Science Plan
University Rover Challenge 2024

West Virginia University
Team Mountaineers

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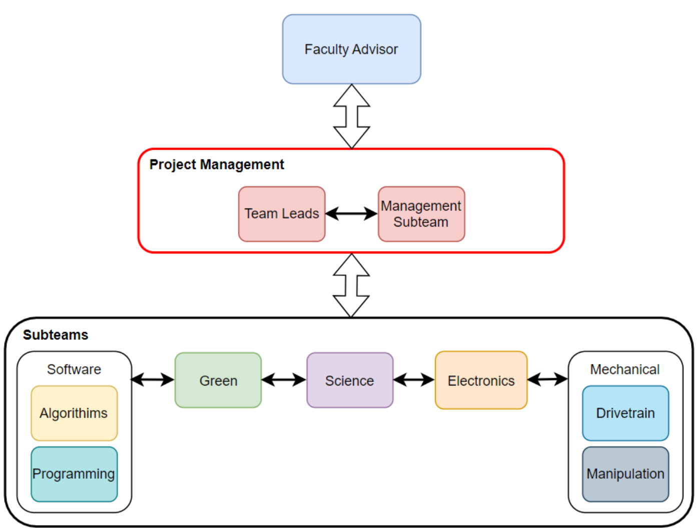
Chemical Safety Plan Status:
We have submitted requested revisions on May 16th and are waiting on final approval.



Basic Knowledge About Mars

NASA describes Mars as a planet “entirely inhabited by robots” [1]. Mars is Earth’s closest neighbor in the solar system with the most similar environment, yet is inhospitable to humans. The first Mars rover landed on the planet in 1997, and collected information about the planet’s core, atmosphere, and potential history of liquid water [2]. Since then, five more rovers have successfully landed on Mars, gathering valuable data that gives scientists a better understanding of the planet and its environment [3].

Mars is commonly referred to as the “Red Planet” due to its distinctive red surface. The coloring is caused by the soil of the planet oxidizing when in contact with the iron minerals in rocks, regolith, and dust. The dust is blown into the atmosphere and makes the planet appear red [4].

Despite being half the size of Earth, the surface area of Mars is similar to the total area of dry land on Earth. One of the distinct features of Mars’ geology is a large canyon system known as Valles Marineris that is measured to be more than 4,800 kilometers in length, 320 kilometers at its widest, and 7 kilometers at its deepest. Mars also is home to the largest volcano in the solar system, Olympus Mons, which is three times taller than Mount Everest. Study of the planet’s geology, river valley networks, deltas, and lake beds have revealed indicators of the presence of water in the past [4].

Many discoveries have also been made about the internal and external structure of Mars. Like other planets in the inner solar system, the planet is terrestrial, with a core, mantle, and solid crust. The core of Mars is measured to be between 1,500 and 2,100 kilometers and is made of iron, nickel, and sulfur. A rocky mantle surrounds the core between 1,240 and 1,880 kilometers in width. The crust is the outermost layer of Mars’ structure and is between 10 and 50 kilometers thick and composed of iron, magnesium, aluminum, calcium, and potassium [4].

One of the defining characteristics of Mars is the two moons, Phobos and Deimos, that orbit around the planet. Both of the moons are asteroids that were pulled into Mars’ orbit. Due to their low mass, gravity does not cause the moons to become spherical; they remain the same shape that they were when pulled into orbit. In around 50 million years, Phobos, the larger of the two moons, is predicted to collide with Mars or split apart [4].

Mars’ atmosphere has a similar composition to Earth’s. It is composed of carbon dioxide, nitrogen, and argon. The atmosphere of Mars is very thin and does not provide much protection against meteorites, asteroids, and comets. The thin atmosphere leads to fluctuating temperatures that can range from -153 degrees Celsius to 20 degrees Celsius. The highest of temperatures occurs on the planet’s surface and quickly dissipates at further distances from the surface due to heat easily escaping the atmosphere. While the planet has no magnetic field, portions of the crust are magnetized, indicating the presence of a magnetic field in the distant past [4].

A day on Mars is similar to that of a day on Earth. Mars completes one rotation around the sun every 24.6 hours, and one year on Mars lasts 669.6 days. Mars also has distinct seasons that vary in length due to the shape of Mars’ orbit around the sun. In the northern hemisphere of the planet, spring lasts 194 days, autumn 142 days, winter 154 days, and summer lasts approximately 178 days [4].

The use of rovers also led to great discoveries about the composition of the soil on Mars. From NASA’s Phoenix Lander, it was discovered that the soil is slightly alkaline and has various different minerals that could theoretically support plants from Earth [5]. The pH of the soil was measured to be between 8 and 9, and magnesium, sodium, potassium, and chloride were the minerals found in the soil [5].

Rover missions have given scientists valuable insight on the planet’s geology, chemical composition, surface temperature, and soil chemistry. This information has led to great strides in determining if life ever existed on Mars and if it is possible for life to exist on the planet.

[1] “Mars - NASA Science”, NASA, https://science.nasa.gov/mars/; [2] “Mars Pathfinder - NASA Science,” NASA, https://science.nasa.gov/mission/mars-pathfinder/; [3] “Mars Exploration Timeline,” NASA,https://nssdc.gsfc.nasa.gov/planetary/chronology_mars.html ; [4] “Mars: Facts - NASA science,” NASA, https://science.nasa.gov/mars/facts/; [5] J. Minkel, “Pay Dirt: Martian Soil Fit for Earthly Life,” Scientific American, https://www.scientificamerican.com

Background Research

The first spacecraft to successfully land on Mars, Viking 1, focused its mission on investigating and searching for signs of life using a robotic arm and an internal biological laboratory [6]. The question of determining how to detect extant life on Mars resulted in the Ladder of Life Detection method that qualified "features of life as we know it, how specific [the features] are to life, and how [the features] can be measured" [7]. One of the features of the Ladder of Life Detection method for searching for extant life is to "examine biosignatures and establish context of the area" [8]. This definition became an important part of the team's research as it was decided to balance the studies of scientific analysis of soil samples with a geological/geographical analysis of the area where samples are taken.

When first beginning to research geological features and building a foundation of geological analysis, "The Regolith Geology of the MDRS Study Area" by Jonathan Clarke was a useful resource in helping to build an understanding of stratigraphic profiles and terrain of the area. The paper provided information on various formations with specific details about the member, age, and lithology of each. Clarke also remarks on the cracking and non-cracking regolith of the area, and what that may mean for the soil. Clarke describes that dissected plains of cracking clays indicate an arid environment that is not suitable for vegetation, while the presence of piping in the clay indicates that vegetation is possible and moisture is present in the ground [9].

One of the guiding factors in the team's decision to analyze soil samples through the use of spectroscopy was due to a study by K. John Scott about detecting carotenoids. His research focused on detecting carotenoids through visible-light spectroscopy due to their easy detection on the visible-light spectrum [10]. Carotenoids "are a class of phytonutrients and are found in the cells of a wide variety of plants, algae, and bacteria" [11]. Carotenoids often appear in foods that are red, yellow, or orange, and indicate a range of macro and micro organisms [11]. Based on Scott's testing, most carotenoids appear on the visible-light spectrum between 400 and 500 nm as their maximum wavelength [10]. Stemming from this research, the team then used a visible-light spectrometer to capture the maximum wavelengths on common carotenoids like egg shell, egg yolk, tangerine, and carrot. These captures from the spectrometer were then used as reference spectra to compare the collected soil samples against to check for the presence of carotenoids.

The Biuret colorimetric test became an option to use as a secondary form of detecting life, specifically through the presence of proteins. To help determine how a Biuret test could be tested on soil samples, the research article, "Influence of Soil Parameters on Protein Presence for a Mars Rover Analogue's On-Board Laboratory Setup" was consulted and helped to inform the team's decision to use this test [12]. Once a theoretical understanding of how a Biuret test should occur was achieved, multiple experiments were run in order to determine how the Biuret reagent should be used in the science package. Tests were run to determine the volume of Biuret reagent that should be used alongside the soil sample and isopropyl alcohol. In addition, experiments were run in order to determine whether a secondary chemical was needed to verify the color change of the Biuret test. Triton and Tween 20 were two options that were tested in addition to the Biuret reagent to ensure that the color change of the soil was due to the presence of proteins and not because of the soil color itself. The results of testing Triton and Tween 20 alongside the Biuret reagent did not result in a significant color change compared to the samples tested solely with the Biuret reagent. The team then decided to focus on using the Biuret reagent to test for a color change in the science package. After testing, it was also decided that in addition to the visual color change, the product should also be captured in the spectrometer to verify a change in wavelength had occurred.

[6] "Viking 1 - Mars Missions", NASA Jet Propulsion Laboratory, https://www.jpl.nasa.gov/missions/viking-1 ; [7] "Life Detection Ladder," Astrobiology at NASA, https://astrobiology.nasa.gov; [8] M. Neveu and L. Hays (2018), "The Ladder of Life Detection," https://www.liebertpub.com; [9] J. Clarke (2003), "The Regolith Geology of the MDRS Study Area," https://www,researchgate.net; [10] K. Scott, "Detection and Measurement of Carotenoids by UV/VIS Spectrophotometry," https://currentprotocols.onlinelibrary.wiley.com; [11] J. Szalay, "What Are Carotenoids?," LiveScience, https://www.livescience.com/52487-carotenoids.html ; [12] A. Olszewska and J. Napora, "Influence of Soil Parameters on Protein Presence for a Mars Rover Analogue's On-Board Laboratory Setup,"https://ieeexplore.ieee.org

Science Payload

The Science payload has been developed through an extensive process of research, rigorous testing, and expert guidance. The main objective of the robot, Heimdall, is to identify locations that support extant and extinct microbial life. To achieve this objective, the team will use on-board cameras to examine geological features that are suitable for supporting life. Upon finding potential sites for life, the instruments carried on board the rover will conduct tests to determine whether soil samples contain extinct and/or extant life. Every site visited will be documented with close-up images, panoramic images, and the results of life detection tests. Additional documentation, including subsurface samples, soil temperature and moisture measurements, and a stratigraphic profile, will be collected at the site with the greatest potential for life. This information will be utilized to ascertain the depositional environment and water history at the site.

The science payload uses wide-angle cameras to capture images for the stratigraphic profile with a panoramic photo at each site. Close-up images taken by on-board cameras document the geological features of the site visited as well as any impact the rover's analysis had on the geological environment. Both panoramic and close up images include cardinal directions, elevation, and scale indicators of sedimentary structures. The elevation, latitude, longitude, and error of the location where the image is taken is read from a Pixhawk flight controller of the rover and printed as text on the image through the Python Imaging Library. The image is then saved to the base station computer through a screenshot functionality on the graphical user interface (GUI). The scale for the stratigraphic profile is calculated using a photogrammetric method of determining the height of an object using the field of view of the camera used to take the image. Using data from the map in the GUI, the distance between the camera and the area of interest is estimated and used with the focal length of the camera to determine the height of each pixel on the image, allowing a sense of scale to be determined and labeled on the image. This method allows for determining the height of sedimentary structures that are not on the same distance plane, which can occur on gradual slopes of hillsides. Using Inkscape, the stratigraphic profile is generated by overlaying the scale and cardinal coordinates on the image and annotating it.

These images are used to justify sample site selection and identify historical depositional environments. Determining geological characteristics that are suggestive of liquid water is a primary objective in the pursuit of locating extant life, given that liquid water is the most fundamental component of life [13]. The investigation of the geology of the MDRS region has additionally stimulated the pursuit of specific formations, including the carbonaceous rocks of the Mancos Shale Formation. The formation of these carbonaceous rocks via chemical precipitation is an exceptionally effective method for preserving microbes that may have existed in the environment in ancient times. The article "The Regolith Geology of the MDRS Area" [9] was extremely helpful in providing insight into the cracking and non-cracking regolith in the region, which facilitated the collection of samples containing minerals and water that had previously been present. After identifying a suitable location, a variety of experiments are utilized to determine the existence of living or extinct life.

Figure 1: External View of Science Package

Soil samples are collected from the surface using three scoops, seven peristaltic pumps, and three drums by the scientific payload. A serrated metal blade is integrated into the capturing edge of the design in order to shear the naturally compacted, hard Utah Desert soil. As shown in Figure 1, every scoop is equipped with linear actuators for height adjustment and digital servos for rotation, enabling the collection and deposition of samples into a containment vessel located within the rotating

[13] "Ingredients for Life," NASA, https://europa.nasa.gov/why-europa/ingredients-for-life/; [14] G. Bergtrom, "Basic Cell and Molecular Biology 3e: What We Know & How We Found Out," https://dc.uwm.edu; [15] Y. Li, D. A. Collins, and K. Grintzalis, "A simple biochemical method for the detection of proteins as biomarkers of life on martian soil simulants and the impact of UV radiation," https://pubmed.ncbi.nlm.nih.gov/37240795/

scoop. Isopropyl alcohol is then transported to the containment vessel via pumps connected to a reservoir; the resulting solution is transferred to a cuvette in a twelve-slot rotating carousel. It is possible to collect four samples from three locations. Each sample is lit by a halogen bulb, and a visual light spectrometer is employed to conduct the analysis. A sample is treated with the Biuret reagent through another pump, and the resulting reaction is captured by a camera. The compartment within the chassis housing the carousel is lined with an alkali-resistant High Density Polyethylene sheet in order to contain any possible overflow of Biuret reagent.

The first test conducted on the rover uses the onboard spectrometer. Once a soil sample is collected, it is combined with 70% isopropyl alcohol in a cuvette contained within a carousel as shown in Figure 2. Biological pigments, including carotenoids and chlorophylls, are essential for photosynthesis [14] and are naturally occurring in various organisms [11]. Their distinct spectra provide easy detection by a spectrometer and indicate the presence of life. The absence of chlorophyll detection precludes the existence of metabolic phototrophs, whereas the absence of carotenoids detection eradicates a variety of micro and macro living organisms. Proteins are frequently present in soil to facilitate nitrogen fixation and other biochemical processes [15]. Secondarily, the rover employs the Biuret test to detect the presence of proteins. For the second test, hydrated copper(II) sulfate, sodium hydroxide, and sodium-potassium tartrate are utilized as the reagent. The reagent acquires an inherent blue hue upon dilution in water. When copper ions in Biuret reagent are exposed to peptide bonds, which connect amino acids to form proteins, they generate stable complexes between the bonds, resulting in the formation of a purple hue [12]. The Biuret test is capable of producing readable results in soil samples containing a minimum of 0.80 mg/ml protein concentration within approximately 25 seconds. A camera mounted in the robot can be utilized to visually inspect the outcome of the biuret test. The utilization of spectrometry as a secondary evaluation method verifies the visual change in color, thereby reaffirming the presence or absence of significant protein.

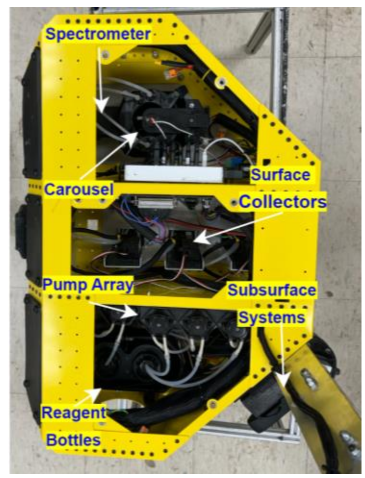


Figure 2: Internal View of Science Package

In order to determine the optimal location for the subsurface soil collection site, life detection experiments performed by the rover are compared with observations of geological features that indicate elevated moisture levels, including vertisols, and soil cracking characterized by surface mud cracks. The investigation of subsurface conditions is conducted by employing capacitive soil moisture and temperature probes. Through the use of a custom drill bit, a subsurface sample can be obtained. The drill is driven linearly via a 12" long actuator, with clockwise rotation driven by a high torque motor. Soil is drilled to a depth of 15 cm. After the desired depth has been attained, the drill reverses rotation to open a compartment for collection of the target soil. Once the sample has been retrieved, the drill is rotated clockwise to seal it prior to its removal from the opening. The drill bit can be detached from the linear actuator for presentation to the judges for evaluation.

This technique was chosen because testing results demonstrated that it provided the highest level of dependability when drilling depths exceeding 10 centimeters. By drilling deeper than 10 centimeters, the team can guarantee the collected sediment is from the desired depth. The sealable sample compartment mitigates the risk of contamination from the uppermost 10 centimeters. The sample can subsequently be securely sealed within the hole, thereby guaranteeing that it will not spill before its presentation to the judges.

[13] "Ingredients for Life," NASA, https://europa.nasa.gov/why-europa/ingredients-for-life/; [14] G. Bergtrom, "Basic Cell and Molecular Biology 3e: What We Know & How We Found Out," https://dc.uwm.edu; [15] Y. Li, D. A. Collins, and K. Grintzalis, "A simple biochemical method for the detection of proteins as biomarkers of life on martian soil simulants and the impact of UV radiation," https://pubmed.ncbi.nlm.nih.gov/37240795/

Science Question: Why was Jezero Crater selected as the Mars2020 (Perseverance) landing site?

The mission objective of NASA's Mars Exploration can be divided into four mission goals:

1. To ascertain the existence of life on Mars by searching for signs of active life and the conditions necessary for life to thrive.
2. To assess the climate conditions on Mars by precisely measuring the levels of dust and water vapor in the atmosphere over continuous missions.
3. To characterize the geology of Mars through the examinations of rocks and geological features.
4. To prepare for human exploration. [16]

The Curiosity rover, which was launched as part of the 2011 Mars Science Laboratory mission, utilized various chemical and biological techniques to search for signs of life on Mars. NASA's Mars 2020 Mission rover, Perseverance, was designed to supplement Curiosity by investigating the planet's geology and retrieving samples for subsequent analysis. NASA's primary objectives when identifying its landing site was a high degree of geological diversity and habitability of the landing site and surrounding area. Two additional objectives of the mission were the accumulation of rock and soil samples, as well as the search for indications of ancient Martian life forms in geological samples. On a future mission, NASA plans to retrieve the gathered samples and transport them back to Earth for additional analysis. A final objective for Perseverance is to evaluate the new technology used in its subsystems to see if it can withstand the challenging conditions on Mars and be used in future exploration missions [17].

The successful execution of the goals for the Mars 2020 Mission relied on the selection of the mission location, which was as important as the rover's design. Between 2014 and 2018, NASA conducted a landing site evaluation through a series of workshops involving over 150 members of the scientific community to narrow the list of potential sites from 21 to three: Jezero Crater, NE Syrtis, and the Columbiana Hills site of the Gusev Crater [18, 19]. Each site possesses distinct characteristics that make them compelling as possible landing sites. Jezero Crater shows evidence of repeated cycles of flooding and draining billions of years in the past. The flood cycles potentially transported clay and minerals to lakebed areas, resulting in a moist and nutrient-rich habitat suitable for microbial organisms. On the other hand, NE Syrtis was previously a location where volcanic activity occurred beneath the surface. The volcanic activity resulted in the formation of mineral-rich hot springs, which could have potentially provided a suitable environment for the growth of microorganisms. Finally, Columbiana Hills was taken into consideration based on the findings of NASA's previous Spirit rover. Spirit discovered indications of extinct mineral hot springs solely in the Columbiana Hills, encompassing the entire 100-mile expanse of the Gusev Crater [20].

The Jezero Crater was chosen as the landing site for the Mars 2020 mission following a concluding site selection workshop. Meteor impacts, which are postulated to have the capacity to generate habitable environments, shaped the crater. Furthermore, indications of a river delta dating back 3.5 billion years were discovered within the caldera. This delta has experienced multiple cycles of drainage and flood. It is conceivable that microbial life may have managed to endure within the Jezero Crater during any of these flood cycles. Clay deposits were deposited by the flood cycles, as confirmed by observations made by NASA's Mars Reconnaissance Orbiter. On Earth, comparable clay compounds can be found in the Mississippi River Delta. Rock samples from the Mississippi River Delta have been found to contain microorganisms. Should the conditions of the Jezero Crater delta resemble those of the Mississippi delta, it is possible that rock-dwelling bacterial colonies still exist within the Jezero delta [21]. The combination of these elements makes the Jezero Crater an exceptionally compelling location for scientific research, affirming its selection as the landing site for the Mars 2020 Mission.

[16] "Mars Exploration Science Goals - NASA Science," NASA, https://science.nasa.gov/planetary-science; [17] "Mars 2020/Perseverance," NASA,https://mars.nasa.gov/files/mars2020/Mars2020_Fact_Sheet.pdf ; [18] "2020 Landing Site for Mars Rover Mission," NASA Jet Propulsion Laboratory, https://marsnext.jpl.nasa.gov/workshops/index.cfm ; [19] J. Grant, and M. Golombek (2015), "Final Workshop Letter describing the outcome of the 2nd Mars 2020 landing site workshop", from the Second Landing Site Workshop for the Mars Rover 2020 Mission, https://marsnext.jpl.nasa.gov/workshops/wkshp_2015_08.cfm ; [20] "Picking a Landing Site for NASA's Mars 2020 Rover," NASA, https://science.nasa.gov/mission/mars-2020-perseverance/ ; [21] "Perseverance Rover's Landing Site: Jezero Crater," NASA, https://science.nasa.gov/mission/mars-2020-perseverance/science/