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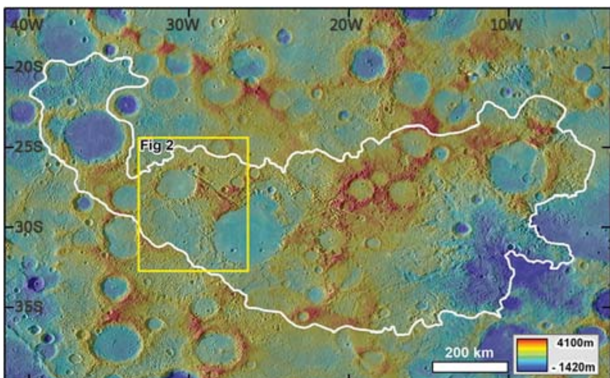
Mercury's Chaotic Terrain Hints At Volatile Past, Potential For Habitability

by Alan Fischer

New research raises the possibility that some parts of Mercury's subsurface, and those of similar planets in the galaxy, once could have been capable of fostering prebiotic chemistry, and perhaps even simple life forms, according to a paper by a team led by PSI Senior Scientist Alexis Rodriguez.



On Mercury, a vast chaotic terrain (white outline) opposite the Caloris basin on the other side of the planet.

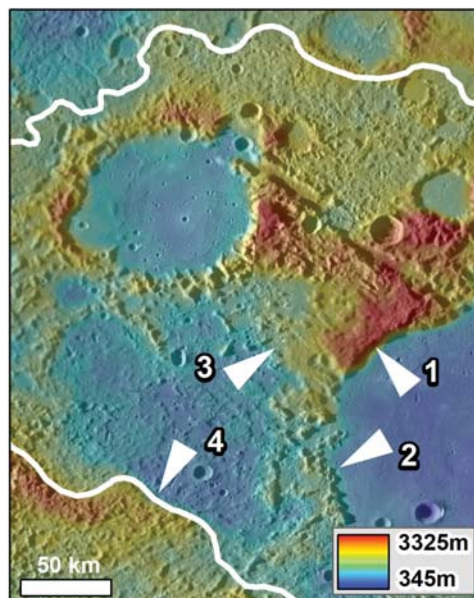
The chaotic terrains of Mercury consist of ancient cratered surfaces that exhibit widespread evidence of collapse which occurred in areas where buried volatile compounds — ones that vaporize when heated at low temperatures — turned to gas and escaped the region, the paper says.

"The findings mean that Mercury had, and might still have, a volatile-rich crust at this and at other similar locations on the planet. Water is one of the potential volatiles that we are considering to have formed part of the planet's volatile-rich crust," said Alexis, lead author of "The Chaotic Terrains of Mercury Reveal a History of Planetary Volatile Retention and Loss in the Innermost Solar System" which appears in *Nature Scientific Reports*. PSI scientists Jeff Kargel, Deborah Domingue, Daniel Berman, Maria Banks, Kevin Webster, and Mark Sykes are coauthors on the paper, written in collaboration with the University of Arizona, NASA Goddard, and the Southwestern Research Institute.

"Mercury's surface temperature reaches a scorching 430 degrees Celsius during the daytime, and in the absence of an atmosphere, it plummets to -180 degrees Celsius at night. So, its surface environments have rightfully been out of scientific consideration as a possible host of life. However, the paper raises the prospect that some subsurface regions of Mercury have shown capacity for hosting life," Alexis said.

"The deep valleys and enormous mountains that now characterize the chaotic terrains were once part of volatile-rich geologic deposits a few kilometers deep, and do not consist of ancient cratered surfaces that were seismically disturbed due to the formation of Mercury's Caloris impact basin on the opposite side of the planet, as some scientists had speculated," said coauthor Dan Berman. "A key to the discovery was the finding that the development of the chaotic terrains persisted until approximately 1.8 billion years ago, 2 billion years after the Caloris basin formed."

Continued on page 2



Close-up of yellow box area from image at left showing variable magnitudes of collapse, which includes a relatively unmodified rim section that is smooth but not broken into knobs (arrow 1). This area adjoins another part of the rim that has been almost entirely removed (arrow 2). The adjacent intercrater regions also exhibit deep and abrupt relief losses (arrows 3 & 4).

Credit: Gregory Leonard of the University of Arizona Department of Planetary Sciences

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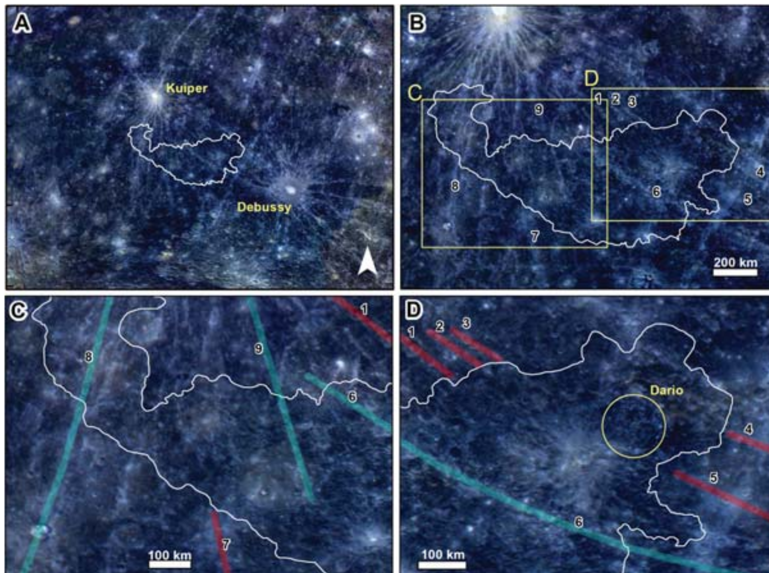
Mercury’s Chaotic Terrain Hints At Volatile Past, Potential for Habitability *(Continued from front page)*

“We identified multi-kilometer surface elevation losses within the chaotic terrains located at the Caloris basin’s antipode. This finding indicates that enormous volumes of crustal volatiles turned into gas and escaped the planet’s upper crust over a surface area slightly larger than that of California, approximately 500,000 square kilometers,” said coauthor Gregory Leonard of the University of Arizona Department of Planetary Sciences.

“Our investigation also shows that there are numerous extensive chaotic terrains in other regions of the planet, which have latitudinal distributions ranging from equatorial to subpolar. Hence, Mercury’s volatile-rich crust appears to be greater than regional, perhaps global, in extent, and it is most likely made up of compositionally diverse volatile compounds. The apparent compositional diversity suggests that the planet’s upper crust might effectively be comprised of a large number of compositional and thermal conditions, some perhaps habitable, existing in Mercury-like exoplanets,” Alexis said.



Context view showing the location and extent of the chaotic terrain (outlined in white) opposite the Caloris basin relative to the ejecta ray systems of the Kuiper and Debussy impact craters. (B) Close-up view of panel A that provides the context and locations for panels C and D. The numbers 1-9 identify individual rays within the region’s view. (C, D) Close-up view showing crater rays that extend over the chaotic terrain (green lines 6, 8, 9) and other crater rays that appear truncated over the chaotic terrain (red lines 1-5, 7). The location of the hollow hosting crater Dario is in panel C. ***Credit: Gregory Leonard of the University of Arizona Department of Planetary Sciences.***

“Vast lava fields formed soon after the development of the chaotic terrains, so volcanic heat could have destabilized and released the apparently vast volumes of crustal volatiles,” said coauthor Kevin Webster.

Coauthor Jeff Kargel said, “We also observe evidence of surficial devolatilization, probably caused by solar heating. If so, we have an opportunity to infer the range of Mercury’s volatile properties and compositions. A possibility is that Mercury’s volatile-rich crust was delivered via impacts from the frigid confines of the outer Solar System or the main asteroid belt. Alternatively, volatiles were outgassed from the interior.”

“While not all volatiles make for habitability, water ice can if temperatures are right. Some of Mercury’s other volatiles may have added to the characteristics of a former aqueous niche,” Jeff said. “Even if habitable conditions existed only briefly, relics of prebiotic chemistry or rudimentary life still might exist in the chaotic terrains.”

“Interestingly, we find that crater ejecta rays, which form some of Mercury’s youngest geologic deposits, appear absent from extensive areas of the chaotic terrain, which we interpret as a possible indication of very recent volatile losses,” said coauthor Deborah Domingue.

“Evidence of recent, and perhaps ongoing, volatile losses from within near-surface geologic materials on Mercury has been previously documented through the investigation of small depressions known as hollows, which kind of resemble melt pits in terrestrial permafrost,” Alexis said. “However, an unresolved issue remains in the age disparity between these hollows and their volatile-bearing geologic units, which are thought to be billions of years old. Our results suggest that some hollows might represent the locations where lavas or sublimation lags covering these ancient geologic materials underwent collapse. This is exciting because their distribution might highlight areas where we can effectively access volatile-rich material, that after billions of years existing in the subsurface, have been finally been exposed to the surface.”

Coauthor Mark Sykes said, “If these results are confirmed, this and other similar areas of collapse on Mercury could be important considerations for future landing sites to investigate the origin of the planet’s volatile-rich crust and, perhaps, even its astrobiological potential.”

Deborah Domingue’s work on this project was supported by a grant to PSI from NASA’s Solar System Workings program.

Frontpage banner: Dagze Co (Lake) is one of many inland lakes in Tibet. The Tibetan Plateau in glacial times was much wetter and the lakes were much larger. The icy rings that circle the lake are fossil shorelines, and attest to the historical presence of a larger, deeper lake. The image (of which we only used a portion for the banner) was acquired by the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) aboard NASA’s Terra satellite on October 8, 2001. *Image courtesy NASA/GSFC/MITI/ERSDAC/JAROS, and U.S./Japan ASTER Science Team*

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Alan Fischer, Writer and Photographer
Special thanks to Dianne Janis, Carol Neese, and Elaine Owens

Jeff Kargel's Climate Confession: "I Was Wrong" *by Alan Fischer*

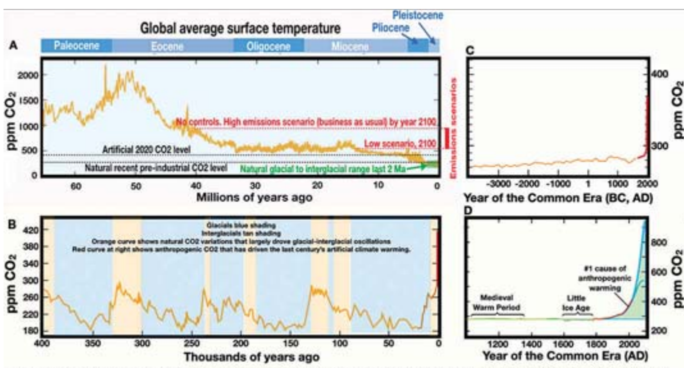
An article recently published in *GlacierHub* by PSI Senior Scientist Jeff Kargel told of how his earlier views on the impact of climate change on our weather underestimated the reality we are now seeing.

"The world is unprepared for the turmoil of further climate change and extreme weather," Jeff writes in "Climate Confession: I Was Wrong" that can be found at https://glacierhub.org/2020/02/11/climate-confession-i-was-wrong.

"I was not thinking about abruptly changing behaviors of the gigantic currents of the Earth's atmosphere and oceans. In 2005, I thought that climate change was gradual and readily manageable. I was wrong," Jeff wrote. "I didn't consider nonlinear effects— the tipping points— that climate change would have on individual components of the Earth system.

Fossils and artistic depiction of life during the subtropical Eocene climate of the Hancock Mammal Quarry (40 Ma) and Clarno Nut Beds (44 Ma) of John Day Fossil Beds National Monument (central Oregon). At that time, global climate had already begun cooling from the Eocene-Paleocene Climatic Optimum, when local conditions in Oregon were like today's Panama.

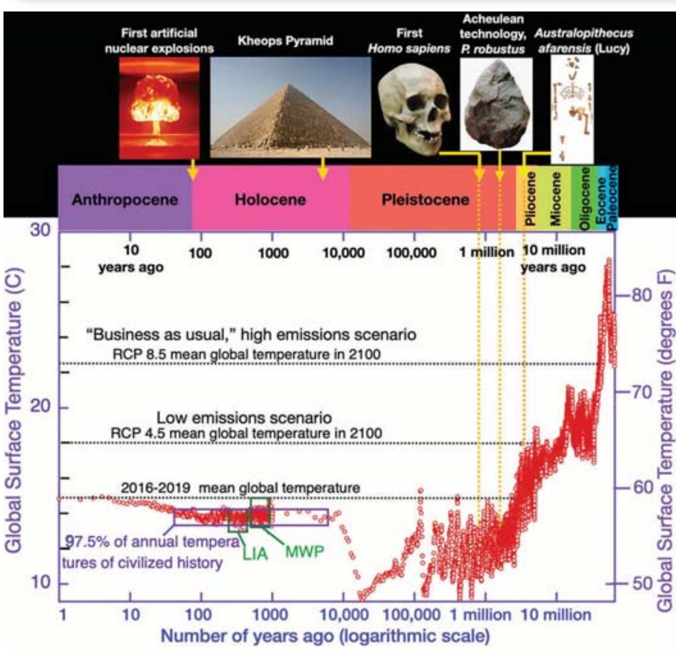
In follow-up comments, Jeff said that alarmingly, politicians are demanding to operate Planet Earth on naïve whims, ignoring expert guidance. With controlled emissions, climate near Eugene, Oregon., for instance, may become like today's Sacramento, California. Lacking controls, it will become subtropical by 2100 and approach the climate of today's Panama by 2150, as exemplified by Eocene fossils of John Day Fossil Beds National Monument, Oregon.



Carbon dioxide levels in the atmosphere during the past 65.5 million years (A after Hansen et al. 2013) and last 400,000 years (B) (after Petit et al. 1999 and Shakun et al. 2012); and during the last 6000 years of civilized human history, and since 1000 AD (D). Panel D also shows two widely considered high and low CO2 emissions scenarios (RCP 8.5 and RCP 4.5, in cyan) and marks the natural CO_2 changes that were partly responsible for the Little Ice Age and Medieval Warm Period.

Much of the world, including most of the southern U.S., Saudi Arabia, Indonesia, India, and Brazil will become uninhabitable with unrestrained combustion. Forty two million years ago greenhouse gases were as abundant as projected by 2100 with no emissions control; despite that, a natural 'hothouse Earth' had resplendent life up to ice-free poles.

Life has resilience but now lacks adaptation time. Will we exercise options to reduce combustion and dodge an Eocene-like Earth for our grandchildren? As PSI's David Grinspoon wrote in his book *Earth in Human Hands: Shaping Our Planet's Future*, "Today we stand at a pivotal juncture, and the answer will depend on the choices we make."



Change of global mean temperatures since the extinction of dinosaurs 65.5 million years ago (after Hansen et al. 2013 for the Cenozoic, Mann et al. 1999 for the last millennium, and the instrumental record since 1880). The small green rectangles show the periods of naturally increased and decreased temperatures of the Medieval Warm Period and the Little Ice Age. The last few years of record warm temperatures have exceeded any in the history of civilization. In a controlled emissions scenario, RCP4.5, global average temperatures by 2100 will reach a level not experienced by any modern human (*Homo sapiens*) or Neanderthal or *Paranthropus robustus*— ever. Lucy, an archaic pre-human, may have experienced such global warmth. Lacking control of fossil fuel combustion, the early 22nd century will have worldwide average temperatures not seen in more than 42 million years; Oregon, for instance, will have a climate like today's Panama. Note that "global mean temperature" is the average across the whole Earth, including poles as well as tropical and mid latitudes, land and oceans combined.

(Credit: Jeff Kargel)

Not one to dwell exclusively on trouble and pessimism, but always looking for opportunity for improvement, David concludes:"Nobody knows the odds of our being able to navigate the evolutionary obstacles before us, but there is real hope, and it is this: that our evolving technological capabilities can allow us to maximize our innate social prowess, equipping us to meet the novel threats we have accidentally created, and to become something new in the process."

Today we face a global pandemic. All pandemics end. We will prevail in this immediate crisis. When our attention returns to climate change, I am hopeful that we will make correct choices, Jeff wrote.

Faith Vilas Receives Fred Whipple Award
by Alan Fischer

PSI Senior Scientist Faith Vilas received the Fred Whipple Award, the highest honor given by the Planetary Sciences section of the American Geophysical Union, at the AGU Fall meeting on December 9, 2019, in San Francisco.

Faith Vilas, at right, being presented the Fred Whipple Award by Rosaly Lopes at the American Geophysical Union meeting.

During her more than 40-year career, Faith has pioneered remote sensing of the Solar System, pushing its capabilities through instrument design and expert telescopic observations of a variety of Solar System targets. She studies the surface composition of airless bodies including asteroids, the Moon, planetary satellites, and the planet Mercury. She has made ground-based visible wavelength spectroscopy her focus, and has excelled in identifying small but telling spectral features in the spectra of these airless bodies.

Her groundbreaking work includes her discovery and analysis of subtle absorption features in reflectance spectra of darker – presumed primitive – asteroids. In particular, this includes a change in the spectrum, which is caused by light reflected from minerals created by water altering the structure and composition of underlying rocks – evidence of water's action throughout history in the asteroid belt.

"I am honored to receive the Fred Whipple Award from the AGU Planetary Sciences section, and I thank them for this recognition of my research and service," Faith said. "No work is possible without the support and collaboration of colleagues, sponsors, and friends, and this prize is shared with the many people I have worked with over the years."

Faith's dedication to planetary science is also reflected in her contributions and her service to the planetary science community through multiple professional positions. She has worked at NASA, the National Science Foundation, and several ground-based observatories, including the MMT Observatory in Arizona, which she led from 2005 to 2010.

"I chose the emerging field of planetary sciences as a college undergraduate, and have had the privilege of watching it grow and expand throughout my career," Faith said. "Each object we explore brings new surprises. Our expansion now with space probes throughout the Solar System is enabled by telescopic observing and these two approaches will remain intertwined as we continue our journey of planetary systems exploration."

Established in 1989, the Whipple Award is given annually to one honoree in recognition of outstanding contributions in the field of planetary science. This award is named in honor of AGU Fellow Fred Whipple, a gifted astronomer most noted for his work on comets.

Michelle Thomsen Wins AGU Fleming Medal
by Alan Fischer

Michelle Thomsen has been named the American Geophysical Union's 2019 John Adam Fleming Medal winner.

PSI Scientist Michelle Thomsen

Michelle, a Senior Scientist at PSI, is honored for her seminal contributions to the understanding of collisionless shocks and the dynamics of the magnetospheres of Earth and the outer planets, and for selfless mentoring of a generation of scientists.

"I am deeply grateful for this award," Thomsen said. "I regard it not as a personal award, but as a testimony to the power of community in scientific research. I have been privileged to be able to participate in ground-breaking space missions, which were the product of other people's imagination and hard work. I have also been privileged to work with amazing colleagues, whose knowledge and ideas fed my own work. I am grateful to all of those whose collegiality and unselfishness has enabled such a richly rewarding career."

Michelle's work includes the study of how shock waves operate in space plasmas, as well as the study of the ways in which material from the Sun, the upper atmosphere, and planetary moons is transported and accelerated within planetary magnetospheres. She is particularly interested in comparative magnetospheric studies, which address the relative importance of the same physical process operating in different magnetospheric environments.

The John Adam Fleming Medal is given annually by AGU to one honoree in recognition of original research and technical leadership in geomagnetism, atmospheric electricity, aeronomy, space physics, and/or related sciences.

Established in 1960, the Fleming Medal is named in honor of John Adam Fleming, who made important contributions to the establishment of magnetic standards and measurements. Fleming served as AGU officer in a number of positions, including: secretary of the Terrestrial Magnetism and Atmospheric Electricity section (1920–1929), Union General Secretary (1925–1947), and honorary president (1947–1956).

Director's Note

The nation has hunkered down in the face of the novel coronavirus in an effort to limit the rate of its spread and keep it from overwhelming our medical infrastructure in the near term. We are buying some time, at significant sacrifice, in the hopes that medical infrastructure can be boosted and testing greatly expanded, so that we can be prepared for the inevitable resurgence that will come with relaxation of business shutdowns and social distancing.

In the meantime, we do our jobs.

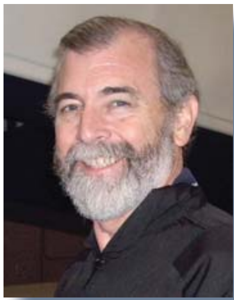
PSI has been recognized for more than a decade for being at the vanguard of remote operations and having a largely distributed workforce. Consequently, the impact on our operations has been less profound than on many other businesses.

However, we do have employees who are and have been infected with COVID-19. We worry about them. We have many families with young children who must now stay at home, be cared for, and be home-schooled. There are only 24 hours in a day and this can be stressful while trying to be productive.

We are a community, and people are generous with sharing their experiences and strategies for dealing with this situation. And there is a fair amount of humor.

We also have numerous videoconferences with each other throughout the week to stay in touch, accommodating our wide range of time zones and geographic concentrations.

I am very pleased that Congress passed the Families First Coronavirus Response Act, which provides for paid sick leave and paid expanded family and medical leave beyond our existing employee benefits. It is much needed relief for many.

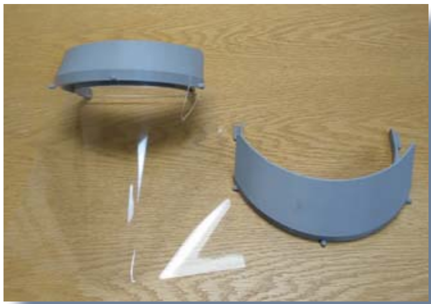


At the same time, our scientists continue to make remarkable discoveries, some featured in this newsletter. Learning more about our planet, other worlds, and the universe beyond and sharing that with the public is fundamentally optimistic.

Mark V. Sykes
April 2020

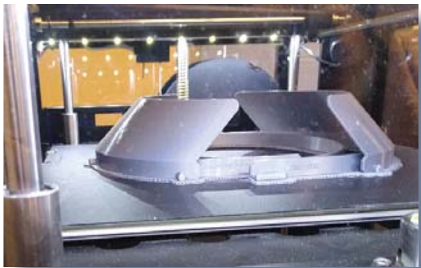
PSI Producing COVID-19 Safety Equipment for Healthcare Workers *by Alan Fischer*

PSI's 3D printers are busy working to fight coronavirus. PSI is producing frames for face shields for the Pima County Health Department to protect healthcare workers from the COVID-19 virus. A replaceable clear transparency sheet is fitted to the 3D-printed frame to protect the medical professional's face.



3D-printed face shield frames. A clear plastic sheet is attached to the frame on the left to show how it will protect area healthcare workers from the COVID-19 virus.

The lengthy 3D fabrication process means PSI's two printers can produce 6 to 8 shields per day, said Gavin Nelson, PSI's Deputy IT Manager.



Face shield frame being produced on a 3D printer at PSI. *Photos by Gavin Nelson*

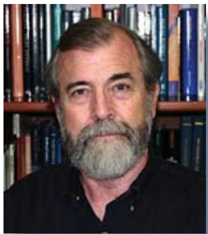
The frames are made of PLA, polyactic acid, a biodegradable material made from plant starch.

The design for the shields came from the National Institutes of Health.

PSI Staff News

Three PSI Scientists Honored as AAS Fellows

Carle Pieters



Mark Sykes

Faith Vilas

Three PSI scientists, Carle Pieters, Mark Sykes, and Faith Vilas, have been named as members of the American Astronomical Society's inaugural Fellows program.

AAS Fellows are recognized for original research and publication, innovative contributions to astronomical techniques or instrumentation, significant contributions to education and public outreach, and noteworthy service to astronomy and to the Society itself.

The AAS Fellows program was established to recognize AAS members for achievement and extraordinary service to the field of astronomy and the American Astronomical Society. AAS Fellows are recognized for their contributions toward the AAS mission of enhancing and sharing humanity's scientific understanding of the universe. The AAS is the major organization of professional astronomers in North America.

Congratulations to our scientists!

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Salt Water May Periodically Form on the Surface of Mars *by Alan Fischer*

Briny water may form on the surface of Mars a few days per year, research by PSI Senior Scientist Norbert Schorghofer shows.

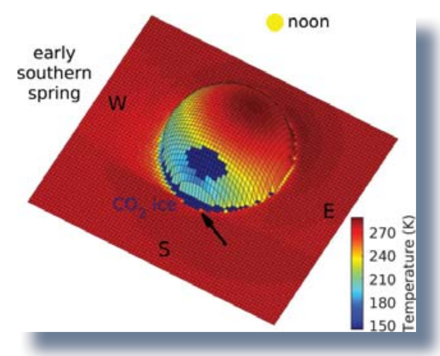
Liquid water is difficult to come by on Mars, because ice rapidly dissipates, or sublimates, into the atmosphere long before it reaches its melting point. That is because the atmospheric pressure on Mars lies near the triple point pressure of H_2O, the minimum pressure necessary for liquid water to exist.

"Mars has plenty of cold ice-rich regions and warm ice-free regions, but icy regions where the temperature rises above the melting point are a sweet spot that is nearly impossible to find. That sweet spot is where liquid water would form," Norbert said.

The process works as follows: A boulder sitting on the surface at mid-latitudes casts a shadow in winter. The continually shadowed area behind the boulder is very cold, so cold that water ice accumulates in winter. When the Sun rises again in spring, the ice suddenly heats up. In detailed model calculations, the temperature rises from -128° Celsius in the morning to -10° Celsius at noon, a huge change over a quarter of a day. Over such a short time, not all of the frost is lost to the atmosphere.

Salt depresses the melting point of H_2O, so on salt-rich ground, water ice will melt at -10° Celsius. Brines, or salty water, will form until all of the ice has either turned to liquid or vapor. Next Mars year, the same process repeats.

The shadowed areas behind the boulders are so cold in winter that not only water frost but also carbon dioxide ice builds up. For Mars, the first day without carbon dioxide ice in spring is called the "crocus date." Melting occurs on or immediately after the crocus date, and therefore the term "crocus melting."



3D view of Mars' surface temperature around an idealized boulder at latitude 30°S. On the side opposite to the Sun, temperatures are around -128° Celsius, and as the sun rises, this area heats up rapidly, so frost melts on salt-containing ground before it sublimates into the atmosphere. ***Credit: Norbert Schorghofer***

"Answering the question whether crocus melting of seasonal water ice actually occurs on Mars required a slew of detailed calculations — the numbers really matter," Norbert said. "It took decades to develop the necessary quantitative models."

Norbert's paper "Mars: Quantitative evaluation of crocus melting behind boulders" appeared in the Astrophysics Journal.

Norbert's work was funded by a grant from NASA's Habitable Worlds program.