Planetary Science and Technology Through Analog Research 2017
Abstracts of selected proposals
(NNH17ZDA001N-PSTAR)

Below are the abstracts of proposals selected for funding for the Planetary Science and Technology Through Analog Research 2017 program. Principal Investigator (PI) name, institution, and proposal title are also included. 47 proposals were received in response to this opportunity. On April 10, 2018, 6 proposals were selected for funding.

Ewing, Ryan/Texas A&M
SAND-E: Semi-Autonomous Navigation for Detrital Environments - Integrating robotic terrain analysis, geochemistry, and sedimentology to assess sediment transport pathways

The strategic goal of this research is to integrate terrain analysis and science operations to improve operational and scientific outcomes during exploration of mafic detrital environments. With this proposal, we will evaluate the effectiveness and capability of rover-based semi-automated terrain analysis (using the Automated Soil Assessment System, ASAS) and Unmanned Aerial Systems (UAS) for navigating, selecting targets for sampling, and characterizing mafic detrital sediments along a glacio-fluvial-aeolian sand transport pathway in Iceland.

To achieve this goal, we will test two working hypotheses:
(1) Science Operations hypothesis: Rover-based semi-autonomous terrain analysis for path and sample selection creates more efficient and capable navigation and target selection than rover-based optical images only, unmanned aerial system (UAS) images, or on-site human input by reducing the time needed to determine a pathway and sample targets and by increasing the quality of the navigation pathways and sample targets.

(2) Science hypothesis: For a given sediment source, geochemical and grain-property variability are coupled by environment-specific (e.g., fluvial vs. aeolian) physical fractionation and geochemical alteration that vary as a function of distance from the source.

We propose the following objectives and approaches to test our two hypotheses.
Science Operations Objective 1: Evaluate the capability and efficiency of rover-based autonomous terrain analysis, and human analysis of UAS images for rover navigation.

Science Operations Objective 2: Evaluate the capability and efficiency of rover-based autonomous terrain analysis, and human analysis of UAS image for sample target selection and their effects on sample target quality

Science Objective 1: Examine and determine causes of variability in the geochemistry and mineralogy of fluvial and aeolian sediments along a transport pathway proximal, medial, and distal from a known source of basalt.

Science Objective 2: Examine and determine causes of variability in the physical grain properties of fluvial and aeolian sediments along a transport pathway proximal, medial, and distal from a known source of basalt.

To test our hypotheses and achieve our objectives, we propose a 3-year field and laboratory study during which we will execute 2 field seasons in Iceland in environments with terrain and geologic characteristics directly analogous to the basaltic detrital environments of Mars. We will use the Argo J-5 rover and a UAS to test 6 operational scenarios while examining the physical, geochemical, and mineralogical variability of fluvial and aeolian basaltic sediments along a sediment source proximal-to-distal transect of two glacial outwash sand plains ý Lambahraun and Askja. We selected these sites based on previous published research that shows Lambahruan has mineral-dominated sediments and Askja has glass-dominated sediments, thereby allowing us to test the variability in two distinct Mars-relevant environments. Our field methods include grainsize analysis, handheld XRF, and handheld VNIR. We will collect samples from the field and analyze them in the laboratory using particle size, shape, and microscopic analysis, scanning and transmission electron microscopy, thermal infrared spectroscopy, X-ray diffraction, inductive coupled plasma mass spectrometry.

Filiberto, Justin/Southern Illinois University
Detectability of Magmatic Intrusions within Sulfur-rich Sediments for Martian Mineralogical and in-situ Operational Analyses

Summary: Magmatism is one of the few geologic processes to provide major changes and energy influx to the Martian surface and subsurface past the Noachian. Eruption and degassing of mafic magmas contribute to the surface volatile species, as well as nutrients and energy that are needed for biological processes. Among the volatile species, sulfur is especially important because of its several redox states, which can be utilized as an energy source by chemolithotrophic microorganisms. On Earth, few mafic magmas intrude sulfur-rich sedimentary rocks. On Mars, however, soils have been found to contain abundant S-species and there is ample evidence for ancient magmatism. Thus intrusion of magmas into sulfur-rich soils and rocks is to be expected on Mars. This may be particularly relevant to the proposed landing sites for the NASA Mars 2020 and for the ESA ExoMars missions at Mawrth Vallis and/or Jezero Crater that have a potential volcanic capping unit directly in contact with sulfate-sediments. In this proposal, we will investigate an Earth analog, in the San Rafael Swell on the Colorado Plateau, for such a scenario of mafic magma intruding gypsum-bearing sediments. We have observed numerous dikes, which contain intruded sulfur-rich sediments and are well exposed throughout our field-site. Therefore, we propose to do a detailed in-situ investigation of the igneous intrusions and metamorphosed sediments using instruments that emulate those on active or future missions. Relevance: This work will demonstrate fidelity to NASA PSTAR science and operations objectives. The proposed work will investigate a: "terrestrial extreme environment that may be analogous to those found on other planets" - specifically proposed landing sites for Mars 2020 and ExoMars. Our investigation will place constraints on potential habitability of igneous intrusions baking and metamorphosing sulfur-rich crustal material, which will "lead to a better understanding of how to seek, identify, and characterize life and life-related chemistry that may exist or have existed on other solar system bodies". Instruments for our field campaign have been chosen to mimic those on planetary-rovers in order to "approximate operations during an actual

planetary mission" and be applicable to current rover and orbital investigations. The outcome of the investigation will be a checklist of what tools a rover, or orbiter would need to investigate a similar site on Mars to investigate the potential for habitability.
Research Team and Facilities: P.I. Filiberto has spent his career investigating volatile species in Martian basalts and degassing of Martian magmas. He will train a graduate student (Crandall) at SIU. Co-I Potter-McIntyre has extensive experience studying subsurface diagenetic redox reactions in the Mesozoic sedimentary rocks on the Colorado Plateau. Co-I Perl is an investigation scientist on Mars Reconnaissance Orbiter and astrobiologist studying mineral-microbial interactions in evaporites. He has extensive experience investigating how fluids interact and assist in the formation of outcrops found on the Martian surface. Collaborator Schwenzer has extensively studied the Martian hydrous environment through noble gas investigations and thermochemical models. Collaborator Bridges has spent his career using TEM to investigate alteration and igneous mineralogy in Martian meteorites. As science team members of the Mars Science Laboratory mission, Bridges and Schwenzer study the environments encountered by the Curiosity rover. Collaborator Olsson-Francis is experienced in studying microbial weathering and their role in biogeochemical cycling. All necessary equipment is available to the team: XRF, XRD, SEM, and VNIR at Southern Illinois University, culturing facility at the JPL, EMPA, SEM, and culturing facility at the Open University, and a TEM at Leicester University.

Stone, William/Stone Aerospace
THOR (Thermal High-voltage Ocean-penetrator Research platform)

Robotic exploration and life search on ocean worlds requires the ability to access habitable ocean environments concealed beneath thick ice crusts. Additionally, an instrument suite is required to perform the complicated task of autonomous life detection. We propose to address these technological and operational requirements for ocean world access with THOR, a robust cryobot capable of rapid (10 m/hr), deep (500+ m) subglacial access that carries an onboard science payload optimized for environmental characterization and life detection. THOR will be deployed at the eastern Skaftafell subglacial lake in Vatnajokull, Iceland where it will penetrate the thick ice cover of the lake. Successful fielding of THOR will mark the first cryobot descent into a subglacial lake, thus enabling unique investigations of both the lake's geomicrobiology and of CONOPS strategies for a cryobot's entry into, and descent through, a subglacial body of water. The THOR team leverages successful work from the VALKYRIE and SPINDLE projects and offers fidelity to PSTAR in the areas of Science, Science Operations, and Technology. a) Science: Investigations of the eastern Skaftafell lake will center around detecting and characterizing microorganisms in the water column and volcanic vents to decipher the contribution of chemical energy liberated from geothermal vs. glaciological processes. To aid these investigations, THOR will carry a suite of instruments chosen to characterize the environment of the ice and subglacial lake, with a specific focus on life-detection strategies. Onboard instruments will include a fluorescence spectrometer, a holographic microscope capable of imaging prokaryotic cells, an inorganic chemistry measurement suite, a transmissometer / backscattering sensor, and a water sampler. A nanopore DNA sequencer will be used on-site to analyze water samples acquired by THOR. Comparative analysis will utilize water column and vent material samples, which will be returned to the surface and analyzed. b) Science Operations: At Skaftafell the THOR cryobot will penetrate a 300 m thick glacier and enter the subglacial lake

in the volcano's crater. Upon reaching the ice-water interface, the cryobot will transition into an instrument sonde and spool itself to the lake floor while sampling and analyzing the water column. This penetrator-to-sonde strategy is a new step-wise approach to the initial exploration of an alien ocean. As the vehicle descends input from the sensor suite will govern decision-to-collect behaviors to trigger processes such as water sampling. The system will be retrieved after each mission and we anticipate completing several descents in each of two field seasons. Exploring methods which could be used to detect extant life on ocean worlds is of high importance. To that end, we will assess how well and in what ways the suite of instruments function together to determine whether life is present and at what quantities. Conventional limnological and microbiological techniques using water samples acquired by THOR will be used to evaluate autonomous sampling decisions. c) Technology: The cryobot design will use a closed-cycle hot water drill approach wherein the water is heated in a novel way: high voltage is applied across a flowing column of water, which serves as the resistive element in an electro-resistive heater. Energy transfer from the electrical source to the water is instantaneous and occurs at 100% efficiency. Direct high voltage heating, combined with new insulation technology, makes possible a compact cryobot that is capable of rapid descent and deep subglacial access with a small field-logistics footprint. Given its simplicity, the cryobot will be inexpensive, easily deployable, and field serviceable. The THOR platform will enable unprecedented access to subglacial environments, making it an ideal payload delivery system for ocean worlds technology development and analog research in this PSTAR project and beyond.

Rader, Erika/University of Idaho

IceCrystal: Portable instrument protocol to delineate ancient ice and water on Mars using microcrystallinity of volcanic products.

Introduction: The zone of interaction between water or ice and lava has been proposed as a potential habitat for microbes on Mars, therefore the ability to detect regions of past water or ice-lava interaction on Mars will help future missions target specific areas where signs of life may be found. These interactions are preserved in the rock record because lava that interacts with water or ice, even briefly, will quench or freeze rapidly preventing further crystallization from occurring at that margin. As rocks become progressively less glassy and more crystal-rich, they emit higher levels of reflected light, meaning the crystal content can be detected with VNIR and FTIR spectroscopy. However, as there are several factors that influence overall reflectance, including whole-rock chemistry, the number of phenocrysts originating in the magma chamber, and the influence of alteration minerals which may have formed from more modern atmospheric processes. Therefore, a robust method to identify regions of water/ice-lava interactions on Earth and Mars requires analyses of bulk chemistry, phenocryst count, and degree of alteration in places which erupted lava into ice, water, and in dry conditions.

To recommend how to locate these areas on Mars we will first characterize the whole-rock chemistry, the degree of alteration, mineralogy, and the crystal texture of three terrestrial analog sites with different hydrologic environments and second determine the fastest instrument protocol for the detection of rapidly quenched lava margins (Fig. 1). Locations include the Lost Jim flow in Alaska, the Holuhruan flow in Iceland, and the Blue Dragon flow at the Craters of the Moon in Idaho, where lava interacted with ice, water, and at dry conditions, respectively. All three sites exhibit surface features (e.g., rootless cones) similar to those described at Cerberus

Palus and Martes Valles on Mars commonly cited as evidence for lava-water interaction, have similar bulk chemistry, suffered little physical and chemical weathering, and erupted in similar geologic settings, allowing us to pinpoint the effect of environmental conditions (presence of water) on lava morphology/crystallinity and allow us to make recommendations for identifying past water-rich environments on Mars.

Goals and objectives: (1) Science: Characterize the spectral signature of mafic lava margins quenched in hydrous and icy environments (PI Rader, 2 graduate students, Co-I Bishop and undergraduate student). (2) Science Operations: Develop a protocol for sample prioritization to focus on finding ancient microbial habitat during Mars exploration (Co-I Sehlke, PI Rader). (3) Technology: Produce recommendations for the use of portable instruments to enable rapid and detailed geologic mapping using the bulk chemistry of volcanic rocks on Marsý surface by humans and/or rovers (Co-I Sehlke).
Methodology: Protocols for the usage of spectrometers for the detection of water/ice-lava interactions in the absence of alteration do not yet exist, although similar science instruments are currently in use or are planned to be deployed during future rover mission on Mars (Table 1). We propose to use spectrometers for in-situ measurements, including a handheld visible near-infrared (VNIR), Fourier-transform infrared (FTIR), X-ray fluorescence (XRF), and a laser induced breakdown spectrometer (LIBS) to build a protocol by finding cutoff values which correspond to different environmental conditions of lava flow emplacement. Our resulting operational protocols will leverage the capabilities of all four portable instruments and sampling requirements to identify regions where lava interacted with water or ice, which will help streamline the search for ancient life on Mars, inform us about cooling rates in lava flows within hydrologic environments on Earth, and provide a simple decision tree to characterize geochemistry to understand Mars petrogenesis.

Sobron, Pablo/SETI Institute
In-situ Vent Analysis Divebot for Exobiology Research (InVADER)

InVADER will study underwater hydrothermal systems at Axial Seamount, the largest and most active volcano on western boundary of the Juan de Fuca tectonic plate off the coast of Oregon. The vents at the Axial Seamount generate chemical energy which can sustain life, and are high-fidelity analogues to putative vent systems on Ocean Worlds.

Our investigation will include in-situ observation, real-time data gathering and interpretation, and sample collection, analysis, and return. To support these efforts, we propose a research program with three main goals.
Goal 1 - Science: Characterize the geochemistry, geobiology, and metabolic activity in Axial Seamount as an analog for planetary exploration. We will identify active microbial metabolisms in hydrothermal environments through in-situ and laboratory analyses of returned samples. In parallel, we will characterize the mineralogy, hydrothermal fluid characteristics, and geological context of vent systems.
Goal 2 - Science Operations: Validate science operations strategies, adaptive science data processing, and instrument control. We will: perform laboratory LRS/LIBS/LINF measurements of hydrothermal fluid and mineral samples; test science operations and science planning strategies in the field; develop data fusion strategies for the synergistic visualization and

exploitation of science data; and develop, test, and validate new exploration strategies based on in-situ laser sensing and sample coring.
Goal 3 - Technology: Demonstrate InVADER's astrobiology technology. We will: performance-test InVADER with natural samples (both fluid and precipitates) from hydrothermal vent sites; deploy InVADER and perform in-situ analyses in Axial Seamount; develop routines for recording imaging and spectroscopic data, first level science data processing, and sample caching, analysis, and return.

To implement these Goals, we will integrate and deploy an astrobiology payload that features a combination of rapid, in-situ, standoff analyses and sample coring instruments: stereo optical imaging; laser Raman spectroscopy, laser-induced breakdown spectroscopy, and laser-induced native fluorescence (LRS/LIBS/LINF); and a coring tool. Both the imaging and coring systems have been successfully tested underwater. The spectroscopy suite is a replica of an existing TRL 4 system for planetary exploration. We will install the payload into the OOI Cabled Array, a chain of power/data distribution nodes connected by subsea telecom cable.

InVADER will integrate a payload containing 3D visual mapping and LRS/LIBS/LINF technologies into a divebot. This payload will enable standoff determinations of: a) relevant disequilibria in vent systems, b) composition and mineralogy of hydrothermal chimneys and associated precipitates, c) relevant small-scale features that are indicators of vent geochemistry and/or habitability, and d) the presence and distribution of organics. Thus, the project is relevant to PSTAR's overarching objectives and addresses multiple areas of Science, Technology, and Science Operations fidelity.

While these vent characteristics can be analyzed using existing technologies, such analyses cannot, at present, be conducted simultaneously, in an autonomous, non-destructive rapid way. InVADER aims to fill these gaps, and advance readiness in vent exploration on Earth and ocean worlds by simplifying operational strategies for identifying and characterizing seafloor vents. We will integrate and apply a novel technology package for the search for signatures of life in extreme underwater environments, thereby addressing the call for "development and application of technologies that support science investigations ... and identification of life and life-related chemistry in extreme environments."

Our team brings expertise in geochemistry, mineralogy, and astrobiology of hydrothermal systems, as well as ocean engineering, spectroscopy, robotics, science operations, and analog research.

Edwards, Christopher/Northern Arizona University

Linking Thermophysical Properties of Earth to Mars: Analog Investigations of Past and Present Habitable Environments

Science Goals & Objectives:

Understanding surface physical properties, linkages to geologic origins, and current/past habitability are key goals of thermophysical investigations on Mars. Lab studies that link physical properties to their thermal behavior are often hindered by sample size, the diversity of environments and most importantly, the complexity of natural landscapes. Recurring Slope Lineae (RSL) may represent the expression of present-day liquid water and are compelling in that they have driven a significant re-evaluation of how liquid water and habitability on present-day Mars.

Pore-filling fluids significantly increase the thermal conductivity of the bulk material and this property has been used to constrain the water content of RSL using Thermal Emission Imaging System (THEMIS) data, though the lower bounds were unable to be constrained with existing data. We propose to make measurements that represent data currently available and likely to be available on future missions simulated by our field team and an Unmanned Aerial Vehicle (UAV), with the ultimate goals of: 1) characterizing the variability in thermophysical properties of analog RSL-like terrains, and 2) assessing the measurements necessary (e.g., time of day, pixel scale, topography quality, albedo, etc.) to constrain soil moisture content based on remotely sensed thermophysical data.

Methodology:

Three specific tasks meet science objectives and produce data useful for current and future Mars missions.

Task 1. Acquire a ýfull suiteý of observations over a uniform field site and relate this to a thermal model. Light Detection and Ranging (LIDAR) topography, structure from motion imagery, hyperspectral visible-near infrared (0.4-1.5ým), and thermal infrared data of an aeolian sand dune will be acquired over multiple diurnal cycles. These data, when paired with solar and atmospheric flux measurements. will be used with our COMSOL-based thermal model to baseline our modeling approach. In situ measurements of the dune will be made with a commercial thermal effusivity measurement instrument, simulating a non-invasive rover-based approach. We will characterize the geologic context and collect samples for grain size analysis to compare to other measurements.

Task 2. Acquire a ýlimited suiteý over multiple field sites. A reduced dataset (similar to what would be available form orbit) will be acquired (visible-near infrared imagery, thermal infrared data) over multiple diurnal cycles and input into our model. Field sites to be visited include alluvial fans, lacustrine sedimentary deposits, and playas with varying soil moisture contents in addition to the sand dune site in Task 1 for cross comparison. Each field site will be characterized to assess geologic context and soil moisture with samples collected for grain size analysis.

Task 3. Synthesis. We will degrade our data to assess the ability of remote sensing infrared data to discriminate between different terrain. This work place constraints on capabilities of current instruments and guide future instruments on upcoming missions. Simulations to derive thermal

inertia and water content will be run and the sensitivity to input parameters assessed (e.g. lower quality DEM, incorrect albedo, pixel size etc.).

Relevance to PSTAR: Our proposed work is strongly responsive to and directly addresses the Science and Technology objectives of PSTAR. This proposal aims to 1) ýfurther planetary research in terrestrial extreme environments that may be analogous to those found on other planets, past or presentý as we investigate how thermophysical data can help constrain present habitable environments from orbit and landed missions on Mars and 2) this proposal will use commercially available off the shelf instruments to test and apply ýtechnologies that support science investigationsý, specifically from ýmobile science platformsý.