Science Plan
University Rover Challenge 2025

TEAM MOUNTAINEERS

West Virginia University
Team Mountaineers

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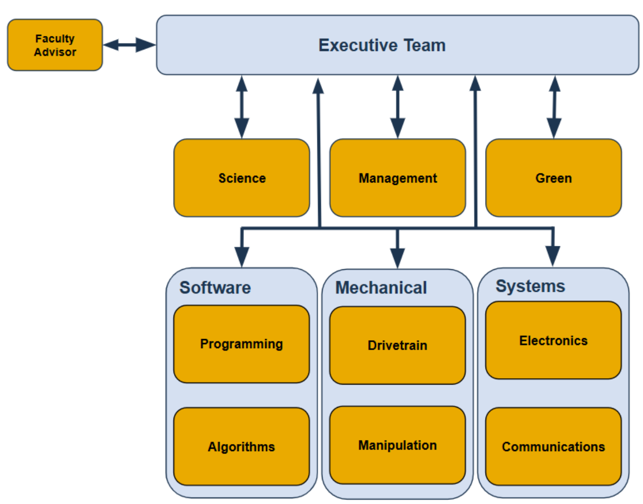
Chemical Safety Plan Status:
We have submitted requested revisions on May 16th and are awaiting final approval.



Basic Knowledge About Mars

Since 1997, six robotically controlled rovers have landed on Mars, with two currently in operation. NASA's *Perseverance* rover was the last successful voyage to land on Mars, containing several instruments within the payload to discover the unknown history of the foreign planet [1]. Mars is Earth's closest planetary neighbor, exhibiting distinct seasons of varying lengths due to its elliptical orbit, and has a daily cycle comparable to Earth at 24.6 hours [2]. While environmental differences are superficially observable between the inhospitable atmosphere of Mars and the ecosystem of Earth, certain biosignatures may lie unexplored, only seen through organic chemical analysis. This interpretation has led much research to focus not on the present Martian environment, but rather on Mars' early conditions and climate change over time. NASA clearly outlined several mission objectives: identification of past habitability, collecting evidence for microforms of life, forming hypotheses from cached rock samples for life preservation, and examining the composition of Martian atmosphere [1].

Much verification has led to the conclusion that water once was present to form the meandering valleys of the "Red Planet". The red color of Mars is caused by iron oxide presence, as the soil rapidly reacts with oxygen under cool conditions [3]. Recent studies have concluded that a primary Martian iron oxide is ferrihydrite, which forms by subsequent oxidation and hydrolysis, suggesting ancient water activity [4]. Geological evidence suggests that either water or lava flows created morphological changes on the surface of Mars, with recurring slopes from liquid movement on the surface still being investigated [2]. Evaporites and hydrous minerals commonly generate through aqueous processes and were found during Mars exploration, showing that Mars had an active hydrological cycle in the past similar to Earth [5].

Mars has a thinner atmosphere when compared to Earth, composed of mostly carbon dioxide, nitrogen, and argon gases [4]. Earth's more substantial atmosphere houses primarily nitrogen and oxygen, where the argon and carbon dioxide concentrations are significantly lower. This thin atmosphere on Mars has several biological consequences, such as the inability to retain liquid water on its surface, extraordinary wind speeds exceeding 68 miles per hour, and incredible temperature fluctuations ranging from -153 degrees Celsius to 20 degrees Celsius [4]. Past traces of a magnetic field seem to be congregated in soil samples near the southern hemisphere, with its absence leading to notable atmospheric erosion [5].

The Martian environment is terrestrial, composed of iron, magnesium, aluminum, calcium, and potassium in its outermost layer [4]. From NASA's Phoenix Lander, it was discovered that the soil is slightly alkaline with a pH range between 8 and 9. Other minerals such as magnesium, sodium, potassium, and chloride were found in the soil, which are essential macronutrients for plant growth, sustainability, and cell membrane maintenance [4]. Collected rock samples indicate the presence of both igneous and sedimentary rocks, providing insight that the solidification of molten rock once occurred on Mars. Silica-cemented carbonate has also been discovered, showing the possibility of past water sources as silica precipitated to form this alternative rock structure [4].

Several impact craters have been identified on the Martian surface, showing the active shaping of the environment being continually changed. The individual crater diameter and clustering has been observed to be increasing over time. Valles Marineris is another distinct Martian feature, with dimensions of 4,800 kilometers in length, 320 kilometers in width, and 7 kilometers at its deepest point [4]. Additionally, Olympus Mons is located on the Marian equator, a shield volcano that is 21.9 kilometers tall and the largest volcanic structure in the solar system [4]. Earth and Mars are also the only planets in the inner solar system that contain moons. Its two moons, Phobos and Deimos, were formed either from asteroids falling into planetary orbit or through debris remaining from a prior collision [2].

Current findings have significantly advanced our understanding of potential for past life on Mars, as well as the planet's present-day habitability. Future rover missions can give researchers valuable insight on the planet's surface geochemistry, thermal gradients, and soil composition.

[1] "Perseverance Science Objectives - NASA Science." Available: https://science.nasa.gov/mission/mars-2020-perseverance/science-objectives/; [2]"Mars | Facts, Surface, Moons, Temperature, & Atmosphere | Britannica." Available: https://www.britannica.com/place/Mars-planet; [3] R. Joseph, R. Dass, V. Rizzo, N. Cantasano, and G. Bianciardi, "Evidence of Life on Mars?," 2019, Available: https://www.astro.umd.edu/~hamilton/HONR289V/Handouts/LifeOnMars.pdf; [4] H. H. Kieffer, B. M. Jakosky, C. W. Snyder, and M. S. Matthews, *Mars*. University of Arizona Press, 2018.; [5]Z. Wu *et al.*, "Earth-like thermal and dynamical coupling processes in the Martian climate system," *Earth-Science Reviews*, vol. 229, p. 104023, Jun. 2022, Available: https://doi.org/10.1016/j.earscirev.2022.104023

Background Research

During our preliminary background literature review, our science-focused team members compared internal documentation from prior team databases to NASA methodologies for life detection. According to *The search for life on Mars: The role of rovers*, scientists primarily focus on four central aims of spacecraft bioform identification: reconstructing a history of evolutionary processes of Martian climate, identifying life's precursors within extraterrestrial soil, examining past biosignatures, and uncovering present organic material [6]. The paper continues to discuss notable features of a rover needed to accomplish these goals, including a high mobile robotic arm and onboard biological instrumentation [6]. This information served as our initial foundation of knowledge, allowing our team to develop a framework for integration of geographical characteristics at sampling locations, lithological indicators of life, and chemical analysis of soil collections.

Two key journal articles were utilized in early understanding of geological observations and criteria for analysis near the MDRS Study Area. *Regolith geology and geomorphology* provided our team with the composition of a comprehensive stratigraphic profile, as well as the preservative properties of regolith and patterns of water associated mineralogy when soil cracks [7]. The author observes that clay commonly displays aggregated sequences of cracking to support plant growth and retain water [7]. This background is essential for the assessment of extant and extinct life potential in soil, showing rover operators promising drill locations. Additionally, the *Web Soil Survey* database was explored to evaluate Utah soil, specifically the regolith classification of MDRS sites, for optimal sampling [8].

Visible spectroscopy was selected as our principal method in soil analysis, due in part to literature confirmation, prior success in preparatory testing, and opinions from experts in the field. From our team's findings, we can display a visible absorption spectrum by plotting absorbance versus wavelength, where electrons transition between orbitals and manifest as distinct peaks in the absorption spectrum. An excerpt from *Structure Determination in Conjugated Systems* states that molecules detectable in low amounts by spectroscopy present strong electron energy absorption, which is typically characteristic of delocalized electron systems within organic compounds [9]. These highly conjugated systems absorb in the visible region rather than UV, thus appearing colored in nature [9]. Longer wavelengths reveal the extent of molecular conjugation, and two abundant substances in soil defined by these properties include carotenoids and chlorophylls [10]. Carotenoids occur in plants, algae, and bacteria for antioxidative purposes, while chlorophylls a/b create chemical energy within green plants [10]. Our science team determined the peak of common carotenoids and chlorophyll to reside at approximately 450 nm and 550 nm respectively. Spectra from egg yolk and carrots containing carotenoids, and oak leaves with chlorophyll were stored as reference captures to compare against samples obtained during competition.

As secondary confirmation of spectra results, we were informed by the Environmental Soil Chemistry department of WVU that the Baeyer's visual assay could be enacted to verify biopigments in soil samples. It was determined that Baeyer's reagent should be added dropwise to the existing cuvette of soil and isopropyl alcohol as a solvent, and can be validated with new spectrometer readings for potential color changes. Experimentation also established that Baeyer's reagent can resist large temperature fluctuations possible at the MDRS. Further testing found that neither spectroscopy nor Baeyer's test could support the presence of carbonates in soil, which are important to signify extinct life [7]. The following *Fizz Test Fact Sheet* directed our team to pursue carbonate content testing through dilute hydrochloric acid reactions, indicating detection as low as 1 mg of calcium carbonate in isopropyl alcohol solution from our investigation [11]. To assure correct following of chemical waste, health, and safety procedures by team members, supplementary steps were taken to approve all techniques through the WVU Environmental Health and Safety department, and Materials Science and Engineering faculty.

[6] C. Stoker, "The search for life on Mars: The role of rovers," *J. Geophys. Res.*, vol. 103, no. E12, pp. 28557–28575, Nov. 1998, doi: 10.1029/98JE01723; [7] G. Taylor, R. A. Eggleton, and R. A. Eggleton, *Regolith geology and geomorphology*. Chichester Weinheim: Wiley, 2001; [8] "Web Soil Survey." Available: https://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx [9] "14.7: Structure Determination in Conjugated Systems - Ultraviolet Spectroscopy," Chemistry LibreTexts. Available: https://chem.libretexts.org [10] B. S. Gebregziabher *et al.*, "Simultaneous Determination of Carotenoids and Chlorophylls by the HPLC-UV-VIS Method in Soybean Seeds," *Agronomy*, vol. 11, no. 4, p. 758, Apr. 2021, doi: 10.3390/agronomy11040758.; [11] "On-Farm Fizz Test Fact Sheet." Grains Research & Development Corporation, Oct. 2022. Available: https://grdc.com.au/__data/assets/pdf_file/0025/581272/GRDC_FS_OnfarmFizz_2203_06.pdf

Science Payload

To address the scientific requirements of the University Rover Challenge and investigate questions posed during our background research, we describe the primary objective of Daedalus as combining topographic data and readings from soil biosignatures that support the presence of extant and extinct lifeforms. Our fundamental science objectives can be accomplished through our science payload, which consists of a wide-angle and pannable cameras, a subsurface drill, surface soil collectors, peristaltic pumping system, an onboard visible light spectrometer, and two separate reagent tests for life detection. When approaching the science mission, the team will firstly prioritize discovering favorable geological conditions for biotic proliferation via use of integrated rover cameras. Once an advantageous site has been recognized, the rover will utilize its instrumentation to test soil samples for ancient and existing organic matter. Documentation of each site visited will be comprised of both close proximity and stitched panoramic images, along with evaluations of our biological testing. The site with the highest estimated potential for life will undergo further analysis through the completion of stratigraphic layer profiling, collection of subsoil samples, and temperature and moisture assessment from soil. These surveys of sediment patterns, water erosion, and loss of soil moisture will be used to develop conclusions between extinct and extant soil distributions at the site.

For initial site selection and characterization, the rover uses an array of wide angle cameras. Close-up images will be taken of surrounding rock strata as well as other features of interest. A wide-angle, pannable camera will be used to capture images in every direction. These images will then be stitched together using the OpenCV library to create a composite panoramic image. All images will be automatically annotated using OpenCV with information from our onboard Pixhawk flight controller. These annotations include elevation, latitude, longitude and error bounds. The stratigraphic profile will be created through manual annotation. Lengths and distances within the images will be calculated with a photogrammetric method from known object sizes and relative distances in the image, pixel distances, and camera focal length. High resolution images received guide rover operators in selecting sites based on observed depositional sequences and identify sedimentary strata most likely to preserve biological traces. Fluvial distributions are characteristic of water systems that may still house extant species, and given that life expressly relies on water as a primary building block, the discovery of such evidence serves as a compelling target for habitability [12]. Another key component to fundamental life generation includes elemental carbon and associated organic matter, which can be contained within distinct geological structures found at the MDRS such as Mancos Shale morphologies from the Late Cretaceous period [12]. Bituminous coal, peat, and shale are considered to be common rocks of biogenic origin, forming under intense pressure and temperature to create a time capsule for a diversity of ancient biota to inhabit [13]. Insights from *The Regolith Geology of the MDRS Area* [13] illustrated the behavior of regolith cracking patterns in the MDRS region, which will support sample collection efforts in nutrient-rich biomes and territories with prior water activity.

After selecting testing sites, surface soil will then be collected and analyzed. To collect surface soil samples, a surface collection package consisting of two rotating scoops and four pumps will be used. The rotating scoops are housed on linear actuators to precisely control their depth as they are lowered. The scoops feature serrated blades to assist in breaking up compact soil and funneling samples into the mixing chamber within each scoop. Once an adequate amount of soil is collected, 70% isopropyl alcohol is then pumped into the mixing chamber via peristaltic pumps to create a soil slurry solution. This solution is then pumped out of the mixing chamber via a second pump into a cuvette within a rotating carousel onboard the rover for further analysis. Up to four cuvettes will be filled with the soil solution [12] per sample site. The tubing, cuvettes, collectors, and pumps are fully separated for each site to avoid contamination. An internal view of the science payload is shown in Figure 1. A view of the external payload components is shown in Figure 2.

Once surface soil is collected and transported to the cuvette carousel, a sequence of tests are performed. Spectroscopy, which acts at the first soil test, is an integral part of biological testing on the rover. Each soil sample will be rotated in front of and analyzed by the onboard visible light spectrometer. Organic matter typically contains biochromes that are necessary to absorb sunlight for photosynthesis

[12] A. Barnett, "Ingredients for Life," NASA, https://europa.nasa.gov/why-europa/ingredients-for-life/; [13] J. Clarke (2003), "The Regolith Geology of the MDRS Study Area," https://www.researchgate.net/publication/253136403;

as well as maintain the biological integrity of organisms [14]. These pigmented molecules include naturally occurring chlorophylls and carotenoids that provided unique wavelength spectra during our extensive experimentation [10]. If biological pigments are undetected, this can exclude the possibility of terrestrial autotrophic species residing in cached soil samples [14]. Two other notable features of organic pigments include their unsaturated hydrogen deficient structure and the antioxidative properties they possess [15]. Both factors are crucial for the second test, the Baeyer's reaction. Potassium permanganate, anhydrous sodium carbonate, and deionized water are used to form the purple reagent, which shifts to a transparent color with a brown precipitate in the presence of alkenes, alkynes, aldehydes, and some alcohols [16]. Baeyer's reagent exposes redox-protecting chromophores that contain these functional groups to increased oxidative stress, while also reducing the permanganate to equilibrate [14]. The Baeyer's test can produce a colorimetric change in soil with a minimum of 0.10 mg/mL of unsaturated compound concentration within approximately 30 seconds. Such compounds may include lipids, nucleic acids, and various pigment molecules. A major indicator for extinct life is carbonate abundance due to its preservative abilities during biomineralization, however, its chemical structure is not detectable by our spectrometer [7]. The third test, the fizzing carbonates test, aims to detect byproducts of these extinct organisms [11]. Hydrochloric acid will be added to the soil solution, causing neutralization of carbonate ions and a release of carbon dioxide gas observable through effervescence [11]. Cameras mounted within the rover can visually determine the result of the Baeyer's and fizzing carbonates tests, while the spectrometer can verify any color changes from the Baeyer's test.

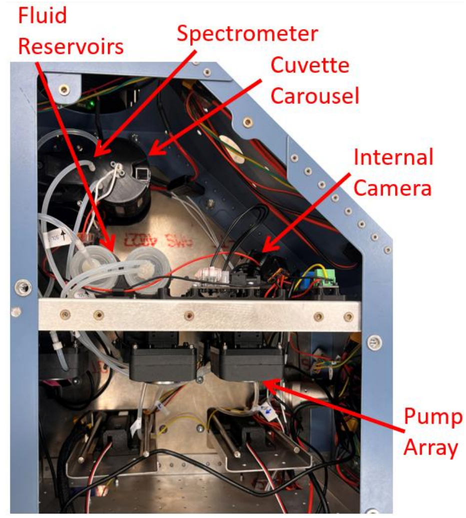


Figure 1: Internal science Payload.

In order to determine the location for the subsurface soil collection site, our life detection experiments are compared with observations of geological features that indicate elevated moisture levels such as vertisols which can contain surface mud cracks. A subsurface sample will be collected using the onboard drill assembly. This assembly features an auger within an aluminum tube that elevates the soil as it is drilled. The drill assembly is mounted to a high-strength linear actuator, providing precise depth control. Above the desired 10 cm sample depth, soil is ejected out of the side of the assembly through an open cavity. When the drill reaches the desired depth and all soil remaining within the tube is flushed out of the side cavity, a servo motor rotates an internal shunt. This shunt seals the external cavity and unseals the soil collection cache. The drill is then lowered to depths of up to 20 cm and all additional soil is retained. Once an adequate volume of soil collected is verified via an onboard camera, the soil shunt is rotated backwards and the cache is once more sealed. A second linear actuator with a temperature probe and a soil capacitance probe is then lowered into the hole to provide temperature and moisture data at depth. From the measured conductivity of the soil, the relative moisture content is determined via an experimentally derived relationship between percent moisture saturation and capacitance, calibrated with regional soil property data to correct for confounding factors, like soil density and salinity [8].

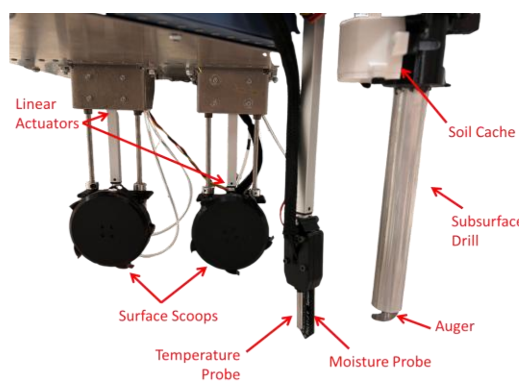


Figure 2: External Science Payload

[14] H.-D. Martin, "The Function of Natural Colorants: The Biochromes," *Chimia*, vol. 49, no. 3, p. 45, Mar. 1995, doi: 10.2533/chimia.1995.45. [15] E. E. Jaffe, "Pigments, Organic," in *Kirk-Othmer Encyclopedia of Chemical Technology*, 1st ed., Kirk-Othmer, Ed., Wiley, 2004. doi: 10.1002/0471238961.151807011001060605.a01.pub2. [16] Francisco Sánchez Viesca and Reina Gómez Gómez, "A complete and sustained organic/inorganic reaction mechanism of Baeyer's test," *World J.Chem. Pharm. Sci.*, vol. 4, no. 2, pp. 001–005, May 2024, doi: 10.53346/wjcps.2024.4.2.0023.

Science Question: Why is the confirmation of serpentine on Mars significant?

Serpentine, a group of hydrous magnesium-iron phyllosilicate minerals, forms through the process of serpentinization: a reaction involving ultramafic rocks like olivine-rich basalts and the presence of liquid water [17]. This process produces key elements necessary for life and may have assisted in warming the Martian surface [18]. The postulation [18] and confirmation [19] [20] of serpentine on Mars provides evidence for past hydrothermal activity and potential conditions for life, as well as insight into the planet's geologic and climatic evolution [21].

Serpentinization is a key indicator of past aqueous activity. Mars contains olivine-rich basalts, particularly in regions like Nili Fossae and the Isidis Basin [20] and is found in Noachian- and Hesperian-period deposits. In serpentinization, olivine reacts with liquid water at moderate temperatures around 300°F to produce serpentine, brucite, magnetite, and hydrogen [21]. Abiotic hydrogen is produced significantly more in iron-rich deposits due to the oxidation of ferrous to ferric iron in the presence of water [23].

$$\text{Olivine} + \text{H}_2\text{O} \rightarrow \text{Serpentine} \pm \text{Brucite} \pm \text{Magnetite} + \text{H}_2 \text{ [23]}$$

Although liquid water rarely exists on Mars' surface due to the planet's thin atmosphere, there is evidence that subsurface liquid water existed below the permafrost [18]. In those subsurface regions with low temperature and an aqueous environment, serpentinization is thermodynamically favorable [18]. The aqueous environment due to serpentinization is highly alkaline [20], which, coupled with the production of abiotic hydrogen, provide the conditions and energy source necessary to sustain chemolithotrophic lifeforms [18].

Outside of the aqueous environment, the H_2 produced from oxidation reacts with CO_2 to form methane and water. From atmospheric methane concentrations, it is likely that extensive serpentinization occurred in early Mars history [18]. This production of H_2 and CH_4 increased the atmospheric ambient temperature and likely had some contribution to the fluctuations of the climate during the Noachian and Hesperian periods [24].

Mapping by the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) has revealed serpentine in key locations such as Nili Fossae, Claritas Rise, and the Isidis Basin, often associated with ancient Noachian terrains [20] [22]. These regions are known to host other hydrous minerals, further supporting evidence of aqueous conditions [19]. Due to the distribution and geologic contexts of the serpentine deposits, it is unlikely that one single mechanism accounts for the formation of serpentine and the local environmental conditions. However, the conditions for serpentinization during the Noachian period in the Nili Fossae grabens suggests favorable conditions for microbial life [20]. This makes serpentine-bearing regions prime targets in the search for biosignatures or extant subsurface life [22]. This astrobiological importance is amplified when considered alongside other minerals such as fougerite and mackinawite, which also support redox reactions conducive to prebiotic chemistry [21]. These findings underscore serpentine's importance in Mars exploration and make it a focal point for future missions investigating the planet's potential to harbor life.

[17] L. Schwander, M. Brabender, N. Mrnjavac, J. L. E. Wimmer, M. Preiner, and W. F. Martin, "Serpentinization as the source of energy, electrons, organics, catalysts, nutrients and pH gradients for the origin of LUCA and life," *Front. Microbiol.*, vol. 14, Oct. 2023, doi: 10.3389/fmicb.2023.1257597. [18] C. Oze and M. Sharma, "Have olivine, will gas: Serpentinization and the abiogenic production of methane on Mars," *Geophysical Research Letters*, vol. 32, no. 10, p. 2005GL022691, May 2005, doi: 10.1029/2005GL022691. [19] B. L. Ehlmann et al., "Identification of hydrated silicate minerals on Mars using MRO-CRISM: Geologic context near Nili Fossae and implications for aqueous alteration," J. Geophys. Res., vol. 114, no. E2, p. 2009JE003339, Feb. 2009, doi: 10.1029/2009JE003339. [20] B. L. Ehlmann, J. F. Mustard, S. L. Murchie, "Geologic setting of serpentine deposits on Mars", Geophysical Research Letters, Mar. 2010, doi: 10.1029/2010GL042596. [21] A. Emran, J. D. Tarnas, and K. M. Stack, "Global Distribution of Serpentine on Mars", AGU Journals, Jan. 2025, doi: 10.1029/2024GL110630. [22] M. Russell and A. Ponce, "Six 'Must-Have' Minerals for Life's Emergence: Olivine, Pyrrhotite, Bridgmanite, Serpentine, Fougerite and Mackinawite", MDPI, Nov. 2020, doi: 10.3390/life10110291. [23] T. M. McCollom, F. Klein, B. Moskowitz, and P. Solheid, "Experimental serpentinization of iron-rich olivine (hortonolite): Implications for hydrogen generation and secondary mineralization on Mars and icy moons," Geochimica et Cosmochimica Acta, vol. 335, pp. 98–110, Oct. 2022. doi:10.1016/j.gca.2022.08.025. [24] Wordsworth, R., Knoll, A.H., Hurowitz, J. et al. A coupled model of episodic warming, oxidation and geochemical transitions on early Mars. Nat. Geosci. 14, 127–132 (2021). https://doi.org/10.1038/s41561-021-00701-8