Planetary Science Institute

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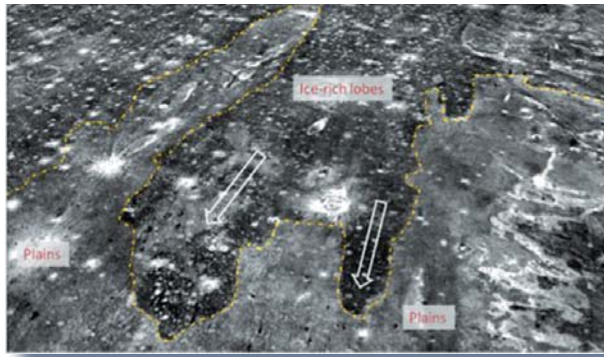
Possible Mega-tsunami Deposits on Mars Revive Ancient Ocean Hypothesis *By Alan Fischer*

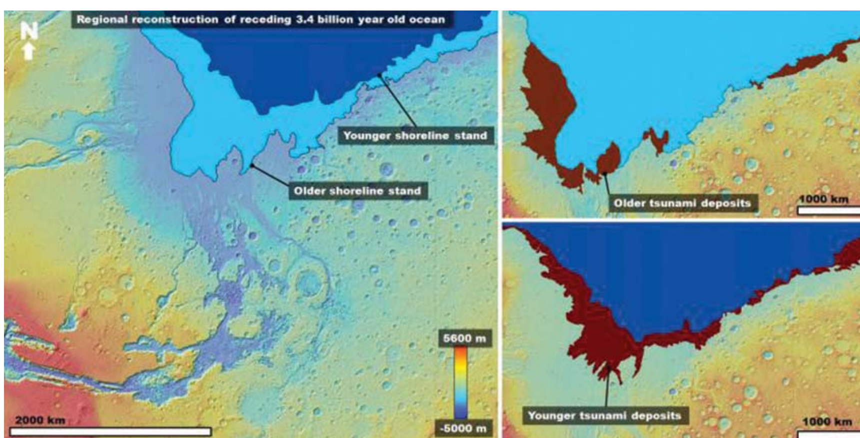
New geologic mapping in the northern plains on Mars reveals vast sedimentary deposits that were left by two mega-tsunamis, according to a new paper published this May in *Nature Scientific Reports* by PSI Senior Scientist, J. Alexis Palmero Rodriguez. The proposed tsunami events had onshore wave heights that likely reached as high as 120 meters (400 feet) and moved several hundred kilometers inland.



Thermal image showing ice-rich lobes, dark and outlined in yellow, believed to be remnants of tsunami waves that became slurry ice-rich flows that spread in extremely cold climate conditions. White arrows indicate flow going upslope. The lobe is about 250 km in length. Credit: NASA/JPL.

"For more than a quarter century, uncertainty in identifying shoreline features consistently distributed along a constant elevation has been regarded as inconsistent with the hypothesis that a vast ocean existed on Mars approximately 3.4 billion years ago. Our discovery offers a simple solution to this problem: widespread tsunami deposits distributed within a wide range of elevations likely characterize the shorelines of early Martian oceans," Alexis said.

"The tsunamis could have been triggered by meteor impacts, which about every 3 million years generated marine impact craters approximately 30 kilometers in diameter. Thus, the proposed tsunami events likely took place a few million years apart," said PSI Research Scientist and co-author Thomas Platz.



At left, a color-coded digital elevation model of the study area showing the two proposed shoreline levels of an early Mars ocean that existed circa 3.4 billion years ago. At right, the areas covered by the documented tsunami events extending from these shorelines. Credit: NASA/MOLA/MSS/JPL.

Mega-tsunamis also form on Earth and their deposits, too, show tremendous variability in their topographic distribution and inundation distances. However, these are extremely rare and catastrophic events. As a consequence, their deposits are mostly obscured – or removed – by younger resurfacing processes.

"During the period that separated the two tsunamis, the ocean level receded to form a lower shoreline and the climate became significantly colder. Evidence for climate change is reflected in the study of the tsunami deposits. The older tsunami emplaced enormous boulder-rich deposits and as the wave retreated back into the ocean it formed widespread backwash channels," Alexis said.

In contrast, the younger tsunami left lobes that are primarily made of water-ice, he said. Sampling of these materials by future landers is of particular scientific importance because they likely consist of frozen ancient ocean water brines. Furthermore, these materials are in relatively close proximity to the Mars Pathfinder landing site, demonstrating possible accessibility with current and tested technologies.

(continued on the back page)

Inside this issue:

Introducing Shawn Wright

Shawn Wright joined PSI in the summer of 2014 as a Research Scientist. Here, in his own words, is his biography:

After earning a PhD at Arizona State University in 2009, I worked for three years for the Institute of Meteoritics at the University of New Mexico as a Research Scientist. After that I taught freshman geology as a postdoctoral fellow at Auburn University in Alabama for three years. Currently I live in Houston, Texas, and have a visitor's badge to work at Johnson Space Center through a cooperative agreement between PSI and JSC Astronomical Research and Exploration Science (ARES).

Shawn Wright accepting congratulations from President Obama upon receiving his PhD at ASU.

I was an Air Force "brat," the son of a bank teller and an electrician. Due to my stepfather's profession, the family moved from east Texas to Ohio to Delaware to Panama City, Florida (where I attended high school) then onto west Texas where I attended college. As a child I liked reading books and math class. For four years of high school I spent after-school hours and Saturday mornings participating on the math competition team, for which I received one eighth-place Italian marble trophy. However, the practice of solving difficult math problems on the math team and in international baccalaureate courses came in handy when I achieved perfect scores on the math portions of the SAT and ACT exams.

As an only child, when told to play outside I did the only thing a lone child can do: throw a baseball against a fence, inadvertently strengthening my throwing arm, after several hundred thousand pitches! After high school I decided to attend junior college to play college baseball. Rather than be a math major I decided not to panic about not knowing what to do with my life and to take upper-level chemistry and physics courses that would serve as electives once a major was decided.

In the late 1990s while working for the Angelo State University Planetarium in San Angelo, Texas, and looking through a telescope, I decided that stars are too far away to study and that the upcoming (at the time) Mars Rover (MER) missions that would actively land on a planet was a more hands-on way to do science.

The revelation has come full circle and I am now a member of the MER Mineralogy/Chemistry theme group. After a week in my first geology course I wondered if the geologic histories of the Moon and Mars were as well known as Earth's and I transferred to Sul Ross State University in the Davis Mountains of southwest Texas to major in geology and play on the baseball team.

After graduating with a Bachelor of Science in Geology, I attended the University of Pittsburgh to work on a master's project regarding remote and sample thermal infrared data of Meteor Crater, Arizona. This spurred my interest in impact cratering and using thermal infrared as a compositional tool. I then studied shocked basaltic impactites from Lonar Crater, India, for my PhD dissertation at ASU. Alluding to those early college courses and majors before settling on geology, I like to say that I can now describe rocks "physically, chemically, and mathematically."

After several disappointing Mars Fundamental Research Program (MFRP) panel reviews, I caught a break when the same proposal submitted to the Planetary Geology and Geophysics program was graded as *Very Good* and *Selectable* in 2013, and was then funded in 2014. For the work I examine the agreement (or lack thereof) between field, sample, and remote data of altered and glassy basalts at Lonar Crater. From recent fieldwork in early 2016 funded by that grant, I made a few neat discoveries that I am submitting to *Geophyscial Research Letters*: shocked pre-impact soil in the impact breccia, and lightly-shocked spall (rock splinters) off of the ejecta blanket.

Shawn was a big Sun Devil baseball fan during his graduate school days at ASU.

When I stopped playing after 12 years in adult baseball leagues in Pittsburgh, Tempe, Albuquerque, and Auburn, I temporarily gained a few pounds so I joined a Houston-area league, playing centerfield, catching, and pitching, when my shoulder isn't aching. As a fast runner and a hard-throwing—yet wild—pitcher, I regularly lead the league in stolen bases and strikeouts, but have also hit batters, walked batters, and noticed opponents removing themselves from the batting order!

While I would like to play with puppies, kittens, and other pets for 30 minutes a day, I have no desire to feed, walk, entertain, pick up after, or generally be responsible for another organism, including plants, during the other 23.5 hours of the day. I spend most of my free time trying to make my girlfriend, Courtney, laugh and wondering how she puts up with me.

And now he makes his PSI colleagues laugh, too. Welcome to the Institute, Shawn!

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

Welcome, Sarah Sonnett

Sarah Sonnett joined PSI in November 2015 as an Associate Research Scientist, based in Huntington Beach, California. Since November 2013, she has been a NASA postdoctoral fellow at JPL.

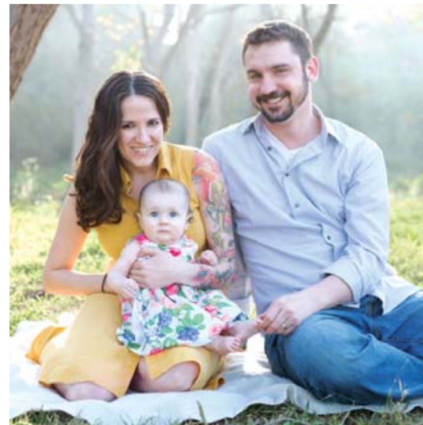
Sarah's science is all about asteroids and comets. She primarily uses rotational light curves of asteroids to determine physical properties (shape, spin rate, surface variegation, binarity), usually acquiring the data herself at the telescope. She tries to focus more on population studies instead of individual objects so she also does a fair bit of survey modeling and debiasing. She also has experience with spectroscopy of icy outer Solar System bodies analyzing water ice abundances. She is peripherally advancing her dissertation work, characterizing outer Solar System objects with seemingly (and unusually) fresh surfaces.

Sarah Sonnett at the Mayall 4-meter telescope on Kitt Peak, near Tucson.

She finished her PhD in August 2013 at the University of Hawaii's Institute for Astronomy in Honolulu. She earned a Bachelor of Science in Astronomy (with minors in math and music) from the College of Charleston in 2006.

Even though she specialized in small body science, what first interested her in astronomy was when she saw the Hubble Deep Field and wondered how many planetary systems could exist in that tiny portion of the sky. But watching the original Cosmos series as a teenager and having a supportive mentor in the physics department at the local college sure helped.

As a NEOWISE team member she primarily uses archival NEOWISE data to explore and compare shapes and binary fractions of various asteroid subpopulations. She is also conducting a multi-facility observational survey of candidate binary asteroids with the aim of confirming and characterizing binary systems in dynamically important groups (e.g., Jovian Trojans and Hildas). In support of the ongoing asteroid and comet discovery efforts made by the NEOWISE spacecraft, Sarah helps ensure new discoveries receive critical follow-up observations and helps with quality assessment of the new data. Sarah is also working on some simulations concerning the proposed NEOCam space mission.


Sarah with her husband and daughter.

Outside of astronomy, she spends most of her time with her husband and infant daughter, especially on trips and outings. Before her current position, she worked gigs as a musician and dancer so if she ever has free time she likes to spend it playing music or tap dancing. Sarah has also recently begun researching her family's genealogy (as if she didn't have enough research in her life) and making her own organic, baby-safe cleaning and skin care products!

We wish Sarah success with all her ventures and a hearty "Welcome to PSI!"

Front page banner: Crisp Crater in Sirenum Fossae region. This "recent" (geologically speaking) impact crater on Mars was captured by the High Resolution Imaging Science Experiment (HiRISE) camera aboard NASA's Mars Reconnaissance Orbiter on March 30, 2015. Signs that it is a fresh impact are its sharp rim and the well-preserved ejecta, the material thrown out of the crater when a meteorite hit Mars. The steep inner slopes are carved by gullies and include possible recurring slope lineae (known as RSL) on the equator-facing slopes. RSL could be a sign that water, its freezing point lowered by a high concentration of salt, could be seeping down these steep slopes. MRO has seen RSL appear in warmer seasons and disappear in cooler seasons in a few locations on Mars, indicating a planet with plenty of active processes. Credit: NASA/JPL-Caltech/University of Arizona.

PSI Scientists at Final MESSENGER Mission Science Team Meeting

In April, the MESSENGER Mission science team had its final meeting, concluding the mission to Mercury after the probe crashed into the planet's surface last April. MESSENGER orbited the closest planet to the Sun for four years.

Some of the PSI team members are pictured here, standing from left: Elizabeth Jensen, Maria Banks, Catherine Johnson, Karen Stockstill-Cahill, and Faith Villas; kneeling: Deborah Domingue Lorin. *(Photograph by Mark Kochte)*

Hartmann Cited in Book on Tucson's role in History of Planetary Science *by Chris Holmberg*

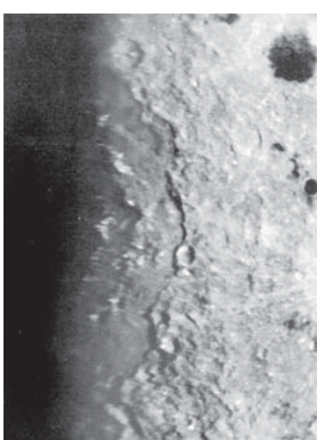
In March, the Arizona Daily Star ran an historical piece about Tucson's significant role in space exploration that included this photograph (below) of PSI co-founder, William K. Hartmann.

Photograph used on the cover of ***Under Desert Skies: How Tucson Mapped the Way to the Moon and Planets*** *by Melissa L. Sevigny (2016 UAPress) showing Bill Hartmann (ca. 1961) photographing Kuiper's half-globe. Image courtesy of William K. Hartmann and Ewen Whitaker.*

Asked about the picture from 1961, Bill explained: "When I arrived as a first year grad student at the University of Arizona, Gerard P. Kuiper* had set up a half globe on which we projected the best lunar photographs. My job was to photograph the globe from various directions, to show lunar formations "as seen from above" for the *Rectified Lunar Atlas* that Kuiper was creating in preparation for the Apollo flights.

"One day, when we projected a photo that had especially good coverage of the eastern edge of the moon, we saw some odd concentric arcs protruding from the far side of the moon as shown in the image below.

"Having read piles of lunar literature, I recognized that this must be part of a huge, hitherto unknown impact basin centered on



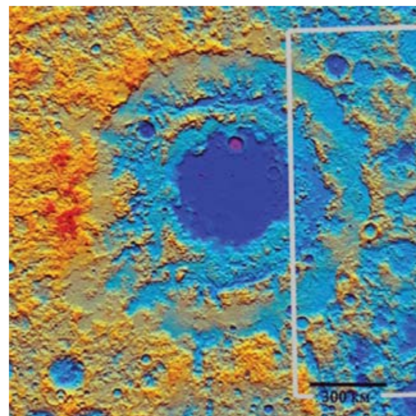
The best of Bill Hartmann's discovery images, showing the rings of the giant Orientale impact basin, as published in 1962.

Photograph by W.K. Hartmann as part of Lunar Rectified Atlas Project.

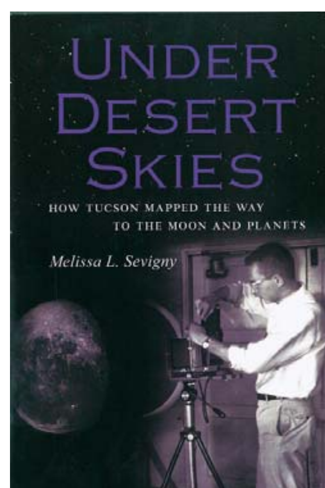
the far side of the moon. I took the pictures to Kuiper and he graciously let me be first author on our joint paper, marking discovery of the Orientale Basin, the first recognition in 1962 of the 1200-km wide, youngest multi-ring impact basin.

"Having recognized the Orientale features, we were able to show that other large lunar impact basins (like Imbrium) had very similar concentric ring systems that had not been fully recognized before, since they are mostly in a vestigial state."

Modern topographic maps from the Lunar Reconnaissance Orbiter show the whole basin in its full glory (see below). The existence of such large impact features helped open the door to modern understanding about the violent collisions that occurred during the formation and early history of planets. This led to the "PSI idea" by Bill and PSI's other co-founder Don Davis that the moon might have formed during a giant collision.



A 2010 topographic map, shows the entire Orientale basin system of concentric and radial fractures. The white box shows the part of the ring system that appears at left. The outer ring is about 1200 km across, 1/3 the size of the moon itself. Credit: Lunar Reconnaissance Orbiter Laser Altimeter Map



Under Desert Skies *tells the story of the U of A's Lunar and Planetary Laboratory and Tucson's amazing contributions to the nascent space program, beginning in 1960.*

**Gerard P. Kuiper was a Dutch-American astronomer whom many consider the father of modern planetary science. The Kuiper Belt was named for him.*

Director's Note

Mars has been intensely studied for decades. It has more orbiting and rover assets in operation than any other planet (except Earth, of course!). So, the discovery of evidence for past mega-tsunamis by PSI Senior Scientist Alexis Rodriguez is a wonderful demonstration that the book never closes on what there is yet to learn about Mars and, for that matter, everywhere else in the solar system.

In just the past few months, PSI scientists have discovered deep basins on Mars, fed by ground water in the ancient past, that could have harbored life. They have probed the subsurface of the dwarf planet Ceres and discovered subsurface water ice. They have found evidence that the eruption of lunar mare that we see from Earth, resulted in a shift in the rotational pole of the Moon. Small comets flying by the Earth were studied by PSI scientists and shown to have surfaces darker than asphalt—a clue to their composition and formation location. Using the Cassini spacecraft to probe the Enceladus plumes by watching spectral variations of star light as it passed behind them, our scientists gained detailed information about how those plumes are ejected and the amount of water ice grains escaping. They have also found evidence that Pluto may have a subsurface ocean that exists today.

Sometimes even seemingly arcane discoveries have remarkable implications. I have been trying to understand the importance of the discovery of a mineral on Mars that is related to silicic volcanism on Earth (think the explosive Mt. St. Helens) and have had conversations with PSI Senior Scientist Dave Vaniman, who is a co-author of the paper announcing this. I am not a geologist, but I have learned in these discussions that silicic volcanism is associated with a lot of volatiles in the magma that cause it to be explosive when it erupts. This is water.

On Earth, water is transported deep in the crust by plate tectonics. There is no plate tectonics on Mars, so what could have driven the silicic volcanism evidenced by this mineral? Impacts? There is evidence on Earth for a lower temperature process forming this mineral, which begins with acidic leaching away of some minerals, leaving quartz, which is subsequently metamorphosed. So, recalling that at some point in the history of Mars its shrinking oceans were acidic, could this alternative process be important?

In science, it is pretty typical that one question will spawn many more questions. For me, it is a never-ending learning process, and discussions like these remind me why I enjoy being in this business.

It is also good to share this with the public! Not just the details of what we learn, but to convey our excitement about the process of science, including ideas that are perhaps wacky and later tossed, but inspire us to move forward. We never stop learning!

Mark V. Sykes
June 2016

PSI Staff Awards

PSI CEO and Director **Mark V. Sykes** has received the 2016 Harold Masursky Award for Meritorious Service to Planetary Science. The Masursky award is presented by the American Astronomical Society Division for Planetary Sciences. The award was established by DPS to recognize and honor individuals who have rendered outstanding service to planetary science and exploration through engineering, managerial, programmatic or public service activities.

Examples of Mark's service to planetary sciences include authorship of NASA's first spacecraft data rights policy; providing groundwork for the first decadal survey for Solar System studies and organizing, editing, and publishing the first collection of community white papers on all aspects of planetary science, which is now a standard practice; establishing (and for nine years editing) the weekly Planetary Exploration Newsletter (PEN), which now has more than 3,000 subscribers; and successfully rallying astronomers around the world against an effort to build a development near Mt. Hopkins in Arizona that would have led to substantial light pollution near major telescope facilities.

Mark was a founding member of the NASA Small Bodies Assessment Group and served both on the steering committee and as chair. He has been a tireless advocate of planetary research and data analysis programs, fairness and integrity in the peer-review process, and NASA budget transparency. He has been an advocate in Congress for competed planetary missions and research.
Mark served the DPS in many capacities, including a term as Chair. He established the Division's Federal Relations subcommittee, began annual meetings between DPS leadership and NASA officials, and established regular outreach between DPS leadership and early career planetary scientists. Finally, over the past 12 years he greatly expanded the Tucson-based Planetary Science Institute, where he is the CEO and Director, to be the largest non-government employer of planetary scientists today and an organization nationally recognized for workplace efficiency and flexibility.

Congratulations on receiving this prestigious award, Mark!

In April, PSI Senior Scientist **Mary Bourke** was elected to Fellowship at Trinity College Dublin. Mary is an Earth and Planetary Geomorphologist with expertise in extreme environments on Earth and Mars. She has published more than 50 manuscripts on landscapes in Antarctica, Australia, Namibia, Mars, and Ireland. She is the Chair of the International Association of Geomorphologist's Working Group on Planetary Geomorphology; President of the Irish Geomorphology Group and serves on editorial advisory panels for the Journal of Aeolian Research, Earth Surface Processes and Landforms and the Journal of Earth Surface Dynamics.

Scholarship or research achievement of a high order is the primary qualification for Trinity College Dublin Fellowship, coupled with evidence of the candidate's contribution to the academic life of the College and an effective record in teaching. *Brava, Mary!*

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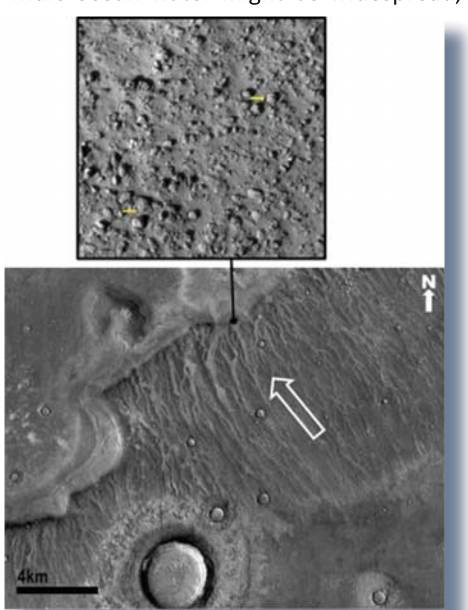
Possible Mega-tsunami Deposits on Mars Revive Ancient Ocean Hypothesis *(continued from front page)*

The vast areas covered by these ice-rich lobes imply that the frozen remnants of early Mars ocean water might be widespread, not just rare and localized occurrences. The fact that many of the lobes have well-defined boundaries and that their flow-related shapes are not significantly modified suggests that they might still retain much of the originally emplaced materials, which could be informative of the ocean's primary composition.



View of boulder-rich surface (yellow bars are 10 m) deposited by the older tsunami and then eroded by channels produced as the tsunami water returned to the ocean elevation level. *Credit upper image: NASA/JPL/UA. Lower image: NASA/JPL.*

In spite of the extremely cold and dry global climatic conditions, the early Martian ocean likely had a briny composition that allowed it to remain in liquid form for as long as several tens of millions of years. Subfreezing briny aqueous environments are known to be habitable environments on Earth, and consequently, some of the tsunami deposits might be prime astrobiological targets.

"Yet this large expanse of currently documented tsunami inundation is but a portion of what occurred along the margin of the Martian northern plains-filling ocean. Tsunami-related features along other parts of the ocean margin, and potentially other smaller former bodies of water, remain to be identified, mapped and studied in detail," said co-author Kenneth Tanaka of the U.S. Geological Survey.

"We have already identified some areas inundated by the tsunamis where the ponded water appears to have emplaced lake-specific sediments, including evaporites. As a follow-up investigation we plan to characterize these terrains and assess their potential for future robotic or human *in-situ* exploration," Alexis said.

Alexis and co-author Jianguo Yan of Wuhan University are currently planning an expedition to Tibet to investigate high mountain lakes, in which they have identified landforms that indicate extreme environmental conditions that are outstanding analogs to features identified within the possible tsunami-generated paleo lakes.