

COMPARATIVE BIOLOGY OF REGOLITH AND EPHEMERAL BASINS: A WORKING TEST OF THE "McDANIEL'S HYPOTHESIS"*

Jonathan Butler, Steve Mcdaniel And Shannon M. Rupert Robles
srupert@miracosta.edu

ABSTRACT

The "McDaniel's Hypothesis" suggests that the ability to detect high concentrations of microbial life on the face of an escarpment might be a means of detecting high concentrations of near surface water. Finding a way to quantify richness and distribution of microbes on Earth may have practical applications on Mars, should we find surface-dwelling microscopic life there. Soil samples taken from areas surrounding the Mars Desert Research Station in Utah were classified as either wet, meaning they were collected from places where water persists, such as washes, run-off channels and ephemeral basins, or dry, meaning they were collected from escarpments and other places where water does not persist (regolith). Incubation of samples using soda lime as a measure of microbial respiration show a significant difference in carbon dioxide output between treatments. Wet samples appear to contain more microbial life than dry samples, based on this measure. This suggests that it is possible to quantify microbial richness across treatments, and that more microorganisms persist during the dry season in areas where water lingered longest before disappearing.

KEYWORDS: Microbial ecology, microbial respiration, desert ecology, biological richness

INTRODUCTION

One of the most talked about aspects of Mars is whether the planet harbors life. In addition, almost every talk about life on Mars includes discussion on whether there is water, because on Earth, water is essential for all life forms. At the Second Biannual Astrobiology Conference, held April 2002 at NASA's Ames Research Center in Mountain View, California, so many of the scientists speculated about the possibilities of water on Mars that the journal Science's story on the conference had this trend in its title (1).

The "McDaniel's Hypothesis" was developed by the first crew to inhabit the Mars Desert Research Station (MDRS) in Wayne County, Utah (2). Originally conceived as a means of creating an analytical tool that would combine geology and biology to locate water and surface microbial life, it held the following assumptions:

1. Escarpments harbor microbial life on their exposed vertical faces.

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2. Microbial life on escarpments is richest at or near the higher concentrations of surface or near surface water (whether that water is liquid or frozen).

3. Microbial life found on escarpments will have evolved a mechanism to locate the highest concentrations of water on an escarpment and a means to translocate from one such locality to another.

4. For any given location on the planet at which there are escarpment faces, there will be a face that is preferential for microbial life living on the vertical escarpment face as to the ambient ionizing (lethal) radiation (i.e., look for faces that are the most protected from ionizing radiation).

5. For any given location on the surface of the planet at which there are escarpment faces, there will be a face that is preferential for microbial life living on the vertical escarpment as to ambient sunlight necessary for photosynthesis (i.e., look for faces that are the most conducive to photosynthesis).

6. For any given location on the surface of a planet at which there are escarpment faces, there will be a face that is preferential for microbial life living on the vertical escarpment face as to the prevailing wind (surface abrading wind assumed to be the least conducive to life).

7. For any given location on the surface of a planet at which there are escarpment faces, there will be a face that is preferential for microbial life living on the vertical escarpment face as to the average surface temperature.

8. Evidence of geological flooding from the face of an escarpment can be distinguished from geological flooding from the plateau area atop the escarpment.

The rationale for the McDaniel's Hypothesis stems from the fairly convincing evidence from NASA's Mars Global Surveyor spacecraft, which has sent back evidence of Martian escarpments flooding down from their vertical faces (3). If the above assumptions are correct, then a means of detecting high concentrations of water on the face of an escarpment will give us a means of detecting areas likely to harbor life. The corollary is that a means for detecting high concentrations of life on the face of an escarpment will give us the means for locating water supplies. Finding a way to quantify richness and distribution of microbes on escarpments on Earth therefore may have practical applications on Mars, should we find surface-dwelling microscopic life on that planet. This project had two objectives: to develop a simple protocol for quantification of biological richness in soil samples of interest and to determine if there is a measurable difference between samples based of presumption of previous water content.

A simple way to detect the presence of soil microbes without microscopy is to seal the sample and measure the amount of microbial respiration in the sample by the uptake of carbon dioxide (CO₂) in soda lime enclosed with the sample. The amount of CO₂ incorporated into the soda lime is used as a measure of richness in each sample. We use CO₂ output as a measure of biological richness in the arctic for Global Carbon Models, and utilization of this technique is also applicable in desert ecosystems (4). Samples in this study were collected and analyzed from as many microhabitats as could be located along several separate escarpments and washes with the potential for harboring microbial life.

The idea of combining biological and geological analysis in an attempt to locate water, whether on Mars or Earth, is an intriguing one. These simple experiments were designed to test that concept, but also to test a scientist's ability to collect field data in an analog simulation.

Since our field season was only two weeks in duration, however, we limited our investigation of the McDaniel's Hypothesis to a variation of assumption two: would microbial richness be highest in places where water was more abundant?

MATERIALS AND METHODS

All samples were collected from the area around MDRS in the spring of 2002. Eleven samples were collected on 27MAR2002 during EVA 47 (Waypoint 238), from an area several hundred meters south of the Hab. UTM coordinates were 4254025 N, 0517925 E, and elevation 1366 m. An additional 6 samples were collected on 28MAR2002 at waypoints 162, 162, 166 and 167 during EVA 48, from sites along Lowell Highway. These samples were excluded from data analysis. Twenty-nine samples were collected during EVA 54 and 55, both executed on 1APR2002. These samples were all taken from Tank Wash (Waypoint 234). UTM coordinates were 4254025 N, 0518197 E, and elevation 1365 m. During the PEV-OE (EVA 57) (3/4APR2002), twenty new samples were collected at Coal Mine Wash (Waypoint 199). UTM coordinates were 4258313 N, 0507446 E, and elevation 1426 m. These were taken back to San Diego, California for later analysis. Samples were classified as either wet or dry. Wet samples were those taken from anywhere water would persist after a heavy rain. These included washes, runoff channels and ephemeral basins. Dry samples included areas where water does not persist after rain, but instead drains quickly away, such as escarpments and small areas of higher ground (regolith). We used a soil corer at a depth of 10 cm to collect samples. The original plan was to collect samples from a depth of 30 cm but that proved difficult in the hard and rocky soils because the corer did not have an adequate tip. Soil samples were transferred in the field from the soil corer into labeled 120-mL plastic specimen containers. The average sample mass was 40 g and both soil samples and soda lime were massed at all times along with the container that housed them. The average mass of a sample container was 16.43 g and the average mass of a soda vial was 4.07 g. We used these averages in our analysis.

Collected samples were massed at the lab and a small glass vial containing approximately 4 g of soda lime was massed and placed in each sample container. Four mL of distilled water were added to each sample and the sample was then mixed with a toothpick. The water was added because all but one of the samples contained no apparent water. Soda lime does incorporate water as well as CO₂ into its structure, but since the same amount of water was added to each sample, it should not affect results. The containers were then sealed and placed in the incubator at 25°C and after 6 days the difference in the mass of the soda lime vial was recorded. The data from three of the above locations (Table 1) were analyzed using JMP-IN (5).

All work completed in the field was done in full simulation mode (analog spacesuit, helmet, gloves, operating under established simulation protocols), and included scouting sites, collecting samples and recording location data. All work completed in the lab was done in street clothes, and included processing and recording sample data before and after incubation.

RESULTS

After six days, the mean difference in the mass of soda lime between treatments using samples from South Hab and Tank Wash was 0.104 g (n = 40), with the soda lime from wet area

samples being on average almost twice as heavy as their dry area counterparts. The mean was 0.142 g (SE = 0.027) for samples classified as being from wet areas and 0.246 g (SE = 0.023) for samples coming from wet areas. This was a significant difference ($F = 8.746$, $df = 1$, $p = 0.005$) between treatments. ANOVA results of treatment across these two locations show the same trend of more microbial richness in water persistent areas ($F = 5.086$, $df = 3$, $p = 0.0049$) (Table 2), so they have been combined in analysis.

The mean mass for dry samples was 56.48 g (SE = 2.29) ($n = 18$), while the mean for wet samples was 56.90 g (SE = 2.07) ($n = 22$). The majority of samples fell between 45- 70 g and I feel confident that any variation in mass of samples did not affect the ANOVA results.

The results for the 20 samples collected in Coal Mine Wash are not included in the above analysis. The difference between the wet samples (mean = 0.340 g, SE = 0.010) and dry samples (mean = 0.315 g, SE = 0.011) was 0.025 g and this difference was not significant ($F = 2.697$, $p = 0.1188$) (Table 2). In addition, ANOVA analysis between the Coal Mine Wash samples and Tank Wash/South Hab samples are significantly different ($F = 11.188$, $p = <0.001$) to preclude combination of data in analysis due to improper lab protocol used in the Coal Mine Wash samples.

DISCUSSION

These results suggest that microbial life around MDRS is distributed in a manner that allows the organisms to maximize their use of water when it is available. The winter of 2001-2002, when these experiments were conducted, had been a particularly dry one in Utah, and there was little soil moisture in areas where water was not typically available year round. The significant difference in CO_2 released from the samples suggest that microbial life forms are distributed in a patchy manner over the landscape, and are richer in areas where water, once present, persists for greater time periods. This could be important in locating and identifying the microbial diversity of the area, and could have implications in the way we look for life on Mars.

The analysis of the Coal Mine Wash samples was different from all other samples in that they were processed and incubated almost a month after they were collected. During most of this time, they were kept in a dark storage area maintained at approximately 20°C. The results obtained from these samples, which should have been much the same as the other samples, suggest that storing the samples effectively destroyed any microscopic life present. This would especially be true if any microbial life in the samples was photosynthetic. Indeed, this suggests that there might have been high concentrations of photosynthetic microbes in the samples we collected. Any future samples should be processed immediately after they are collected.

Originally, this project had three objectives: 1. Develop a simple protocol for quantification of biological richness and water content in soil samples of interest, 2. Determine if a correlation exists between biological richness and location of soil/rock samples (Life leading you to water), and 3. Determine to what extent the level of water present in the sample has an influence on biological richness (Water leading you to life.) These objectives were identified as being necessary to adequately test the McDaniel's Hypothesis. However, with only a single two-week rotation to do fieldwork and the unexpected dryness of the soil samples, a narrowing of our

objectives was required. The focus instead was to demonstrate that biological richness of samples could be quantified in a simple experiment, and to determine if there was a significant difference in richness between wet and dry treatments (effectively, test assumption two). Those objectives were met. However, there are a number of issues that should be addressed in any future repetition of this experiment. Foremost, no analysis was done to conclusively determine the presence of microbes in the samples. Although the results were dramatic, and suggest that indeed there were microbes present in the sample, there was no definitive proof that the samples contained microorganisms. Continuing work on this project should include soil, gas, lipid and/or protein analysis of samples, in addition to traditional microscopic and microbiological methods for detection and identification of organisms. Also, while the amount of water in each sample appeared to be negligible, no samples were conclusively tested for water content. This should be done in the future, perhaps by doing a mass comparison of a portion of the sample both prior and after desiccation. Finally, the six-day incubation period was dictated by the length of the rotations at MDRS and may not be optimal. We mention these things as the research begun here warrants future investigation and it is our intent to implement these improvements while continuing this project in subsequent years.

One of the most ambitious outcomes of the McDaniel's Hypothesis, at least in terms of analog research, would be to identify the patterns of microbial richness around the Mars Desert Research Station on both spatial and temporal scales over a number of years. These patterns could lead to the derivation of an equation that calculates the likelihood of water and microbial life at a given location. Higher variables would be assigned for, among other things, geological evidence of water runoff, leaching of salts indicative of evaporation of water, actual water, microbial discoloration, and preferential sun, wind and ambient surface temperature. Teams of geologists and biologist could study the Martian terrain in tandem, looking for the most promising sites to find water and life. Even if the knowledge gained from the identification of microbial distribution around MDRS is never used for studies on Mars, the information will be beneficial to any long-term ecological monitoring program here on Earth.

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Table 1. Sampling locations in the area around the Mars Desert Research Station. All information is from data generated by MDRS Crew 4 and was current at the time of this study. Location name and waypoint number may have been changed by subsequent crews.

LOCATION NAME	WAYPOINT	UTM COORDINATES	ELEVATION (meters)
South Hab	238	4254025 N, 0517925 E	1366
Tank Wash	234	4254025 N, 0518197 E	1365
Coal Mine Wash	199	4258313 N, 0507446 E	1426

Table 2. Differences in carbon dioxide output between wet and dry samples taken from South Hab (WP238)/South Hab (WP234) and Coal Mine Wash (WP199). All data are from samples collected in March and April 2002 by MDRS Crew 4. Differences were calculated by subtracting the post incubation mass of soda lime from the pre-incubation mass. Data were analyzed using one-way ANOVA.

	Mean (g)	SE	F	df	p
Waypoints 238 & 234 (n =40)			8.746	1	0.005
Dry	0.142	0.027			
Wet	0.246	0.023			
Waypoint 199 (n = 20)			6.697	1	0.118
Dry	0.315	0.010			
Wet	0.340	0.011			