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Earth analogues for Martian fossil life: What is the ExoMars mission capable of detecting?

A summary of research completed in 2019
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Abstract

Over the course of two years, this project aimed to develop an understanding of the potential of finding microbially induced sedimentary structures (MISS) in the geological record of Mars. Early Mars has abundant evidence of aqueous activity, indicating that the conditions on the planet could have been conducive to life. A field campaign in Iceland identified and studied different MISS, with a particular focus on the habitability of basaltic sedimentary systems. A second field campaign to South Africa enabled the use of an emulator of the Close-up Imager (CLUPI) aboard the ExoMars 2020 mission. 700 images were collected with variable conditions to assess the capabilities of CLUPI in identifying MISS. Further work will potentially see the publication of the database, as well as further analysis and potential publication on the nature and development of microbial systems on ancient Earth.

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1. Introduction

Finding life on other planets is hard. The quest is filled with caveats, assumptions, and significant difficulties, yet geologists remain steadfast to attempt to answer the ultimate question: are we alone?

This project aims to assess the potential that the ExoMars 2020 mission has to identify biosignatures visible to the photographic systems aboard the rover. The primary objective of the mission is to identify organic substances on the surface and near subsurface of Mars, with hope to understand whether life ever existed on Mars (Vago et al., 2017). Alongside drilling, spectrometry and mobile chemistry equipment, the rover is fitted with a set of visible light cameras; a Panoramic Camera (PANCAM), and a Close-up Imager (CLUPI). Particular focus has been put on the CLUPI imager in this study, as its resolution from close-up images are very promising for identifying sedimentary structures which can be attributed to biological activity (Josset et al., 2017).

To understand what forms of life had the potential to evolve on Mars in its history, it is important to understand what the environment was on Mars in its distant past. The Noachian age (4.1-3.7 billion years ago) is of particular interest due the geologic record suggesting water was abundant on the surface of Mars during this period (Poulet et al., 2005). The climate was likely rather temperate, and conditions point to an environment similar to where life probably evolved on Earth. However, this period of Earth-like climate was (relatively) short-lived, as soon after the end of the Noachian age much of the surface water on Mars vanished, for reasons still unclear (Westall et al., 2013).

This 400-million-year period might have allowed life to evolve on the now desolate planet. This summer's research focused on capturing images through the CLUPI emulator, a camera with identical specifications to the camera being launched next year. A particular interest was imaging microbially induced sedimentary structures (MISS) – structures within rocks that are influenced in their shape by microbial life. The study area was the 3.2-billion-year-old Moodies Group sediments in the Barberton Greenstone Belt, South Africa. Over a period of 14 days 700 images were captured systematically of a variety of MISS in different paleo-environments with varying states of weathering.

This report discusses the literature and summarises our current understanding of the environment on Early Mars and the potential for life during this time, the findings of last year's research and the conclusions drawn thus far from this year's project.

2. Early Mars and its Potential Habitability

The earliest chondritic material from our solar system has been dated to 4.56 billion years ago, suggesting this to be the time which matter first condensed forming dust particles (Bouvier and Wadhwa, 2010). Gravitational forces drew these microscopic particles together, forming progressively larger objects. Each successive impact released large amount of energy, re-melting the rocks and homogenizing the mixture. Ultimately, this process formed the planets visible today. The early planets would have been hellish blobs of magma, with surface temperatures well over 1500°C. As the planets cooled, they would begin to differentiate; the denser material would sink to the centre and form the cores, and the lighter, more volatile elements floated to the surface (Boyet and Carlson, 2005). Because of Mars' smaller size, it probably happened first there. At some point, the temperatures would have reached a critical point in which water would precipitate out of the atmosphere rapidly, forming oceans at incredible rates (Elkins-Tanton, 2011). As the water cooled, an environment hospitable for life would have arose. With the right materials and correct conditions, life might have evolved on Mars before it ever did on Earth.

Evidence for water in early Martian history became apparent with the Mars Reconnaissance Mission orbiter, launched in 2005. Hyperspectral imaging identified an abundance of phyllosilicates (clays) within select regions exposed on the surface today (Poulet et al, 2005; Bishop et al., 2008). Phyllosilicates are produced by the alteration of fresh rocks by water and are thus a key indicator in identifying the presence of water in ancient environments. The regions with most abundance of these clays are Noachian sediments, suggesting that liquid water was present on the surface of mars between 4.1 and 3.7 billion years ago. If life did evolve on Mars, it would have been during this period of a wet, temperate climate (Zahnle, 2007). These conditions persisted for at least 400 million years, during which the environment on the Red Planet would have been very similar to early Earth, and conducive to life (McKay, 2010).

However, unlike Earth, this window of habitability of Mars was short lived. A transition of clay formation to sulfate alteration indicates that a period of intense volcanic activity followed the Noachian age. The Hesperian age (3.7 - ~3.0 billion years ago), is the intermediate period during which the removal of the atmosphere led to liquid water becoming unstable, and the oceans rapidly drying up, leaving the planet in the desolate state it is in today (Westall, 2013).

Because of the planet's short-lived period of habitability, any life that did evolve would have remained primitive, restricted to single celled prokaryotic organisms. These organisms could very well have been prolific however, and thus Noachian age sediments are the primary target for most missions to Mars today (Vago et al., 2017).

3. Microbially induced sedimentary structures

One method in which single-celled organisms are preserved in the rock record is through their colonial behavior. Colonies of microbial life can form sticky mats which glue themselves onto the surface, which can be preserved under unique conditions. Such structures are termed microbially induced sedimentary structures (MISS).

The identification of microbial activity forming classic wrinkled textures in the rock record was first successfully recognized in 1997 (Hagadorn and Bottjer, 1997). Noffke (2001) termed MISS as a new category of primary sedimentary structure soon after, and the literature became flooded with this new category of structures.

Noffke (2001) identified five methods in which microbial activity can influence primary deposition of sediments. Some examples are; biostabilisation, leveling and baffling, trapping or binding of grains. Each process describes a different method in which microbes can interact with the surface they develop on. These processes can leave a permanent mark in the rock record, which can indicate the presence of life during the time of their deposition.

Caution must be had, however, as an increased understanding of abiotic processes has shown that similar morphological features can often be misattributed to microbial activity (Davies et al., 2016). Many earlier workers on MISS have been criticized for overlooking the extensive literature detailing abiotic mechanisms for forming wrinkled textures (e.g. Dzulynski and Walton, 1965, Reineck and Singh, 1986, Gibling and Stuart, 1988, Long, 1993).

More recent experimental work has proven that “classic” microbial textures can be formed through abiotic processes which might have been common in the Archean (4.0-2.5 billion years ago), thus complicating our understanding of early microbial activity (McLoughlin et al, 2008).

Nevertheless, biogenic structures can be distinguished in the rock record with sufficient evidence and remain pivotal to our understanding of how life evolved on Earth. Some workers further implicate the importance of life in preserving. Therefore, recent missions to Mars have been focused on collecting the necessary set of information to discern the presence of life on the planet.

To understand how microbial structures are formed in environments similar to what was present on Mars, a one-week expedition to Iceland in 2018 was completed. This expedition had a primary aim of identifying and describing microbial activity in differing environments, and discerning which traces may be preserved in the rock record.

Microbial activity observed in lacustrine environments produced thin biofilms which bound basaltic sediments together, as is seen in classic siliciclastic systems (Figure 1). These mats were isolated systems, no more than 50 cm in diameter, and were buried during periods of rainfall and raised water level. Rapid burial in fluvial systems promote the preservation of sedimentary structures, indicating that such colonies may be observable on Mars.



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Figure 1: The green filamentous chains, observable to the naked eye, are formed by colonies of microbes producing polymer chains and biofilms which can act as a binding material to sediments.

Raindrop impressions on riverbanks were also observed (Figure 2). Their preservation for multiple days in an erosive environment suggests the sediment has an enhanced resistance to weathering. Preliminary carbon isotopic analysis indicates a $\delta^{13}\text{C}$ of around -22, which suggests organic carbon is present within the sediments.



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Figure 2: The raindrop impressions observed on the riverbanks in this image have been preserved for multiple days under flowing water. This suggests some hidden mechanism for binding sediments and inhibiting erosion is at play.

The isotopic fractionation of carbon (or $\delta^{13}\text{C}$) is an indicator used to identify whether carbon within a sample is organic in nature. A very negative value suggests that lighter carbon is more abundant in the sample than usual, which is an indicator that it has been formed biogenically.

With this knowledge, one can begin to interpret structures observed in the rock record both on Earth and Mars, and determine whether there is evidence of life in the system.

4. The CLUPI Imager and its potential for finding life

The Close-Up Imager (CLUPI) aboard the Rosalind Franklin rover of the ExoMars 2020 mission is designed with the purpose of close up observations of rocks. The images obtained by the camera aim to aid geologists with describing and interpreting the strata near the rover. Focusing on identifying life, the CLUPI imager can help distinguish biofilms within the units, and provide the important context of further geochemical analyses that will be performed on samples collected by the rover (Josset et al, 2017).

The camera has a field of view of 14° , and a resolution of 2652×1768 pixels, with each pixel being made up of three colours. With these capabilities, the camera can have a maximum resolution of $7 \mu\text{m}$ per pixel at its closest working distance of 10cm. For reference, a fine-grained sandstone typically has a grain size of $\sim 250 \mu\text{m}$, which would be well resolved by this camera.

The camera has the capability to autofocus, from 10 cm to infinity, and automatically determine the correct exposure as well. These capabilities are crucial for allowing the camera to be used in a wide range of scenarios. It is mounted at the front of the rover, attached to the drill box. The maneuverable nature of the drill box allows the camera to both view directly ahead of the rover, as well as to the side and observe nearby outcrops.

No published work has been done to date to study what MISS would look like through the camera, and what can be resolved in such biofilms through the images.

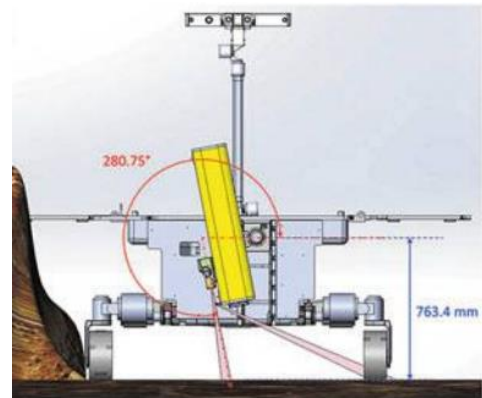


Figure 3: the Rosalind Franklin rover, with the drilling arm coloured yellow. CLUPI can be observed attached to the yellow boom. Adapted from Josset et al, 2017.

5. The CLUPI emulator and the Barberton Greenstone Belt

This summer, a two-week field campaign in South Africa was successfully completed. The aim of the campaign was to use a CLUPI emulator, a camera with the same specifications as the CLUPI camera, to photograph and interpret microbial structures in ancient environments on Earth. The Moodies group sediments of the Barberton Greenstone Belt are an approximately 3.5-kilometer thick succession of alluvial-marine stratigraphy with abundant evidence of wrinkled structures attributed to life (Heubeck, 2009). This sequence contains the first evidence of life on land (Homann, 2018), and is thus an excellent candidate for using the CLUPI emulator.

The camera used was a Sigma SD15, with a 105mm fixed length f/2.8 lens. Its resolution is 2640x1760 pixels and has a field of view of 14° when fitted with this lens. It can thus produce near identical images to the official CLUPI camera.

Over the course of the campaign, a systematic imaging study was done, collecting over 620 images through the camera. The camera was positioned at 3m, 1m, 50cm, 30cm and 15cm away from a target and a pair of images was taken at each distance. The camera was also angled at variable orientations to target faces, to simulate non-ideal imaging situations. Each target was a sedimentary structure attributed to microbial activity, and each sedimentary structure was imaged in varying states of weathering to further enhance the scope of the collection. Lighting remained controlled, as images were collected between 10 am and 3 pm, during which the light intensity remained consistent, and an even lighting was produced by covering the target by human shade.

An example set of images is shown in Figures 4 and 5. Each successive image is can resolve more detail of the sedimentary system the images were taken in. However, a notable loss of context is observed by the closer images. For example, the large grey clast observed in the 1m and 50 cm images indicate a particularly high energy environment, which would not be noted through the images at 30cm and 15 cm.

Another result observed by imaging non-flat surfaces or capturing images at an angle is the limited depth of view that is obtained from the images obtained from within 30 cm (as seen in Figure 5). To obtain a good image, a series of images must be z-stacked, a process in which images are taken at varying focus lengths and overlapped to produce one clear image. This process is possible on the Mars rover (Josset, 2017), however requires more processing and a larger image to be sent back to Earth. Careful consideration must thus be taken to decide what feature in the rock to focus on prior to capturing the image, to maximize the efficiency of the rover.

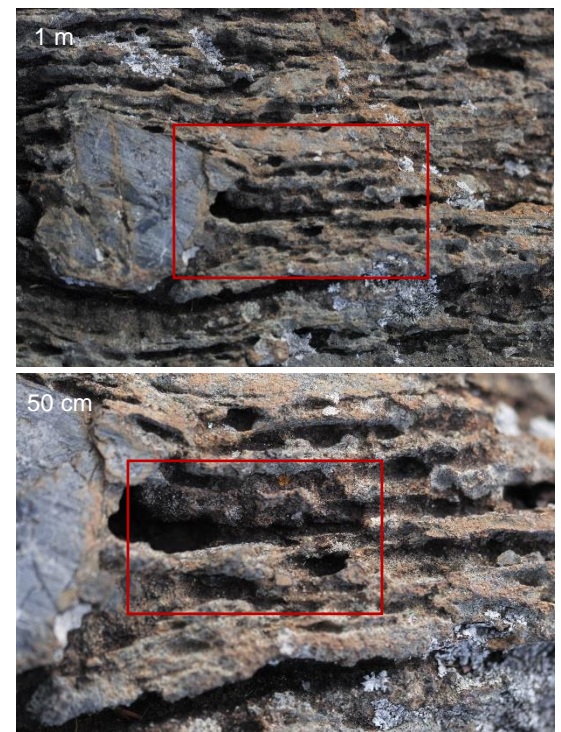


Figure 4: 1m and 50 cm CLUPI images of a highly weathered sandstone interbedded with microbial mats (sandstone weathering out). Red boxes denote field of view in image below.

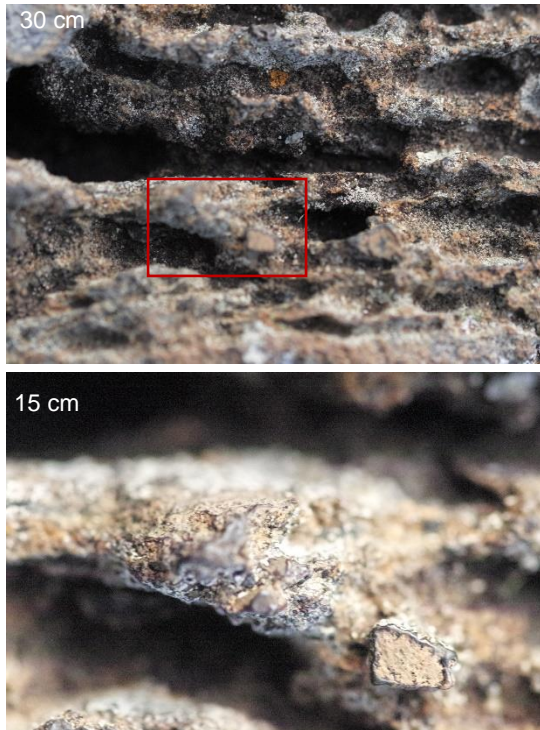


Figure 5: 30 cm and 15 cm CLUPI images of a highly weathered sandstone interbedded with microbial mats. Red box indicates field of view in image below.

CLUPI has proved itself an effective and powerful method of obtaining important data to aid geologists in their interpretation of the environment the rover is in. On the basis of the work this summer, a database that can be cross-referenced by geologists working in the science team of the mission has been created, and important limits in application have been observed.

6. Future work and goals

The images and samples collected during the field campaign in South Africa have enormous potential. Work will continue throughout to compile and complete the catalogue of images collected, and pair them to mosaic images collected with a separate image, with hopes of publishing the work in an academic journal and provide the ExoMars mission with a valuable dataset that is unique and specialized for the mission.

Samples collected during the campaign will also be used to better understand the processes in which the microbial structures formed in the Moodies group. A trip is being planned to the Diamond Light Source Synchrotron in Oxford, where multiple analytical techniques will be used to map out how certain elements have been concentrated along the microbial structures. We hope to publish on a new and unique set of structures observed in the rocks, that have not been analyzed in detail before.

The goal is thus to obtain at least two publications from the Laidlaw programme from this summer.

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