (LRO) suggest that rocks melted by the impact event were thrown out as part of the ejecta around the crater, and launched tens of kilometers from its rim. The newly appointed "Pierazzo Crater" provides an important data point toward testing the various theories for how impact melt is emplaced.

Betty giving a talk about impacts in 2007. *Photo: Chris Holmberg*

This crater was the topic of a recent paper titled "Lobate impact melt flows within the extended ejecta blanket of Pierazzo crater" by Veronica Bray and co-authors, one of whom—PSI Research Scientist Catherine Neish—is profiled on page 3 (2018, Icarus 301, 26-36).

Congratulations to our scientists!

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Giant Cyclones Dot Jupiter's Poles *by Alan Fischer*

Large cyclones have been discovered clustered around Jupiter's poles by NASA's Juno spacecraft, a Nature paper reported in March. The circumpolar cyclones were discovered on Juno's first pass over Jupiter's poles, and subsequent data has revealed how remarkably stable they are. The circumpolar cyclones ring a single cyclone at each pole.

Using visible images from NASA's JunoCam camera headed by PSI Senior Scientist Candice "Candy" Hansen, and infrared images obtained by the spacecraft's Jovian Infrared Auroral Mapper (JIRAM), researchers found eight circumpolar cyclones arranged around a single Northern polar cyclone and five circumpolar cyclones encircling a Southern polar cyclone.

Candy is a co-author of "Clusters of Cyclones Encircling Jupiter's Poles" that appears in Nature. Alberto Adriani of Istituto di Astrofisica e Planetologia Spaziali in Rome, Italy, is lead author on the paper.

"Jupiter's circumpolar cyclones are unique; the polar regions are unlike any of the other gas giants," said Candy, JunoCam instrument lead and Juno Co-Investigator. "The circumpolar cyclones in the north are as big as the continental United States. The cyclones in the south are even larger, and they are surprisingly stable. They are identifiable from one close pass to the next, with a 53-day separation, and they are in a very stable configuration — no new ones have spun up, no old ones have dissipated," she said. Wind speeds measured 580 miles from the center of these giant storms range from 100 mph to 220 mph.

Candy's work on Juno is funded by a grant to PSI from NASA's Juno project, operated for NASA by CalTech/JPL.