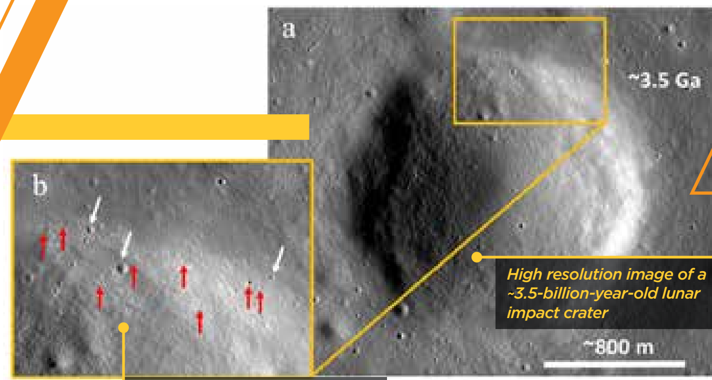
EARTH & PLANETARY SCIENCES

Terra Firma

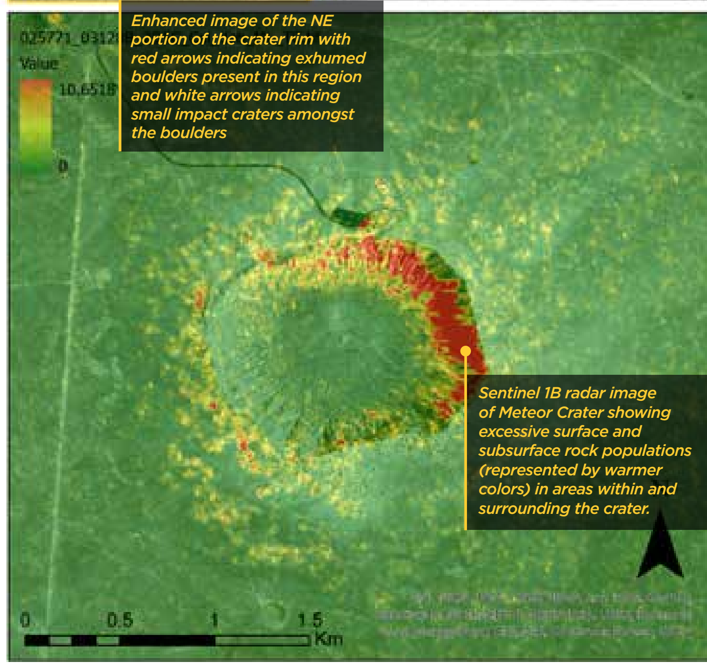
FALL 2021 NEWSLETTER

Radar Imaging as a Geologic Tool



High resolution image of a ~3.5-billion-year-old lunar impact crater

Enhanced image of the NE portion of the crater rim with red arrows indicating exhumed boulders present in this region and white arrows indicating small impact craters amongst the boulders



Sentinel 1B radar image of Meteor Crater showing excessive surface and subsurface rock populations (represented by warmer colors) in areas within and surrounding the crater.

After the mid-20th century development of imaging radar systems as navigational and detection instruments for World War II efforts, radar data began to see use as a geologic tool due to instrument simplicity and the multi-faceted sensitivities of the resulting data. Specifically, the sensitivity of radar image data to material composition and geometry at planetary surfaces and at depth makes these data ideal for geomorphic investigations of planetary surfaces throughout our Solar System. Although radar instruments have been used to provide vital information regarding the surface conditions of Earth, Venus, Earth's Moon, Mars, and various small bodies throughout our Solar System, the understanding of what is geologically represented by those radar data remains theoretically derived. To improve the geologic understanding of what is represented in those radar images, we proposed a series of controlled radar imaging experiments in the Planetary Radar Investigation, Demonstration, and Exploration (PRIDE) Lab at the Universities Space Research Association (USRA) Lunar and Planetary Institute (LPI). The goal of these experiments was to image a regolith simulant with a radar instrument while altering various geologic attributes of that regolith including surface and subsurface rock content, water and ice content, and rock burial depth. This method would place vital, physical constraints on radar data as measurement of planetary surfaces throughout the Solar System.

Unfortunately, the COVID-19 pandemic placed severe constraints on the construction and testing of the PRIDE lab over the past year. Therefore, this project has been revised to achieve the same goal of constraining orbital remote sensing image interpretations but under different, field-based conditions. Our revised methods include comparing orbital radar and thermal infrared data from the European Space Agency (ESA) Sentinel-1B and NASA The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instruments with surface sediment samples from the ejecta material surrounding Meteor Crater in northwest Arizona. We will also collect drone-based, high-resolution thermal infrared data over the ejecta of Meteor Crater for further characterization of the Meteor Crater surface sediments. The comparison of the aforementioned remote sensing data with true surface sediments will allow us to constrain orbital radar and thermal infrared observations of geologic materials. Our revised methods will have the additional benefit of furthering our understanding of Meteor Crater origins and impact cratering dynamics on atmospheric bodies. This revision of scope has therefore allowed us to expand our goals to address several outstanding science questions that were previously unattainable in a laboratory setting.

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what's inside:

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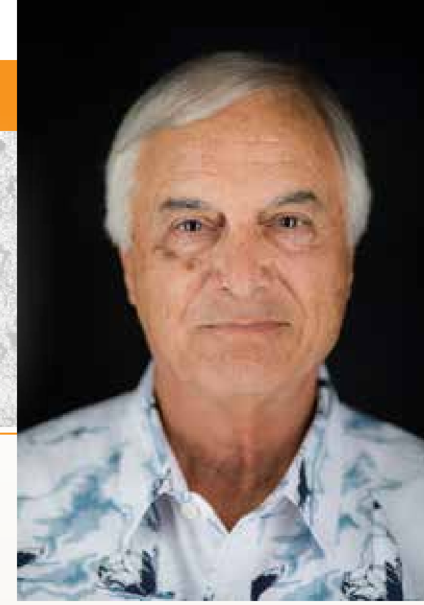
The surface of Earth's Moon is geologically dynamic. Even now, after cessation of large-scale volcanism and the late-heavy bombardment, frequent meteoroid impacts of varying sizes combined with extreme thermal cycling have the power to quickly alter the lunar landscape. One such surface alteration is the rapid breakdown of rocks and boulders that have been excavated and deposited on the lunar surface by the formation of large impact craters. Prior studies have indicated that those rocks should be reduced to fine grained regolith within ~300 million years due to micrometeoroid sandblasting. In their recent work, however, **Bradley Thomson** and EPS graduate student **Cole Nypaver** used a combination of radar and thermal infrared data to identify rocks and boulders at the rims of several-billion-year-old impact craters that are being continually exhumed from the subsurface. These rocks are being uncovered from the overlying regolith at a rate that outpaces the rate of rock breakdown. This means that, in some cases, rock exhumation at crater rims has been an ongoing process for >3.5 billion years.

Even after the success of the Apollo program, the lunar surface remains under sampled. Therefore, sample collection will be a key aspect of future NASA Artemis lunar missions. The ability to confidently collect lunar surface samples that are relatively in place and have gone unperturbed over the last several billion years will be crucial to better understanding the geologic history of the Moon. Due to this recent discovery of rapid rock exhumation at crater rims, those impact crater rims provide ideal locations to collect samples that will provide the most accurate geologic interpretations possible. Sampling at crater rims will therefore aid in the success of future lunar surface science initiatives.

OK, So What's the Speed of Dark?



After slogging through last year's COVID darkness, which descended faster than anyone expected, we had hoped for a return to normalcy. But fall semester has begun with mandatory masking in classes and laboratories. Nevertheless, UT's enrollment is burgeoning and our classes are in-person and mostly full. I'm proud of how our faculty and students have adapted to the challenges of innovative teaching, graduate student mentoring at a distance, and conducting their own research programs while under pandemic restrictions.

In the past year, we graduated 30 BS, six MS, and one PhD students (a number of doctoral students defended this summer but will graduate in the fall) – they are an impressive group who will have a significant impact on the profession, as have our many hundreds of alumni. We are adjusting our undergraduate curriculum, adding concentration areas for majors (water science and planetary geoscience, to complement our existing concentrations in geology and environmental science), as well as minors in paleontology (mostly for biology majors) and geochemistry. We continue to develop new research facilities, such as a state-of-the-art ICP-MS geochemistry laboratory, with the university's support. With the support of generous alumni and the department's alumni advisory board, we have had marked success in generating endowments and funds to support the activities of our students and faculty.

Other changes abound. As the new academic year started, Professor Ed Perfect retired after a long and distinguished career, and Associate Professor Stephen Romaneillo left for a position in industry – we have already begun searching to fill that position. At midyear, Melody Branch, our extraordinary office business manager, will retire after 40 years in the department.

You may be as surprised as I am to see that I've (again) taken on the responsibility of acting department head. I suppose I was failing retirement anyway. My appointment is just a stopgap measure, while we conclude an outside search for a new head. We hope to have this search wrapped up during the fall semester, and the next newsletter will introduce our new leadership and administrative team. As we emerge from the dark, we will have an opportunity to reinvigorate our academic and research programs – that's not just upbeat words but a real likelihood, so stay tuned.

Please continue to support us as you can, and contribute news about your successes that we can share in future newsletters. As always, you remain our most important achievements.

Hap McSween
Acting Department Head

INTRODUCING OUR NEWEST **Emeritus Professors**

In 2021 **Tom Broadhead** and **Ed Perfect** retired from UT. EPS faculty voted to award them Professor Emeritus status in recognition of their distinguished service to the department and the university.


Tom Broadhead

Tom retired at the end of March, 2021, following a 42.5-year career from UT. Tom and Ann moved to Knoxville in August 1978 when had graduated with his PhD from the University of Iowa and accepted an assistant professor position in the department. He enjoyed teaching paleontology at all levels and especially liked educating large numbers of introductory students about the wonder and truth of Earth history.

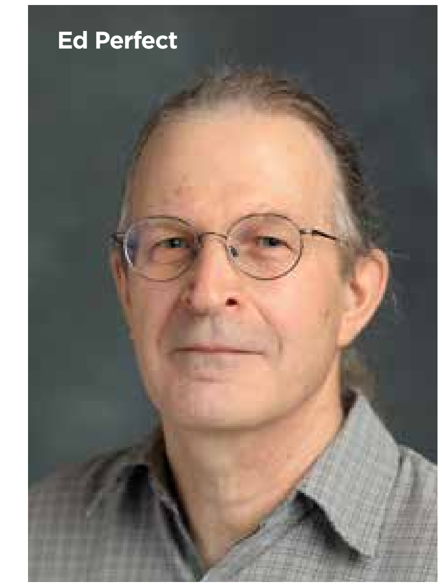
In 1994, Tom was appointed director of the University Honors Program, UT's campus-wide program for high achieving students. During his nine years in that position, he oversaw growth of the program from 150 students to more than 600, which included some notable geology majors.

In 2003, he was appointed director of Undergraduate Academic Advancement in the UT Office of Undergraduate Admissions. In that capacity he coordinated recruitment efforts and programs for high achieving students and for several years worked with the recruitment and admission of international students.

Tom and Ann are the proud parents of three grown children and three grandchildren. Tom's personal interests have been stamp collecting and scuba diving, and as a self-styled "museum brat," he has worked with the UT McClung Museum of Natural History and Culture as curator of the permanent geology exhibit and consultant for odd objects, including "dinosaur eggs" (which invariably are chert nodules). He has served the museum as a member of its advisory board for more than 25 years and was appointed chair of that body in spring, 2021.

Ed was born and grew up in Peterborough, England. He graduated from the University of Newcastle-upon-Tyne in 1977 with a BSc degree in geography. He earned a master's degree in geography from Carleton University, Ottawa, Canada in 1980. He then moved to Ithaca, New York, to study frost heaving at Cornell University, obtaining his PhD degree in soil physics in 1986.

Ed returned to Canada in 1987 to spend eight years as a post-doc at the University of Guelph, Ontario. Following a six-year spell on the faculty at the University of Kentucky, he joined the Department of Geology (now EPS) at UT in 2001 as an assistant professor. Ed was promoted to associate professor in 2004, and to full professor in 2010. During his 20-year career at UT he served two terms as associate head, and led the department as interim head from May 2020 until his retirement on August 1, 2021.


Ed Perfect

Ed's research and teaching during his time with EPS focused mainly on hydrogeology, vadose zone hydrology, and geostatistics. As an advisor or co-advisor, he graduated five PhD and 14 master's students. He established productive collaborations with scientists from several research groups at ORNL. The lab's neutron imaging capabilities, in particular, enabled him and his students to make significant breakthroughs in visualizing, quantifying, and modeling the capillary uptake of water in fractured rocks.

To read more from EPS, please visit us online at ***eps.utk.edu/newsletter***.

In October, **Terry Hazen**, Governor's Chair in Environmental Microbiology, and EPS students Andrew Putt and Erin Kelly did studies at the S-3 ponds legacy site with a Cone Penetrometer (CPT). This was part of the Ecosystems & Networks Integrated with Genes & Molecular Assemblies (ENIGMA) DOE Science Focus Area.

The S-3 ponds legacy site has some of the highest Nitrate concentrations in groundwater in the world >10,000 mg/L, even though the ponds were neutralized and capped more the 30 years ago. The geology and hydrology in the shallow subsurface are very convoluted since the shales dip at 20-40° and the site is near Bear Creek. M&W drilling was contracted by Berkeley Lab to have Fugro from Houston bring their CPT rig to the site. The CPT rig can push a cone sensor at 2 cm/sec and provide depth profiles of sleeve friction, cone resistance, pore pressure, friction ratio, and soil behavior type. They also took sediment samples at various sites to do additional sampling for the ENIGMA team. 131 pushes were made from 10 ft to 35 ft in a grid allowing real-time analysis of lithology (soil types). By using RockWorks interpolation between pushes it provided the most detailed 3-D structure of the subsurface ever obtained for this site which will aid ENIGMA in establishing a long-term SubSurface Observatory (SSO) at the site.

Noah Hooper

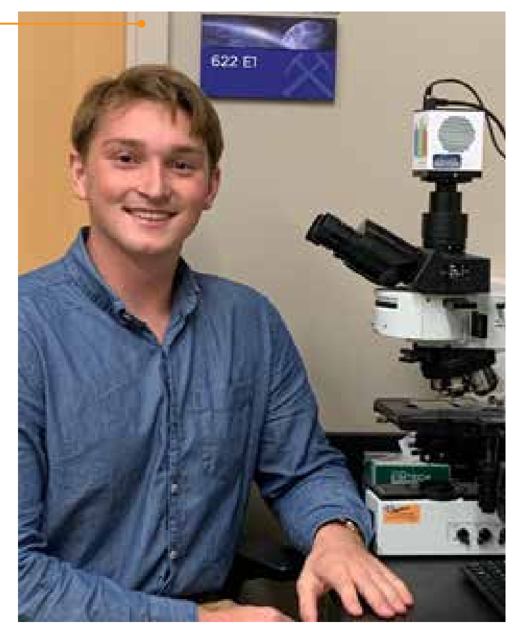
Last summer, undergraduate geology major and Memphis native Noah Hooper stayed in Knoxville to complete a NASA Space Grant funded project in UT's experimental petrology lab. Along with PhD student Jesse Scholpp, Noah assembled a gas-mixing conditioning furnace. Noah took the lead on wiring a control box from scratch using electronic components purchased from industrial suppliers. With the device Hooper built, PI Nicholas Dygert was able to repurpose an old but barely-used horizontal furnace inherited from Larry Taylor, saving thousands of dollars and providing Noah a valuable learning experience.

The purpose of the gas mixing furnace is to prepare starting materials for crystallization and melting experiments under controlled atmospheric conditions, critical for investigating igneous processes on planetary bodies across the Solar System. The gas mixing furnace produces a two-component mixture of CO_2-H_2 supplied to an inner alumina tube within a horizontal furnace. As the mixed gases enter the tube's hot spot, they react with experimental powders placed in an alumina boat to create a specific, temperature-dependent partial pressure of oxygen.

Temperature is regulated by the computerized control that Hooper built, which can operate at up to 1000°C. Heating elements in the furnace are wired to a solid-state relay that supplies power, while readings from a K-type thermocouple are sent to a computer to monitor and regulate temperature output. Depending on the proximity of the temperature reading to the set condition, a signal passes from the computer to the relay, turning power on or off and thus regulating the furnace. This process it repeated iteratively until the set point temperature is reached. The controller accurately regulates the temperature to ±0.1°C.

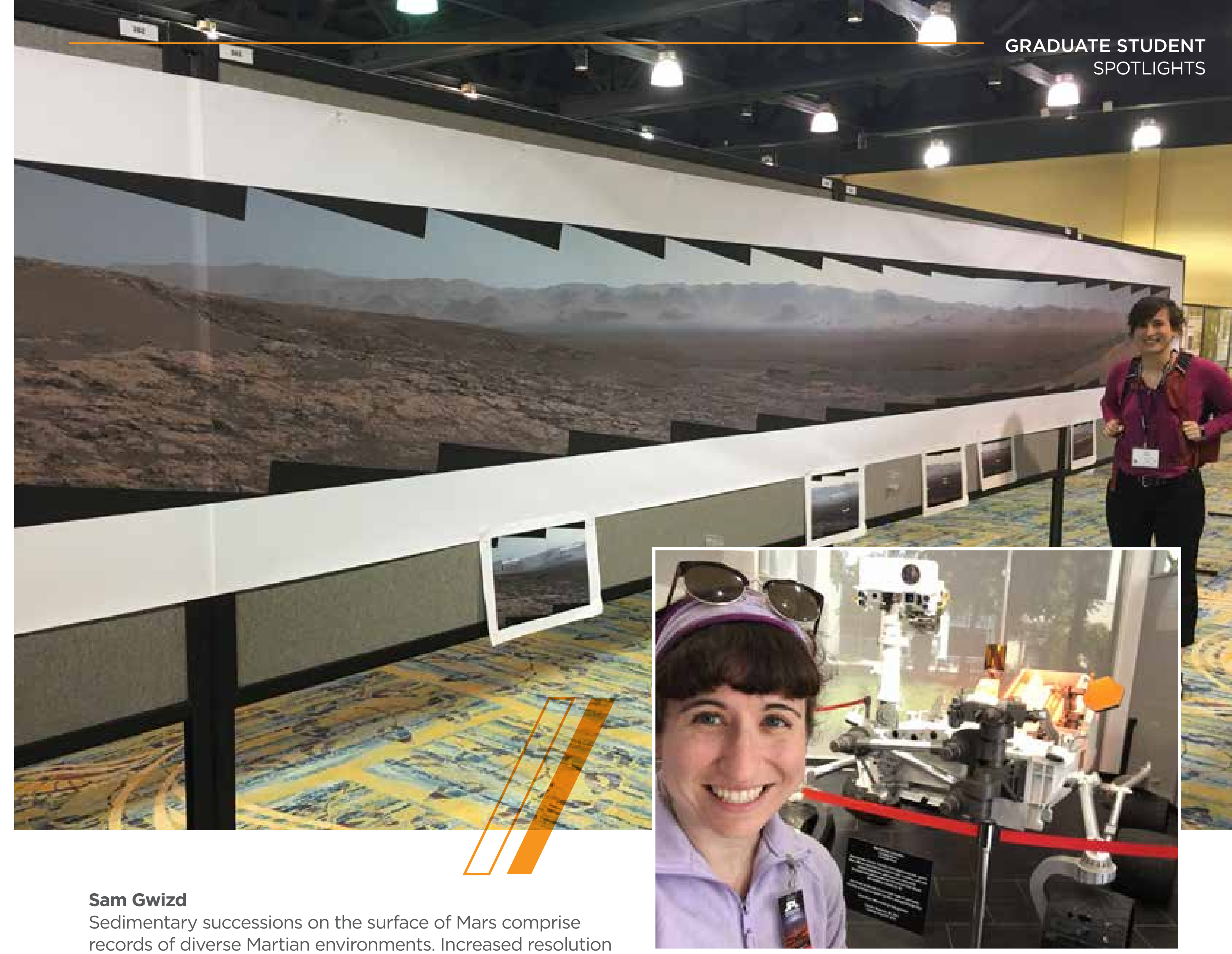
According to Noah, "The process of building this apparatus was an exceptional experience and many fond memories were made along the way. It provided knowledge and skills previously unbeknownst to me, and I am proud to say the project was a success. I can only hope it proves to be a useful resource for future researchers paving experimental pathways into the unknown."

Julian Nosarzewski



So, what do you do when you start college in a pandemic and want to get involved in research? Julian Nosarzewski is a sophomore undergraduate who is majoring in geology, minoring in Portuguese, and has a deep interest in the evolution of life and environments on Earth. But with most labs locked down last year, Julian had to get creative in his undergraduate research, and he took a deep dive into learning about life and environments in the Precambrian with Linda Kah, Kenneth G. Walker Associate Professor of Carbonate Sedimentology and Geochemistry. Specifically, Julian has been delving into the world of stromatolites. When we think of stromatolites (fossil microbial structures), we most commonly envision domal to columnar laminated features that occur in modern environments Shark Bay, Western Australia, and throughout the geologic record. But how do you explain microbial columns that are inclined—sometimes more than 30° from vertical—or even sinusoidal in their structure? With Professor Kah's guidance, Julian began to think about stromatolites in terms of their individual layers. If the main layers of a stromatolite represent the microbial community that colonized the stromatolite surface at any one time, then successive laminae could really be considered snapshots of the interaction between the microbial surface and the sedimentary substrate through time.

Just before the pandemic started, Kah had been in the field looking at stromatolites in 1 billion-year-old rocks of central India (Chandi Formation, Chhattisgarh Basin). Julian took the pictures of some particularly unusual, inclined stromatolites and began tracing lamination. In the spring of 2021, Julian presented his work at UT's undergraduate research competition, EUREKA, and showed how individual beds of inclined stromatolites could be attributed, in some cases, to post-construction toppling, and in other cases, to the successive migration of stromatolitic laminae, possibly in response to long-shore currents. Julian in continuing his work this fall, adding more complex inclined columns of the 1.4 billion-year-old Altyn Formation, Montana, to his analysis. And, with the reopening of lab spaces, Julian is adding some petrographic analysis to his research repertoire, exploring whether changes in composition of the sandy dolomite associated with the Altyn stromatolites may give clues to why the columns change orientations. Results of this combined project were presented by Julian at the GSA annual conference in October.



Sam Gwizd

Sedimentary successions on the surface of Mars comprise records of diverse Martian environments. Increased resolution of sedimentological, stratigraphic, and compositional measurements from rovers has revealed variability in ancient environments extending from orbital- to µm-scales. Developing a cohesive understanding of 3-3.5 Ga environments and depositional processes on Mars requires a combined facies and compositional approach. While sedimentologic and stratigraphic characteristics help distinguish the distribution and type of different environments (e.g. lacustrine, aeolian, fluvial), geochemical analyses help to constrain climate and additional aspects of basaltic sedimentary systems along the path from source rock to deposition (e.g. weathering, transport, diagenesis).

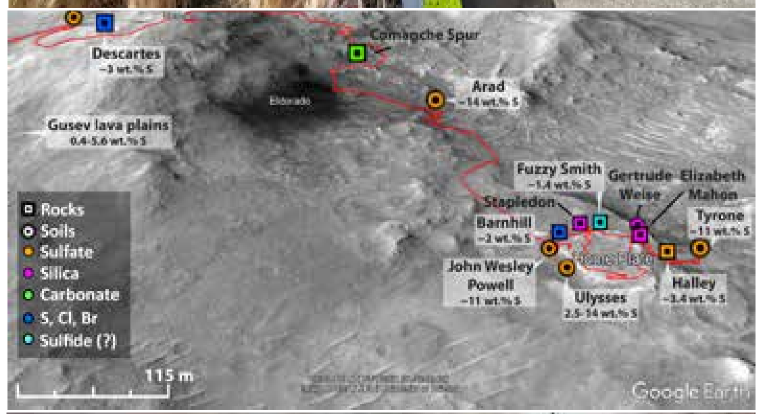
Sam Gwizd and her advisor Professor Chris Fedo are working to constrain depositional environments from a succession of sedimentary rocks at Gale crater using the suite of cameras and compositional instruments onboard the Mars Science Laboratory (MSL) Curiosity rover. The Hartmann's Valley and Karasburg members comprise 65 m of stratigraphy within the lacustrine Murray formation. Facies within these members represent deposition in aeolian and subaqueous lacustrine-margin environments as well as lacustrine environments which experienced long-lived standing water. Bulk rock geochemistry across facies represents the combined influence of a basaltic source rock which has been modified by chemical weathering and subsequent transport of sediment as well as lithification. These environments are interpreted to be similar to semi-arid to arid basaltic sedimentary systems of modern-day coastal Iceland. Ongoing work in the overlying 90 m thick Sutton Island member aims to further understand the evolution of these ancient lake and lake margins at Gale crater.

Sam is also a member of the mission operations science planning team, and fulfills a rover operations role as "Keeper of the Plan" (KOP). This role involves working with multiple instrument teams, engineers, and science planners to populate one sol (Martian day) or multiple sol's worth of science observations. A large contingent of the operations team is based out of the Jet Propulsion Laboratory in CA, but otherwise, operations are done remotely all over the world. Team members at all levels, from undergrad to faculty or staff scientist, can request images or geochemical measurements, or even drill samples (though those require meticulous months-long planning) which will help to answer their scientific questions. Sam has been a member of the Curiosity science team and participating in rover operations since 2017, and has proudly named multiple bedrock targets.

Rhianna Moore

Sulfur is a ubiquitous but ambiguous part of Mars geology. Sulfates are commonly found in a wide variety of environments across much of the planet, but the sources and formation mechanisms of these minerals are still not well constrained. Other forms of sulfur, like sulfides and elemental S, are difficult to detect and seem to be mostly absent from the Martian regolith. This is inconsistent with what is seen on Earth, and may suggest a gap in our understanding of sulfur on Mars. Working with Associate Professor Anna Szynkiewicz, doctoral student Rhianna Moore has been using geochemical and geospatial data from terrestrial analogs on Earth to better characterize factors that controlled sulfur minerology, concentration, and cycling in ancient aqueous environments on Mars.

Studying soil samples from acidic hydrothermal systems in Iceland, Valles Caldera, Lassen, and Yellowstone, Rhianna has shown that climate and hydrology play a role in sulfur preservation, as concentrations decrease under wetter conditions due to aqueous transport, when mud pots and hot springs become more interconnected by ephemeral drainages. Laboratory analyses also indicate that sulfur oxidation is not a simple process in these extreme environments, and that it is usually incomplete leading to high quantities of elemental sulfur, rather than sulfate. These findings have implications for similar places on Mars like Gusev crater, the landing site of the MER Spirit rover, suggesting that moderately wet conditions were initially present that enabled high concentrations of elemental sulfur to slowly oxidize over billions of years. Other terrestrial analog sites, like the Hawaiian Islands and Iceland, have been used to determine aqueous sulfate fluxes in volcanic terrain. This study aims to better constrain the source of sulfate found in the ancient playa environment of Meridiani Planum, which was investigated by the MER Opportunity rover. The results may provide better estimates on the timing and extent of the hydrological cycle that fed the playa, and answer a long-standing question of the sulfate source.



ALUMNI SPOTLIGHTS

Thomas Cronin (BA '80, MS '83) received the 2021 UT College of Arts and Sciences Volunteer Service Award. This is a significant award that recognizes exceptional service or long-term leadership to the College of Arts and Sciences or to an academic department or program within the college. The award is in great appreciation for the service and leadership Tom has made to help the EPS department through donations, career mentoring for students, and reimagining and renewing the EPS advisory board.

Tom grew-up in the Knoxville area and after his studies at UT, he spent 34 years working in the oil and gas industry on a multitude of projects around the world including the Gulf of Mexico, Trinidad, SE Asia (Indonesia, Thailand, Vietnam, Bangladesh & China), and parts of onshore US. He developed an enjoyment for mentorship, which he continues on the EPS advisory board. Tom has served on the EPS advisory board in leadership roles including the chair, mentoring and outreach chair, and continues as secretary. With the help of Tom's leadership and support the EPS advisory board has grown to more than 30 members and the board is active through giving for departmental scholarships and mentoring both undergraduate and graduate students in the EPS department helping prepare them

for a successful job search and career. In Houston, Tom 'Volunteers' at the AAPG Grants-in-Aid and Critical Minerals Committee, Houston Chapter of the UT Alumni, Houston Food Bank, and assisting elementary and secondary schools get access to earth science teaching materials. Tom received the Volunteer Service Award at the College of Arts and Sciences Alumni Awards dinner on Friday, October 8, 2021. Tom was nominated for this prestigious award by Larry McKay.

The **EPS Young Alumnus Award** recognizes recent graduates (<10yr of last degree) of the department for significant early career contributions and/or service to the department. This year the EPS advisory board was proud to recommend two recent alumni for the Award: **Geoff Gilleaudeau** and **Arya Udry**.

Geoff Gilleaudeau (PhD '14) was presented the EPS Young Alumnus Award before a departmental seminar on Sept. 9, 2021. Geoff is an assistant professor at George Mason University. His studies focus on the physical and chemical characteristics of sedimentary rocks to decipher important events in Earth history. Geoff's research has almost come full circle from interest in Devonian-Carboniferous black shales as an undergraduate at the SUNY Binghamton to his current research into the reconstruction of the watermass composition of Devonian epieric seas of North America. His research after UT took him to a postdoc at the University of Copenhagen, Denmark, studying Cr isotopes in Mesoproterozoic carbonates, followed by a postdoc at the Arizona State University examining the cycling of transitional metals in greenhouse oceans. He also held a research scientist position at the University of New Mexico. Geoff's collaborative projects and accomplishments at this young age are a testament to his hard work, but even more so are the aspects of being a well-rounded scientist.

Arya Udry's (PhD '14) also received the EPS Young Alumnus Award in 2021. Udry's research focuses on planetary igneous petrology, including Martian petrology to better understand the interior composition, magmatic processes, and general evolution of the planet Mars. After completing her PhD at UT, she gained an assistant professor position in the Department of Geoscience at the University of Nevada, Las Vegas, and is now an associate professor.

Arya has won six grants that total over $1.5 million to support her role as a participating scientist on the Mars 2020 (Perseverance) program, graduate research assistantships, NASA research grants for her studies on Martian meteorites, and NASA funded equipment grant for a new laser ablation system at UNLV. Arya has served as a member of the Mars Sample Return Science Planning group, multiple workshop and award committees in the planetary field, and as a member of the curation and analysis planning team for extraterrestrial materials. She has presented over 15 invited seminars and colloquia, as well as a multitude of outreach events and media coverage highlighting her research. Arya was the recipient of the UNLV Barrick Scholar Award, which "recognizes faculty members who have established a record of distinguished research or demonstrated excellence in the area of creative activity" and also the Meteoritical Society's 2022 Nier Prize recipient, which recognizes outstanding research in meteoritics and closely allied fields by young scientists.

The **EPS Distinguished Alumnus Award** is the highest departmental award given to alumni that had a distinguished career with exceptional contributions to the field of the geology and/or significant service to the department. This year the award was given to **G. (Shan) Shanmugam**, a recognition that is well overdue.

Shanmugam (PhD '78) received the EPS Distinguished Alumnus Award for an exceptional career in oil and gas and a prolific research record. Shan retired from Mobil Research in 2000 (before the merger with Exxon) and had a second career in consulting and research. Shan published ~130 peer-reviewed research articles. His research has helped redefine our understanding of deep-water sedimentary deposits and their role as oil reservoirs. One of his papers (Shanmugam, 1996, J. Sed. Research) was the most highly cited paper in three journals in his field for a seven-year period and another paper (Shanmugam et al., 2009, J. Sed. Research) was listed by Web of Science as one of the most cited papers in this field over a five-year period after publication. Several of his papers have received more than 100 citations. Shanmugam is associate editor-in-chief of the *Journal of Paleogeography* and on the editorial board for two other journals. Shan is a dedicated contributor to EPS (Strong Hall fund, Shanmugam Graduate Fellowship Endowment, Walker Briggs-Shanmugam Excellence in Sedimentology Endowment), and a long-time enthusiastic supporter of the department.

The **EPS advisory board** continued its growth and involvement with the department and students. Scholarship and emergency funds generated by the board were awarded to several EPS students who continued to experience hardships related to COVID-19 during the academic year. The board met in the spring 2021 for its third virtual meeting, all members are now expert 'Zoomologists.' The meeting had several good mentoring sessions with EPS students. The board was honored to help recognize several alumni for career contribution awards and welcomed new board members: Matthew Huebner and Pat Hackworth, and new student member Jake Perez.

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GIVING OPPORTUNITIES

We rely on the generous financial support of our alumni and friends. Your contributions, no matter what the size, are essential to the vitality and financial security of the department.

The Professors' Honors Fund recognizes various professors in the department, and is used for a variety of expenditures, including vehicle rental costs for field trips, travel for visiting speakers, software products for teaching, and unexpected costs related to research laboratories or facilities maintenance.

Donations can be mailed to EPS, with check payable to the UT Foundation. You can also donate online at eps.utk.edu.

Have you ever thought about setting up a departmental endowment? It is easier than you might think. An endowment is a gift with earnings that go to support students, faculty or programmatic activities as designated by the donor.

If you would like to discuss setting up a departmental endowment, please contact Professor Hap McSween at mcsween@utk.edu or 865-974-9805. You can also contact Chris Cox, executive director of development for the college, at ccox65@utk.edu or 865-974-2365.

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