Rover Instrumentation: Identifying Extraterrestrial Biosignatures

By

Ruby L. Schaufler

A thesis submitted in partial fulfillment of the requirements of the degree of

Bachelor of Arts
(Geology)

at

Gustavus Adolphus College

2017

Rover Instrumentation: Identifying Extraterrestrial Biosignatures

By
Ruby L. Schaufler
Under the supervision of Julie K. Bartley

ABSTRACT

Of the planets in our solar system, excluding Earth, Mars is the most likely to preserve evidence of life. Although Mars has a thin atmosphere today and lacks water at its surface, its early history may have been habitable. The three rovers sent to Mars share a common mission, to explore whether or not Mars has or ever had a habitable surface environment. To date, these rover missions have identified several ancient environments that were potentially habitable, including fluvial, lacustrine, and subsurface water systems. The next rover mission to Mars, scheduled to launch in 2020, has biosignature detection as its primary mission.

Like their terrestrial counterparts, habitable environments on Mars have a range of potential for biosignature preservation. At a scale detectable by rovers, water-influenced sediments may preserve evidence of biological activity, including microbially-induced sedimentary structures (MISS) in clastic rocks and microbialites in chemical sedimentary rocks. Identifying these mesoscale structures and confirming whether they are microbially influenced is a challenge due to the scale and often subtle nature of their features.

Differentiating abiotic sedimentary structures from MISS and microbialites is a challenging task, even for geologists on Earth. It is even more difficult for operators to distinguish these features using a rover millions of kilometers away. Choosing instruments that are capable of capturing the scale and detail of these features is crucial to finding biosignatures on Mars. If the instrumentation is not capable of resolving or is unable to capture the detail of features at near and far scales, the biosignatures will be overlooked and the mission will be unsuccessful. This study aims to identify these key scales for biosignature identification based on a Mars analog mission, conducted in a biosignature containing setting on Earth.

Research and field tests conducted by the Geo-Heuristic Operational Strategies Test (GHOST) team in the spring of 2016 demonstrated that mesoscale (0.1-10 mm) data is crucial for identification of MISS and microbialites. Without clear resolution on the sub-mm to cm scale, key features that allow confident assessment of biogenicity are unrecognizable. Understanding the type of instrumentation necessary for identifying mesoscale biosignatures and the appropriate resolution needed to distinguish MISS and microbialites from abiogenic structures at outcrop scale will improve the likelihood of identifying biosignatures on Mars, if the planet contains them.

ACKNOWLEDGMENTS

I would like to thank my advisors Dr. Laura D. Triplett and Dr. Julie K. Bartley as well as Dr. James Welsh of the Gustavus Adolphus College Department of Geology for their support and advice. I would also like to thank the Geo-Heuristic Operational Strategies Test (GHOST) team especially our project leader Dr. Aileen Yingst for having me be a part of a great research project and experience. Lastly, I would like to thank my family and fellow classmates for input, feedback, and support. My research with the GHOST team was funded by the Planetary Science Institute and facilitated by Gustavus Adolphus College.

TABLE OF CONTENTS

FIGURES AND TABLES

INTRODUCTION

Rovers sent to Mars share a common mission, to explore whether or not Mars has or ever had a surface environment suitable for supporting life. Better known as a habitable surface environment. To date, these rover missions have identified several ancient environments that were potentially habitable, including fluvial, lacustrine, and subsurface water systems. With habitable environments identified, mission goals have shifted from identifying habitable environments to locating and identifying evidence of past or present life forms. The next mission to Mars, planned to launch in the summer of 2020, is the first mission with the key goal of identifying and sampling past microbial life. For a biosignature (evidence of life) to be considered proof of life on Mars, it must be of biological origin and formed from Martian constituents (Cady, et al. 2003). This is true for both meteorites that come from Mars and samples collected on Mars.

The first mission to Mars was the Mariner 9 launched in 1971. The Mariner 9's mission was to map the general topography of Mars and gather other geologic data to prepare to the 1975 Viking mission. Mariner 9 also searched for evidence of seasonal changes and water on Mars. Features indicative of past water activity were discovered, but further investigation using 1975 Viking orbiters and landers revealed no organic matter or evidence of metabolism in the soils (Klein, 1979). Although no evidence of life was found, the Mariner 9 mission and Viking orbiters and landers imaged the entire planet of Mars with resolution ranging from meters to hundreds of meters per pixel (Dohm et al. 2011). These first images of the entire planet surface were used to construct geologic and topographic maps of Mars.

Because little evidence of life had been discovered, further missions to Mars did not ensue until the 1990s when extreme life forms were found living in some of Earth's most extreme environments. These discoveries on Earth inspired scientists to take a closer look at Mars.

In 1997 a small rover named Sojourner was sent to Mars equipped with a camera and an alpha particle x-ray spectrometer (APXS). In 2004 two rovers, Spirit and Opportunity, were sent to two different locations on Mars. Spirit was sent to Gusev crater and Opportunity was sent to Meridian Planum. Each location was chosen based on its potential relation to water, which by consensus is agreed to be universally necessary for sustaining life. Each rover found abundant evidence of paleo environments which contained water. In Gusev crater, evidence of aqueous alteration of minerals and hydrothermal activity was observed (Squyres et al. 2006), and the sediment in Meridian Planum appeared to have been deposited during periods when intermittent acidic dune lakes formed (Grotzinger et al. 2005). Although evidence of past liquid water on the martian surface was abundant, the analytical capabilities of the Spirit and Opportunity rovers were too limited to assess whether these environments were habitable.

The promising features of habitable paleo environments informed the 2012 Curiosity mission. The Curiosity rover is a traveling lab that is, to date, the most capable rover exploring Mars. The Mars Science Laboratory (MSL) payload aboard Curiosity includes three different cameras, four different spectrometers, two radiation detectors, and environmental and atmospheric sensors (NASA (e)). Curiosity has used the MSL to collect geologic, atmospheric, and environmental data along with gathering information about potential biosignatures.

The early geologic history of Mars has many parallels with that of Earth. In Mars' early history its core was hot enough to support tectonic movement on the surface and a magnetic field strong enough to maintain a relatively thick atmosphere compared to Earth's modern atmosphere. Over time, the core began to cool and Mars underwent a heavy bombardment interval, which caused water and oxygen to cycle inefficiently between the surface and the underlying geology (Dhom et al., 2011). The poor oxygen cycling along with sunlight and gamma rays eventually thinned the atmosphere. The thin atmosphere and inefficient cycling caused the surface of Mars to freeze. During this time, the remaining internal energy of Mars would store up and release in large episodes. The large episodes of energy release would result in flooding in the northern plains, and transient hydrological cycling (Dohm et al. 2011). The cycling would cause snow fall in southern polar regions, creating glaciers and rock glaciers. In addition to shifts in climate, the large release of internal energy would cause other temporary geological changes such as the creation of alluvial fans, slumping and mass movements, and spring-fed activity (Dohm et al., 2011). The planet's response to internal heat release would eventually slow to dormancy, as the energy source was not continuous, but released in a large episode. As energy and oxygen reduced after such events, the atmosphere would thin and the surface of Mars would become frozen once again.

Tectonic activity on Mars and the conditions caused by episodic internal heat release could have created environments capable of supporting life on Mars. Dohm et al. (2011) compiled a table of ten potential habitable environments on Mars based on the linkage between life on Earth and specific environmental conditions. Of these environments, paleosols, evaporate deposits, hydrothermal environments, ice bodies, vent and spring environments, caverns, and marine and lacustrine basins have the potential to preserve morphological biosignatures (Table 1). The types of life found in these environments are generally primitive microorganisms, which may or may not leave a visible or chemical biosignature. For example, water-influenced sediments may preserve evidence of biological activity, including microbially-induced sedimentary structures (MISS) in clastic rocks and microbialites in chemical sedimentary rocks. Biosignature type and scale may be speculated based on analogs of Mars on Earth, but preservation and weathering on Mars is still not fully understood do to the dramatic differences between Earth's and Mars's atmospheric histories (Sheldon, 2014).

Environments with the potential to preserve morphological biosignatures After Dohm et al., 2011	Macroscale (>10mm)	Mesoscale (0.1mm-10mm)	Microscale (<0.1mm)
Paleosols		X	X
Evaporite deposits		X	X
Hydrothermal environments		X	X
Ice bodies			X
Vent and spring environments		X	X

Table 1**:** Habitable environments on Mars with the potential to preserve morphological biosignatures. X's show the scale of life or biosignatures typical of these environments on earth.

The range of environments with potential for preservation of biosignatures may result in preservation at several distinct spatial scales. If the goal of a rover mission is to determine whether Mars contains evidence for past life, it is crucial to establish the observational scale most likely to detect biosignatures. For this task, a biosignature-bearing terrestrial field area can serve as an analogue, permitting evaluation of various observational scales and strategies in a field area known to contain biosignatures. This project thus uses an analog approach to determine the optimal observational scale for diagnosing potential Martian biosignatures. Looking at terrestrial analogs of Martian environments helps determine the likely kinds and the scale of the biosignature(s) that would be expected to occur in the environments already discovered on Mars.

Field work in an analog site located in southeastern Utah was conducted by the Geo Heuristic Operational Strategies Test (GHOST) team in April 2016. This work focused on rover sampling and collection, comparing the efficiency of two different methods of locating and sampling biosignatures. This research aims to find the most systematic and productive method of sample collection to ultimately improve mission efficiency. My research focuses on the instrumentation aspect of mission efficiency, particularly, what type of camera and photo resolution is necessary for confident assessment of biogenicity. Images are useful for capturing broad data, meaning that the information found in one image can lead to many interpretations. Whether the image reveals something new or something familiar, an interpretation or comparison to other locations can be made. Chemical and mineralogical data are useful for collecting specific data. Although chemical and mineralogical data are useful for confident assessment of biogenic origin, it would be difficult or nearly impossible to know where to collect such data without first seeing an image of the area of interest. Images of Mars have been used to map and detail the geologic history of Mars since the first mission in 1971. With improved technology, images are still some of the most useful data taken for site interpretation. With proper instrumentation and resolution features indicative of biogenic or abiogenic origin can be confidently identified.

GEOLOGIC SETTING

Choosing a Mars analog

Choosing a field site representative of Mars for field work and testing can be a challenging task. A Mars analog must have similar rock types as those on Mars, contain sparse or no vegetation, and few or no large fossils. In order to provide a positive control, the analog site must also contain microbial biosignatures of the type hypothesized to occur in habitable environments on Mars.

Numerous sites have been studied as field analogs for various environments on Mars. The GHOST team has done similar work in New Mexico (Yingst et al. 2011), Alaska (Yingst et al. 2014), and a site on the eastern side of the San Rafael Swell, on Bureau of Land Management land south of Green River Utah (Yingst 2015). The site chosen for spring 2016 GHOST was chosen by Brian Hynek, a professor at University of Colorado Boulder. He worked with Sally Potter-Mclntyre, a professor at Southern Illinois University Carbondale to choose a site that would contain evidence of past habitability that could be seen in orbital data, in situ, or preferably both. The field site they selected is located in southeastern Utah near Green River. This site is currently being studied by Potter-Mclntyre for evidence of subsurface biota-water-rock interactions. This field site was chosen as an analog for testing various methods of identifying and sampling biosignatures. The site does not necessarily contain all the same rocks that are on Mars; however, it has an overall similar habitable environment and stratigraphy that contains biosignatures useful for exploration and interpretation by each team.

Geologic setting of field site

The analog selected is in southeastern Utah (38.851°N, 109.985°W) just southeast of the town of Green River. The majority of our field work was conducted in the uppermost member of the Morrison Formation. The Morrison Formation crops out from central New Mexico to just north of the US-Canada border. It was deposited during the late Jurassic through early Cretaceous, and is characterized by two transgressive-regressive cycles followed by a period of tectonic uplift that exposed approximately 100 million years of geologic history (Peterson, 1994).

The Morrison Formation is composed of three members. Stratigraphically, the Tidwell member is the lowest member and is composed of two layers of sandstone that average about 75ft thick. The Salt Wash is the middle member, 200-400ft thick, and is composed of sandstone interbedded with red and gray siltstone and shale. The top layer, the Brushy Basin member is 200-350ft thick. The top portion of this member was deposited during the early Cretaceous (about 146mya). The Brushy Basin is composed of gray, green, and red silt stone, shale, limestone, and conglomeritic sandstone (O'Sullivan, 2004).

During the late Cenozoic regional uplift caused thousands of meters of the exposed cretaceous and tertiary sedimentary rocks to erode away, causing the Brushy Basin member to be exposed at the top. Cretaceous Cedar Mountain Formation and the Dakota sandstone were deposited on top of the Brushy Basin erosional surface. In the present day, large summer rain storm and mass wasting from cliff edges continue to erode the landscape. Much of the eroded rock gets carried away either by the Green River or the Colorado River.

The lacustrine deposits and curvilinear fluvial channels commonly found at the site are similar to features observed on Mars, making this an ideal Mars analog (Yingst et al, 2017). The ancient inland sea followed by basin drainage and erosion have exposed underlying units that contain micro and macroscopic biosignatures. The primary biosignature found here is a lithified siliceous algal mat. This biosignature, based on the environment found on Earth, may be representative of life potentially preserved from Martian intermittent sea incursion environments (Yingst et al, 2017).

METHODS

The GHOST research team went to the Mars analog site in April 2016. The research team was divided into three teams that each tested a different observation and collection strategies for locating, identifying and sampling the biosignature. The three collection strategies that were compared are walk-about, linear, and traditional geology. The walk-about method simulates what it would be like if the rover would traverse a site as many times as necessary before selecting a sample. This strategy allows one to compare previous areas to the next and return to the optimum sample if needed. The linear method simulates what it would be like if the rover would traverse through a site once, choosing whether or not to sample with no option to return. Traditional geology is methods used by human geologists with no rover involved.

The walk-about and linear teams each consisted of a human acting as a rover a "roverless rover". The team leader, Aileen Yingst, prefers to use roverless rovers to focus on the science behind the mission rather than the engineering of the rover itself. Each roverless rover was equipped with a set of instruments that could gather data similar in type and resolution to that which is collected by Curiosity (Table 2). Each roverless rover was "operated" by their own individual set of "drivers" located at a base camp outside the analog region.

The analog was selected in private by a "site god". Orbital context (CTX) images, Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) data, slope maps, and elevation maps of the site were sent out to each team member to analyze (Figure 1). The location of the field site was kept a secret until all field work was complete. This was done to ensure no team member was able to research the geology of the area, as we would not have that luxury when looking at data from Mars. After looking over the information separately, the team discussed potential routes that would be traversable by the "roverless rovers", and that contained the largest array of stratigraphy and diversity in CRISM signatures. When choosing the route, we also tried to include as many apparent variations in depositional, and preservational environments as possible (based on remote sensing data), with the aim of identifying biosignature potential. The chemical signature obtained from CRISM data in conjunction with stratigraphy, obtained from CTX images, provided crucial information when choosing what route to take and which waypoints to prioritize.

Similar routes had to be taken by each rover to ensure each had access to the same range of geology. Roverless rovers had to try their best to not pay attention to what was around them while walking back and forth between the waypoints and the base camp. In doing so, the rovers would avoid subconsciously collecting information about the analog, which could potentially result in data collection bias. Each collection strategy resulted in different types of data requested by the driver and collected by the rover, as well as different use of the instrumentation. The third team, which performed traditional terrestrial geology, was allowed to choose their route and use any methods they found most effective to interpret the site.

Each of the roverless rovers was to follow operations and collect data at the request of the drivers. Keeping the base separated from the analog site and waiting for data to be brought back and downloaded simulated how data is viewed and decisions are made with rovers on Mars. Decisions on where the rover should sample and take data were all made remotely based on photos, X-ray diffraction results, and mass spectrometry data.

Different types of photos were needed at each waypoint. Instructions to take panoramic photos across different azimuth distances and different heights (tilting up/down) was typical, photos of specific rocks or units were requested at some waypoints, sometimes photos of the ground were taken to see clasts or eroded debris. The location and resolution of photos was chosen and directed by each rovers corresponding driver. If the drivers at base needed more photos from a location after seeing a feature of interest, the rover would have to walk back from the camp where the data was downloaded, to the same field location and collect more data until the base had enough information to move forward.

Photographic data was taken using a lens on a digital SLR camera that would produce an image similar in type and resolution to either the Mastcam/Mastcam-Z or Mars Hand Lens Imager (MAHLI)/Watson. Landscapes (macroscale) or outcrop (mesoscale) features were resolved using a lens similar to the Mastcam. Hand lens (microscale) features were resolved using a lens similar to MAHLI.

Instrument	Acronym	Function
Compact Reconnaissance Imaging Spectrometer for Mars	(CRISM)	CRISM is a visible infrared spectrometer designed to image the surface of Mars looking for mineralogical and chemical evidence for past or present water on Mars. CRISM is aboard the Mars Reconnaissance Orbiter and is looking to identify iron and oxides, materials that have been altered by water, and, phyllosilicates and carbonates, minerals that form in the presence of water.
High Resolution Imaging Science Experiment	(HiRISE)	HiRISE is aboard the Mars Reconnaissance Orbiter and is the first ever camera of its kind on a planetary exploration mission. It is used to take high resolution images of the surface of Mars at about thirty to sixty centimeters per a pixel. This allows for the study of objects and morphology about one meter large on Mars.
Context Camera	(CTX)	CTX is aboard the Mars Reconnaissance Orbiter and takes grayscale images at six meters per a pixel over an area that is thirty one kilometers wide. CTX is used to collect images simultaneously with CRISM and HiRISE data.
Chemistry and Minerology X-Ray Diffraction	(CheMin)	CheMin will take powdered rock samples on Mars and run them through an x-ray diffraction analyzer. Atoms of the sample will absorb and scatter the x-rays causing constructive and destructive interference that will create a diffraction pattern that will indicate what mineral is being sampled.
Chemistry and Camera	(ChemCam)	ChemCam has the ability to analyze rocks and outcrops that the rover cannot reach or traverse. From seven meters away, ChemCam can identify rock type, soil and pebble composition, measure abundance of chemical elements and depth and composition of weathered rocks, recognize water

		molecules in crystal structures, and provide visual assistance when drilling.
Mast Camera	(Mastcam)	Mastcam consists of two cameras that can take color images and color video. One camera has moderate resolution for taking images far from the rover. Any set of images has the option to be stitched together into a panorama. Mastcam generally takes images in full color spectrum but it also has the option to use different colored filters that can be used to interpret light absorption in multiple zones of the electromagnetic spectrum.
Mars Hand Lens Imager	(MAHLI)	MAHLI is the equivalent of a geologists hand lens in the field. This is a camera used to image close up views, down to twelve and a half micrometers in size, of rock and sediment on Mars. MHALI images in both white and ultraviolet light in order to work both during the day and at night to identify carbonates indicative of water.

Table 2: Mars Curiosity Rover instrumentation set (NASA (e)).

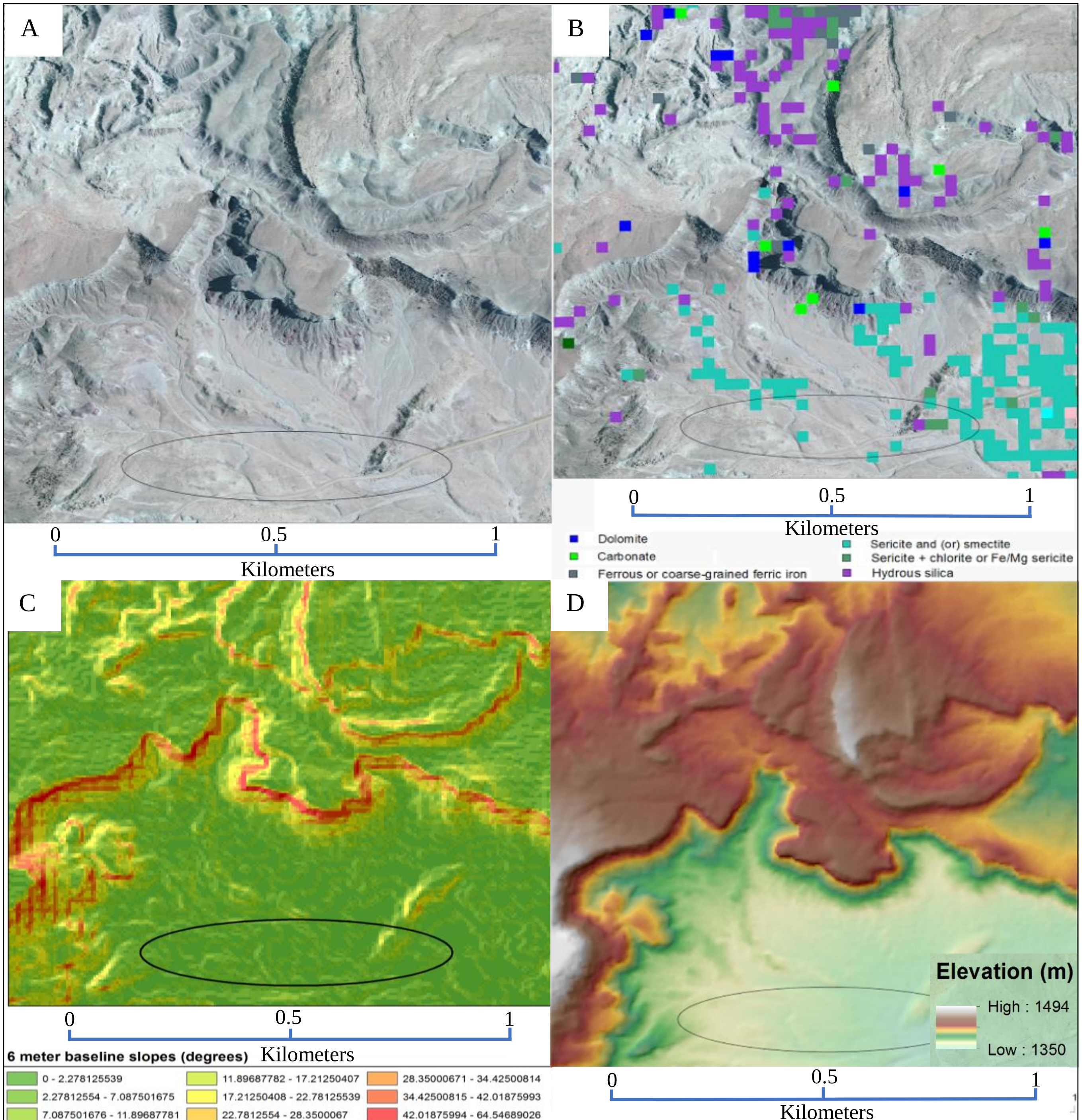

Figure 1: Example of each type of data given to the GHOST team members prior to visiting the analog in person. A: Orbital context (CTX) images B: Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) C: slope map D: Elevation map. Analysis of this data determined the traverse that would be taken by the walk about and linear rovers.

RESULTS

After three days in the field interpreting the site, the linear traverse team had found and identified the algal biosignature present at the site (Figure 2). The fossilized algal mat was first identified in an image that belonged to a panoramic series of images taken at a waypoint. Originally, the panoramic series was requested because the first photos taken of that waypoint did not show what was to the left or right of the rover. The forward-facing photos did not show any geology that differed from what had been observed at previous waypoints. 180◦ panoramas at three heights (upper, eye-level, and lower), were requested in order to view the geology of the waypoint vertically and laterally. The biosignature identified was seen in float (fallen block from upslope), in a photo taken of the lower stratigraphy and ground.

At the outcrop scale (macroscale), the linear rover team was able to recognize, that the rock in float was different than any units previously observed. The difference in the initial appearance of the rock was apparent but the rock type was not. Mesoscale images revealed wavy layering, a promising feature that could indicate biogenic origin (Figure 2B). Microscale MAHLI images revealed oversteepened and draping laminae (Figure 2C). These microscale features were the final piece of data that allowed the linear team to confidently assess and sample the algal biosignature.

Figure 2: Fossilized algal mat (biosignature present at analog). A: First discovery of the algal mat in float (from stratigraphy above the man in the blue shirt) B: A closer look at the algal mat reveals crinkled lamina C: A final small scale image (about mm scale) reveals features such as oversteepend lamina, which allow confident assessment of biogenicity.

While conducting field research in Utah, each rover team had its own set of "drivers" instructing the rover to gather the data they requested. The drivers of the linear traverse rover were Senior Scientist at Planetary Science Institute, and the leader of the GHOST team, Aileen Yingst, and Linda Kah, Kenneth R. Walker Professor Carbonate Sedimentology and

Geochemistry at the University of Tennessee. The drivers of the walkabout traverse rover were Michelle Minitti, Senior Scientist at Planetary Science Institute, and Geoff Gilleaudeau, NASA Postdoctoral Fellow, Arizona State University. Each set of drivers had different scientific backgrounds and different levels of experience resulting in different data collected and different methods of interpreting the site.

The walkabout team chose not to "deploy the arm". Meaning they would not use the instruments that are on the rover arm, in order reduce the amount of Martian sols (days on Mars) it would take to complete the traverse. Without deploying the arm, the walkabout team did most of their interpretations from lower resolution photographs. The linear rover team spent time looking at different rock units, comparing what had been seen at the previous waypoint with anything new or different at the following waypoint. If something new or different was observed the linear team would assess if it was an indication of a habitable environment or habitable paleo-environment. The linear team did not hesitate to deploy the arm which resulted in interpretations based on multiple data types, but also used significant mission time and resources.

DISCUSSION

Earth analogs of habitable environments on Mars can be used to get an idea of, or make an inference as to what types of life would be found on Mars. However, habitable environments are not always preservational environments. Looking specifically at the environments or paleo-environments with potential to preserve morphological biosignatures makes it possible to constrain the most likely biosignature types, which allows us to specify the ideal biosignature detection.

Table 1 lists the known habitable environments on Mars with potential to preserve biosignatures along with the scale/size of potential life of biosignatures that may be found in each particular environment. All environments with potential for preservation would be able to support and preserve small microscale (<0.1mm) organisms which are generally primitive life forms (typically expected of the Martian environment and geologic history). Mesoscale (0.1mm-10mm) organisms have potential to be found in all preservational environments identified excluding ice bodies. The only environment identified on Mars that could or would have supported larger life forms at the macroscale (>10mm) are marine and lacustrine basins.

Many factors beyond environment or paleo environment type dictate what data are collected and what features are distinguishable on Mars. Topography on the surface of Mars is steep in certain regions and may not be traversable by rovers. A rover cannot enter a crater on the surface of Mars if it does not have the ability to drive back out. The driver and purpose of the mission also dictate what traverse is taken and what data are collected. Missions aiming for high efficiency in covering a lot of surface may not collect as much data as missions looking at a specific environment type or feature in detail. Finally, instrumentation and characteristics of Mars climate and surface dictate what can be confidently distinguished and identified. Limitations in camera resolution along with lighting, shadows, and dust can create discrepancy when collecting data through images.

Typically, images are not corrected before being released to the public. However, images are compressed using a JPG compression algorithm. Images must be compressed in order to increase storage space, download speed, and speed of image processing (Lam et al., 2001). Raw images are stored on the rover incase the full data set (resolution) is needed. Objects with a large amount of relief often require multiple images to be taken and combined (z-stacked) to create one image with all featured in focus. These images created from many are often color corrected using an approximate white balancing so that the rocks and sediment appear in the photos as they would on earth (NASA (f)). Shadowing can useful when determining the shape or roughness of a feature or outcrop (Minitti, 2013). However, images in half shadow are difficult to further process as the reflectance values across the image are bimodal making poorly-lighted features more difficult to resolve. When imaging on Mars, dust is unavoidable and the only measure of reducing data obscured by dust is to image areas that have been recently cleared of dust (due to wind) or areas that are naturally clear of dust.

Understanding the scale of life that is potentially present is key in developing proper instrumentation for confident assessment. Table 3 lists the camera instrumentation and the resolution each camera can obtain in ideal settings. Most often when images are taken on Mars it is delivered as a compressed raw image from the Navigation camera (Navcam). Navcam images are black and white and are useful in getting a sense of the surroundings and choosing what path to take as the rover travels from one location to another. Often Navcam images have low resolution and are not useful for collecting data. When data from an area is to be collected, higher resolution images and color images are taken using the Mastcam or MAHLI (figure 3). These cameras have resolutions that can capture features as large as 7.4cm from a kilometer away and features as small as 13.9μm from a few meters away (NASA (f)). The camera that will be used for the 2020 mission can capture features as small as 0.15mm, allowing for confident identification of either macroscale or mesoscale biosignatures (NASA (c)).

The 2020 mission aims to find signs of past microbial life. The first step in this is choosing the correct environment and landing site. The current landing site has been narrowed down to three options, Columbia Hills Gusev Crater, Jezero Crater, and NE Syrtis (NASA (g)). Columbia Hills Gusev crater was first explored by the rover Spirit. Spirit discovered that this is an area that once had hot springs flowing which had potential to create a lake during floods. Further exploring this with new instrumentation could reveal unknown information about Mars history. Jezero Crater shows evidence of two major flooding and drying out periods about 3.5 billion years ago. During these flooding periods a lake would form. During dry periods water would still transport clays into the crater basin. Cycles of wet then dry in a basin filled with clay and lake sediment create an environment, recognized on earth, as ideal for preservation of potential life forms (NASA (g)). The last potential landing location is NE Syrtis. This area was once warmed by volcanic activity which allowed hot springs to melt surrounding ice (NASA (g)). Again, this is seen as an ideal paleo environment for microbes on earth and may be on Mars as well.

Looking at Table 1, each of the final three landing locations can be categorized as sites with known paleoenvironments that have potential to support and preserve life. Columbia Hills Gusev Crater, a vent and spring environment with potential for a small lake or lacustrine environment. Jezero Crater, a lacustrine environment with wet and dry cycles. NE Syrtis, a hydrothermal environment. When looking at Table 1, each of these environments, when compared to similar analogs on earth, have the potential to host biosignatures. Biosignatures have diagnostic features that are best identified in outcrop at the scale of one to several lamina (0.1 to 10 mm). Mesoscale (0.1-10 mm) data is there for crucial in identifying MISS and microbialites. Without clear resolution on the sub-mm to cm scale, key features that allow confident assessment of biogenicity are unrecognizable.

Rover	Instrument	Resolution	Smallest Feature Size Distinguishable
Curiosity	Mars Hand Lens Imager (MAHLI)	13.9 µm/pixel	Microscale
Curiosity	The Mast Camera (Mastcam)	M-100 IFOV: 7.4cm/pixel scales at 1km and ~150µm/pixel scale at 2m M-34 IFOv: 450µm/pixel at 2m and 22cm at 1Km	Mesoscale
2020	Mast Camera Z (Mastcam-Z)	0.15-7.4mm/pixel	Mesoscale
2020	The Scanning Habitable Environments with Raman and Luminescence for Organics and Chemicals (SHERLOC)	Spectrometer, camera, and laser to identify chemical biosignatures	Some ability to image mesoscale structures

Table 3: Camera instrumentation on both the Curiosity and 2020 rover. Each camera has a different purpose and use for collecting data and thus each has different resolution. The 2020 rover has a camera that can see features as small as mesoscale and beyond that will depend on chemical data to confirm biogenic or abiotic origin. Curiosity rover has cameras that are able to resolve features ranging from macroscale to microscale. Microscale images are useful for identifying small features typical of primitive life forms. The scale defined in the right column is based on the scales given in table 1.

Information received from NASA (a-d)

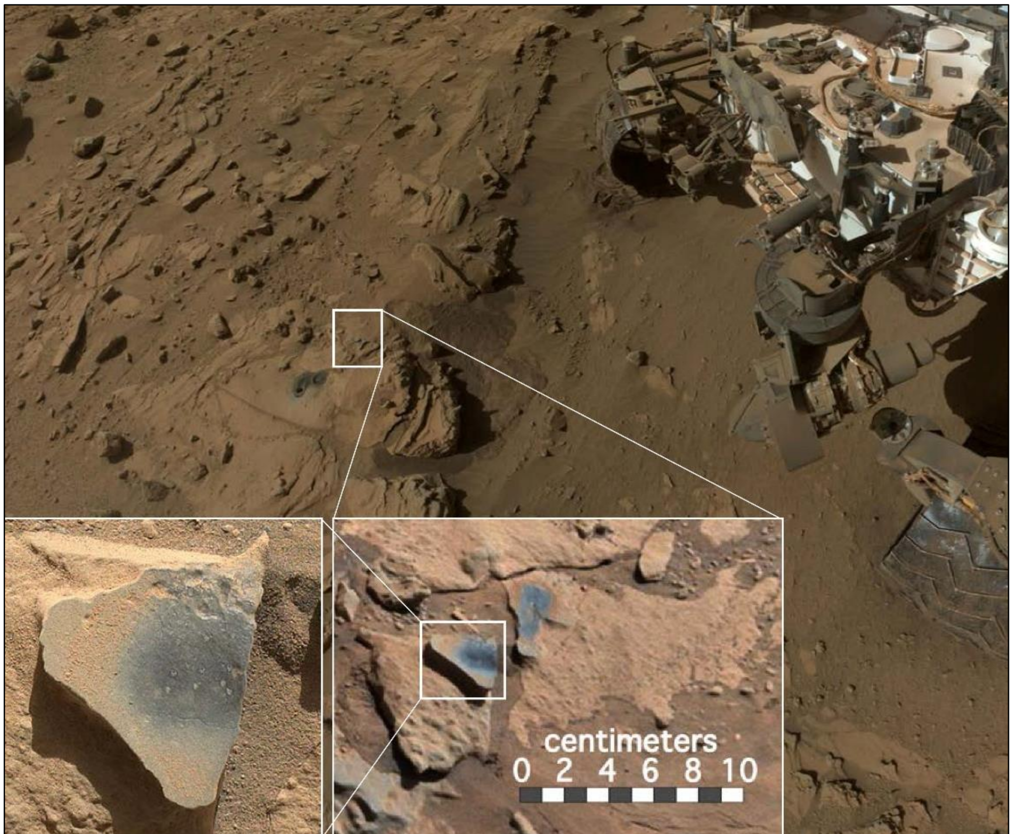

Figure 3: An example of the various scales of features the MAHLI camera can capture. This particular photo was taken June 27th, 2016 to further explore the manganese oxides in these rocks (manganese requires water and oxidizing conditions to form and may be indicative of habitable paleo environment). (NASA (f))

REFERENCES

Cady, S.L., Farmer, J.D., Grotzinger, J.P., Schopf, J.W., and Steele, A. (2003). Morphological Biosignatures and the Search for Life on Mars. Astrobiology. 3(2): 351-368

Dohm, H.M., et al., (2011). An inventory of potentially habitable environments on Mars: Geological and biological perspectives. Geologic Society of America Special Paper. p. 483, 317-347

Grotzinger, J.P., Arvidson, R.E., Bell, J.F., III, Calvin, W., Clark, B.C., Fike, Jolliff, B.L., Knoll, A.H., Malin, M., Mclennan, S.M., Parker, T., Soderblom, L., Sohl-Dickstein, J.N., Squyres, S.W., Tosca, N.J., and Watters, W.A., (2005). Stratigraphy and sedimentology of a dry to wet eolian depositional system, Burns formation, Meridiani Planum, Mars. Earth and Planetary Science Letters, v. 240, p. 11-72

Klein, H.P., (1979). The Viking mission and the search for life on mars. Reviews of Geophysics. v. 17, issue: 7, p. 1655-1662

Minitti, M.E., Kah, L. C., Yingst, R. A., Edgett, K. S., Anderson, R. C., Beegle, L. W., Carsten, J. L., Deen, R. G., Goetz, W., Hardgrove, C., Harker, D. E., Herkenhoff, K. E., Hurowitz, J. A., Jandura, L., Kennedy, M. R., Kocurek, G., Krezoski, G. M., Kuhn, S. R., Limonadi, D.; Lipkaman, L., Madsen, M. B., Olson, T. S., Robinson, M. L., Rowland, S. K., Rubin, D. M., Seybold, C., Schieber, J., Schmidt, M., Sumner, D. Y., Tompkins, V. V., van Beek, J. K., and van Beek, T., (2013). MAHLI at the Rocknest sand shadow; science and science-enabling activities. Journal of Geophysical Research: Planets. v. 118, Issue 11, p. 2338-2360

NASA (a), Jet Propultion Laboratory, California Institute of Technology. Mast Camera (Mastcam). Retrieved from http://mars.jpl.nasa.gov/msl/mission/instruments/cameras/mastcam/

NASA (b), Jet Propultion Laboratory, California Institute of Technology. Mars Hand Lens Imager (MAHLI). Retrieved from http://mars.jpl.nasa.gov/msl/mission/instruments/cameras/mahli/

NASA (c), Jet Propultion Laboratory, California Institute of Technology. Mars 2020 Rover, Mast Camera Z (Mastcam-Z). Retrieved from http://mars.nasa.gov/mars2020/mission/instruments/mastcam-z/

NASA (d), Jet Propultion Laboratory, California Institute of Technology. Mars 2020 Rover, SHERLOC. Retrieved from http://mars.jpl.nasa.gov/mars2020/mission/instruments/sherloc/

NASA (e), Jet Propultion Laboratory, California Institute of Technology. Mission: Instruments. Retrieved from http://mars.nasa.gov/msl/mission/instruments/

NASA (f), Jet Propultion Laboratory, California Institute of Technology. (2016). Multimedia: NASA's Curiosity at Site of Clues About Ancient Oxygen. Retrieved from https://mars.jpl.nasa.gov/multimedia/images/nasas-curiosity-at-site-of-clues-about-ancient-oxygen&s=2

NASA (g), Jet Propultion Laboratory, California Institute of Technology. 2020 landing site for Mars rover mission. Retrieved from https://marsnext.jpl.nasa.gov/

O'Sullivan, R.B., (2004). Correlation of middle Jurassic San Rafael group and related rocks from the Bridgeport to ouray in western Colorado: U.S. department of the interior, U.S. geological survey, scientific investigations map 2849 version 1.0

Peterson, J.A., Caputo, M.V., Franczyk, K.J., (1994). Sand dunes, sabkhas, streams, and shallow seas: Jurassic paleogeography in the southern part of the western Interior Basin: Mesozoic systems of the Rocky Mountain region, USA, p. 233-272

Sheldon, N.D., (2014). Insights and challenges for using the early Earth to understand potentially habitable environments on Mars. American Geophysical Union, Washington D.C. Fall Meeting, San Francisco, CA, United States

Squyres, S.W., Arvidson, R.E., Bollen, D., Bell, J.F., III, Brückner, J., Cabrol, N.A., Calvin, W.M., Carr, M.H., Christensen, P.R., Clark, B.C., Crumpler, L., Des Marais, D.J., d'Uston, C., Economou, T., Farmer, J., Farrand, W.H., Folkner, W., Gellert, R., Goltch, T.D., Golombek, M., Gorevan, S., Grant, J.A., Greeley, R., Grotzinger, J., Herkenhoff, K.E., Hviid, S., Johnson, H.R., Klingelhöfer, G., Knoll, A.H., Landis, G., Lemmon, M., Li, R., Madsen, M.B., Malin, M.C., McLennan, S.M., McSween, H.Y., Ming, D.W., Moersch, J., Morris, R.V., Parker, T., Rice, J.W., Jr., Richter, L., Rieder, R., Schröder, C., Sims, M., Smith, M., Smith, P., Soderblom, L.A., Sullivan, R., Tosca, N.J., Waenke, H., Wdowiak, T., Wolff, M.J., and Yen, A., (2006). Overview of the Opportunity Mars exploration rover mission to Meridiani Planum: Egale crater to Purgatory Ripple. Journal of Geophysical Research Atmospheres. v. 109

Yingst, R.A. (corresponding author), Berger, J., Cohen, B.A., Hynek, B., Schmidt, M.E., (2015). determining best practices in reconnoitering sites for habitability potential on mars using a semi-autonomous rover: a geoheuristic operational strategies test: submitted manuscript to Planetary Science Institute

Yingst, R.A., Cohen, B.A., Crumpler, L., Schmidt, M.E., Schrader, C., (2011). Testing Mars-inspired operational strategies for semi-autonomous rovers on the Moon: The GeoHeuristic Operational Strategies Test in New Mexico: Mars v. 6, p. 13-31

Yingst, R.A., Cohen, B.A., Hynek, B., Schmidt, M.E., Schrader, C., Rodriguez, A., (2014). Testing Mars Exploration Rover-inspired operational strategies for semi-autonomous rovers on the moon II: The GeoHeuristic operational Strategies Test in Alaska: Acta Astronautica v. 99, p. 24–36

Yingst, R.A., Bartley, J., Chisdsey, T., Cohen, B.A., Gilleaudeau, G.J., Hynek, B.M., Kah, L.C., Minitti, M.E., Williams, R.M.E., Black, S., Gemperline, J., Helsius, R., Schaufler, R.L., (2017). Determining efficient rover science protocols for robotic sample selection. 48th Lunar and Planetary Science Conference. Abstract #1162.