# Evaluating the Performance of Field Science in an Analogue EVA suit: Stromatolite Identification by Geologists and Non-Geologists

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**Summary:** Understanding the constraints of field work while in a space suit is critical when considering crewed exploration on the surface of the Moon, Mars and other accessible Solar System bodies. Mars Society Australia studied the effect of simulated space suits on field work during the Arkaroola Mars Robot Challenge Expedition in 2014. A simulated EVA suit from the Victorian Space Science Education Centre was used. The study attempted to assess the validity of predictions made from earlier trials in the Pilbara region with a different suit. The trial showed, as predicted, that the performance of geologists was greater than non-geologists, as determined by accuracy of observations. However we also observed, contra predictions, the analogue EVA suit did not degrade observational performance, but enhanced it. Further trials are recommended to test these observations. Perhaps most importantly, the experiment confirmed that suited geologists and appropriately briefed non-geologists would have no difficulty in correctly identifying stromatolite-like features on Mars.

**Keywords:** Mars analogue research, EVA suits, geology, astrobiology, human factors research, stromatolites, Arkaroola.

## Introduction

Detailed, complex, and sophisticated field science investigations will be a key part of future crewed missions to the Moon and Mars (Refs. 1, 2, 3). Quantifying the capabilities of scientists and non-scientists to do such investigations while wearing EVA suits is important for designing mission goals, setting expectations, refining suit and field tools or instrument design, and mission architecture.

A prior example of this was the development of procedures, systems, and technology for Apollo EVAs on the Moon. These were based on extensive trials of varying levels of fidelity at many sites including Hawaii, New Mexico, and Arizona (Ref. 4). Trials included full and partial simulations with actual and simulated EVA suits or parts of suits (e.g. gloves, backpacks, helmets, etc.) As a result of these trials the need for suit cooling was indentified, along with the need for specialised tools to overcome postural limitations of the gas-pressure suits and the safety of using standard geological tools such as rock hammers while wearing EVA helmets.

This paper describes a small, low-cost trial that examines one particular aspect of the performance of science tasks, the recognition of stromatolites by geologists and non-geologists under analogue EVA conditions and the suitability of one analogue EVA suit to such studies. It builds on previous research (Ref. 5) and is intended to more complex and sophisticated studies at a later date.

## Aim

The aim of the trial was to assess the suitability of the Victorian Space Science Education Centre (VSSEC) analogue EVA suits to test the ability of geologists and non-geologists to recognise specific scientific features. Stromatolite outcrops were chosen as typifying a class of readily recognised feature of great scientific interest if found on Mars, that occurred in the field area, and had been used for other trials (e.g. Ref. 5).

This was done by testing a set of pre-trial predictions, based on experience given by Ref. 5) which were:

1) Useful field science and operational research can be performed while wearing analogue EVA suits.

2) The suits measurably reduce observational abilities compared to an unsuited baseline (termed "ground truth" in Ref. 5).

3) (a) That geologists would make fewer observations than non-geologists but
(b) would out-perform them in the accuracy of their observations; and

4) The performance of geologists would be less impeded than that of non-geologists.

Of these predictions, 1), 2), 3(b), and 4), consistent with common sense expectations of the limitations of working in an EVA suit. Prediction 3(b) however, is not, as we would have expected geologists to make more observations. This unexpected result may be due to the greater degree of metal processing by the experienced and trained observer resulting in greater caution before voicing their observations as a statement.

For this experiment we note that, while the VSSEC suits overall are a poor gas-suit analogue (although better as a mechanical counter-pressure suit analogue, e.g. Ref. 6, the study was an observation trial, and therefore the helmet is most significant in contributing to the success or otherwise of tasks performed in the suit. The helmet of the chosen suit is a good analogue for a real space suit (Ref 6).

## Experiment Context

The experiment was carried out during the Mars Society Australia (MSA) Arkaroola Mars Rover Challenge Expedition (Ref. 7), which took place in the northern Flinders Ranges, South Australia, in

July 2014 . This expedition conducted research across several fields relevant to Mars exploration, including palaeobiology, operations research, field robotics, as well as suit trials, in a Mars analogue environment side by side with educational and public engagement programs. The Arkaroola region had been previously selected by MSA as an ideal location for such multidisciplinary analogue research programs (Ref. 8).

## Scenario

The scenario used in the study was the investigation of a potentially fossiliferous carbonate outcrop on Mars identified by satellite imagery and hyperspectral data and accessed by a sortie from a landing site several tens of km distant. Geologically-briefed engineers and specialized geologists would spend a limited amount of time assessing whether or not the outcrop contained mesoscopic signs of life in the form of stromatolites. These are typically columnar or hemispherical structures formed by the growth of generally shallow water and usually photosynthetic microbial communities (see benchmark compendium in Ref. 9). As the oldest macroscopic structures constructed by life (Refs. 10, 11) stromatolites and other microbial structures are targets to be looked for in the astrobiological exploration of Mars (Refs. 12, 13). Indeed possible microbial structures have already been observed on Mars (Refs. 14, 15), although their validity remains to be tested.

The limited time for assessment per location is also analogous to the Apollo-like traverses where a number of locations were visited on an EVA (see Ref. 16 for examples from Apollo 14). Each location was allocated an investigation time duration on the EVA schedule. Thus the Apollo astronauts undertook investigations within scheduled time limits to, assess, take samples and document geological locations. If the investigation showed that more time at the location would provide better science return then a decision was made to change the schedule for the remaining EVA.

## Study site

The site was required to have moderate (10-20%) outcrop and reasonable number (i.e., enough to be easily found in the allocated time) of stromatolites. The site also should not be too rocky or have excess vegetation for safety reasons and needed to be accessible by vehicle, which could be driven to within about 50 m of the base.


*Fig. 1: The Google Earth image of the test site south of Arkaroola. The scale bar is 57 m.*

The selected site (Figures 1, 2) was at 30°26'29.47"S and 139°19'45.42"E with an elevation of 204 m above sea level at the foot of slope. It is 14.3 km in a direct line south of Arkaroola, and 18.1 km by road. The outcrop begins 55 m east of the Arkaroola road.

The outcrop is west dipping at 25-35°, northeast-southwest trending strike ridge composed of stromatolitic grey limestone with stratabound orange-brown to yellow dolomitisation and cross-cutting dolomite and calcite veins. The best exposures were found on the lower part of the ridge. The outcrop is a low strike ridge 400 m long, 40 m wide and about 5 m high, and is visible in Google Earth imagery (Fig. 1). The Google Earth aerial photography resolution is about ~30 cm, which is equivalent to the HiRISE camera on the Mars Reconnaissance Orbiter (MRO) and to ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) hyperspectral data, which has a resolution of 15 m (Ref. 17), roughly equivalent to the CRISM (Compact Reconnaissance Imaging Spectrometer for Mars) instrument on the MRO, as per Ref. 18). The ridge is visible as a FeOH and MgOH feature in the visible to near infrared ASTER data and has having low silica in thermal infrared ASTER, this suggests the presence of ferroan dolomite.

The outcrop is approached from the east across a lightly gullied parna-mantled pediment with minor alluvial reworking of siltstone fragments. Because of the approach direction and the topography the outcrop mostly represents the bedding plane, although cross sections are exposed on the sides of some blocks. Vegetation consists of forbs and small Acacias. Areas of denser vegetation, mostly on the ridge, were avoided during the course of the experiment to avoid entanglement. The area used in the trial was ~70 m x ~20 m.

*Fig. 2: The low ridge of Trezona Formation selected for the experiment.*

The outcrop was mapped as Trezona Formation (Ref. 19). This Neoproterozoic formation (Ref. 20) is composed of grey to pink, fine-grained, oolitic, intraclastic and stromatolitic limestone with variable dolomite interbedded with shale and siltstone. The ooids and complex intraclasts are often stained red by haematite and were term "hieroglyphic limestone" by Mawson (Ref. 21). Stromatolites are of two types: broad elongated hemispheres with cuspate ridges and pseudo-columnar forms. The Trezona Formation has been subsequently assigned to the Cryogenian (Ref. 22).

The stromatolites at the outcrop are simple columns, typically 5-10 cm high and 2-5 cm across. They are exposed largely as circular impressions on the upper surfaces of bedding planes on massive to slabby outcrop (Figure 3). The outcrop is grey, with stromatolites partly enhanced by patchy dolomitisation and silicification. Side views are difficult to obtain as because of the massive to slabby nature of the outcrop, however side views can be obtained on loose blocks, generally small enough to be picked up by hand. Where pervasively dolomitised, however, the stromatolitic textures are obliterated by the buff to red-coloured secondary carbonate.

## Methods

### Analogue EVA Suits

The analogue EVA suits (Figure 4) worn on the expedition were originally developed as a collaboration between Strathmore Secondary College and MSA in 2004 for VSSEC. As they would be used daily by groups of students exploring a simulation Mars landing site, the key requirements were safety, robustness, comfort, low cost, easy donning/doffing, high maintainability, and the provision of a memorable EVA suit-like experience and appearance for the wearer. As such, the suits were developed as a basic mimicry of a future gas-pressurised planetary exploration suit. Accurate generation of the high joint torques of true gas-pressurised suits was not pursued as this would compromise almost every design priority; however bulky gloves and boots were specified to provide some inhibition to mobility and hand dexterity. Cotton drill coveralls were provided by Yakka in a wide range of sizes to form a replica gas-pressurised garment.

*Fig. 3: Bedding plain exposures of small hemispherical stromatolites at test site. A pocket knife (10 cm) provides scale.*

MSA developed a pseudo life-support system consisting of a helmet, backpack and ventilation system based on previous analogue suit designs and experience from the MarsSkin program. The helmet configuration was based on two half sphere domes: a clear upper dome and solid base dome with a large entry port and neck ring. The clear dome can be attached in various alignments so that the inevitable scratches produced from closely inspecting objects can be rotated away from the line of vision, while also reducing the frequency and cost of replacement domes. Strathmore Secondary College requested that the helmets be easily removable, so they rest lightly on the shoulders of the wearer.

Life support is contained within a Boblbee hard-shell backpack. High ventilation sufficient to meet safety requirements is met by two fans that are installed inside a simulated oxygen canister on the backpack and plumbed to each side of the helmet. This ventilation air is directed forwards against the faceplate to reduce fogging and prevent cold spots on the head by small deflectors internal to the helmet, improving appearance and covering any sharp edges of attachment plumbing. A 7Ah 12V lead-acid battery provides approximately 5 hours of ventilation, and gives appropriate weight to the life-support system. For long duration EVAs, water packs can be stored in the backpack and connected to a bite valve mounted inside the helmet. UHF radios can also be incorporated, for example by the use of a simple ‘snoopy cap’, headphones, microphone and VOX operation. Normally at VSSEC the communications are carried out through a WiFi system operated by a laptop computer, also carried in the backpack.

**Participants**

The seven participants of the study comprised three with geological training and four without. “Geologists” were those with some degree of formal geological training. “Non-geologists” had a range of qualifications, including general science, paramedical, education, and heritage. All had been briefed on what to look for verbally and with illustrations, and had seen similar stromatolites in the field previously, both at Arkaroola and elsewhere. The participants were four males and three females, with both genders represented in each skill-set. Ages varied from 20s to 60s. Only one participant had previous experience in testing analogue EVA suits, being part of the team in Ref. 5.

*Fig. 4: VSSEC analogue EVA suits of the type worn for this experiment.*

**Experimental Method**

Each experiment lasted 20 minutes and was supervised by the experiment controller. Participants were directed to leave the starting point and walk to the northern end of the target area. When they reached the first limestone outcrop the start of the timed experiment commenced. The participants performed the observations at their own pace.

The participants were required to point out any stromatolites and describe them as probable or possible. Probable stromatolites were features identified as stromatolites with a high degree of confidence. Possible stromatolites were features identified as possibly stromatolitic but with lower confidence. False positives (sites identified as probable or possible stromatolites that were judged as non stromatolitic by the experiment controller) and false negatives (sites rejected as stromatolites that were considered stromatolitic by the controller), were also noted. Communications were transmitted via a UHF radio on VOX setting for the suit and manual setting for the controller.

Assessment of each observation was by the controller, who had previously scouted the site and has thirty years experience in field geology, including extensive field experience with stromatolites of Holocene (West Australia, South Australia), Pleistocene (South Australia), Ordovician (Tasmania), Cambrian (South Australia), Neoproterozoic (South Australia), Mesoproterozoic (Queensland, Northern Territory) and Archean (West Australia) age. Additional comments on the impact of the equipment on operations by the wearer were also recorded by the controller.

After the suited trials were completed the same participants were asked to repeat the exercise but without wearing the suit. The same observations were made and these were assessed in the same manner as the previous suited trial.

Ethical review was not necessary as it was suit performance that was being assessed rather than the human wearers.

All results from the tests were tallied and entered in an Excel spreadsheet.

## Results

### Suited Results

The results of the suited results are shown in Table 1. Overall 89.2% of the observations were judged correct. As expected, geologists were more accurate than non-geologists in their identifications, with 97.0% accuracy compared to 84.2%. Overall, observers were more likely to make a false positive identification (7.8%) than a false negative (3%), however the likelihood of a geologist making a false positive or negative observation was the same (1.5%). Non-geologists were eight times more likely to make a false positive observation than geologists and 2.6 times more likely to make a false negative.

*Table 1: Results of the trial: Accuracy while suited*

| SKILL | PROBABLE | POSSIBLE | FALSE POSITIVE | FALSE NEGATIVE | TOTAL | TOTAL VALID | TOTAL ERRORS |
|---|---|---|---|---|---|---|---|
| GEOLOGISTS | 36 | 28 | 1 | 1 | 66 | 64 | 2 |
| % | 54.5 | 42.4 | 1.5 | 1.5 | 99.9 | 97.0 | 3 |
| NON-GEOLOGISTS | 49 | 36 | 12 | 4 | 101 | 85 | 16 |
| % | 48.5 | 35.6 | 11.9 | 3.9 | 99.9 | 84.2 | 15.8 |
| TOTAL | 85 | 64 | 13 | 5 | 167 | 149 | 18 |
| % | 50.9 | 38.3 | 7.8 | 3 | 100 | 89.2 | 10.8 |

### Unsuited Results

Results of the unsuited trials are shown in Table 2. Overall 87.4% of the observations by geologists and non-geologist were correct. Geologists were more accurate than non-geologists in their identifications, 94.9% as against 80.9%. A false positive identification was less likely (5.5%) than a false negative (7.1%). Unsuited, geologists made a false positive identification 3.4% of the time and a false negative 1.7% of the time). Non-geologists made false negative identifications 11.8% of the time compared with false positives 7.4% of the time. Thus non-geologists were almost seven times more likely to make a false negative observation than geologists and were just over 1.3 times more likely to make a false positive.

*Table 2: Results of the trial: Accuracy while unsuited*

| SKILL | PROBABLE | POSSIBLE | FALSE POSITIVE | FALSE NEGATIVE | TOTAL | TOTAL VALID | TOTAL ERRORS |
|---|---|---|---|---|---|---|---|
| GEOLOGISTS | 24 | 32 | 2 | 1 | 59 | 56 | 3 |
| % | 40.7 | 54.2 | 3.4 | 1.7 | 100 | 94.9 | 5.1 |
| NON-GEOLOGISTS | 27 | 28 | 5 | 8 | 68 | 55 | 13 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **%** | 39.7 | 41.2 | 7.4 | 11.8 | 99.5 | 80.9 | 19.1 |
| **TOTAL** | 51 | 60 | 7 | 9 | 127 | 111 | 16 |
| **%** | 40.2 | 47.2 | 5.5 | 7.1 | 100 | 87.4 | 12.6 |

*Table 3: Results of the trial: Number of observations*

| SKILL | SUITED | # OBSERVATIONS | # OBSERVERS | MEAN |
|---|---|---|---|---|
| GEOLOGIST | YES | 66 | 3 | 22 |
| NON-GEOLOGIST | YES | 101 | 4 | 25.3 |
| TOTAL | YES | 167 | 7 | 23.9 |
| GEOLOGIST | NO | 59 | 3 | 19.7 |
| NON-GEOLOGIST | NO | 68 | 4 | 17 |
| TOTAL | NO | 127 | 7 | 18.1 |

### Qualitative comments by participants

All participants commented on experiencing several difficulties when wearing the suits. There was difficulty in seeing out of the helmets when looking up-sun, because of glare associated with light scattering from scratches and dust on the helmets. Rock colour was more difficult to assess in the helmets, possibly from slightly reduced contrast and the previously mentioned light scattering. There was uncertain footing because of the large boots worn and the associated increase in care needed while moving, especially with respect to foot placement. Participants only occasionally crouched or knelt to make observations. Sometimes loose specimens were picked up, however most exposures were on large slabs, precluding handling.

## Discussion

### Caveats

The sample size of this study is small and therefore conclusions drawn from the above statistics are both tentative and provisional. It is the researcher's aim to expand on these results with future trials.

### Success of predictions

Prediction 1), that useful field science can be performed while wearing analogue EVA suits, was confirmed. This is as expected from the success of Apollo astronauts on the Moon.

Prediction 2), that the suit would impede performance was not borne out (Tables 1 and 2). Overall the suited and unsuited participants scored 89.2% and 87.4% correct results respectively. Geologists correctly identified stromatolites better when suited compared to non-suited (97.0% versus 94.9%), as did non-geologists (84.2% versus 80.9%).

Prediction 3(a), that geologists would make fewer observations than non-geologists, was only partly borne out (Table 3). The prediction was correct while the participants were suited, with an average of 22 observation per geologist as opposed to 25.3 for the non geologists. When unsuited, geologists made more observations per observer (19.7) than non-geologists (17) on an observer basis.

Prediction 3(b), that geologists would out-perform non-geologists in the accuracy of their observations was validated (Table 3). Geologists achieving 12.8% greater accuracy in identifications while suited and by 14% while unsuited, compared with non geologists.

Prediction 4), that geologists would be less impeded by the suits than non-geologists, was shown to be incorrect (Tables 1 and 2). While neither group were noticeably impeded by the suit, the performance gap between the geologists and non-geologists narrowed from 3.3% without a suit to 2.1% while wearing a suit, and geologists made more observation while not wearing the suit than non-geologists.

**Possible explanations**

The apparent increase in performance whilst wearing a suit is a surprise. Ref. 5 reported that while using the University of North Dakota's NDX-1 pressurised suit participants made 25% fewer observations than when unsuited and made three times as many incorrect observations. This was not repeated. There are several explanations for this discrepancy:

1. These analogue suits do give not an accurate representation of the difficulties of doing field science in a gas-pressurised EVA suit, in particular the greater flexibility of the VSSEC suits (Figure 5).

2. Because the unsuited trials were carried out subsequently to the suited trails, the participants may have been more fatigued and less capable of observations than when they were wearing the suits. A priori this appears unlikely as the tests lasted only 20 minutes and the participants were all in good health and of reasonable fitness.

3. It is possible that the actual wearing of the suit may have led to increased observational focus and thought in the participants whilst carrying out the test.

4. It may also be possible that the participants did not take the unsuited test as seriously and so were less diligent in their observations.

5. The participants in the NDX suit trials in the Pilbara had no previous experience in wearing or working with the suit. The suit was not individually fitted and some wearers experienced significant discomfort from the poor fit. It is possible that greater training and familiarity might eliminate the difference in suited and unsuited performance while wearing the NDX suit.

6. Furthermore the Pilbara trials were carried out over rougher terrain than at Arkaroola. This would have resulted in the participants directing more attention to operating the suit and less to observations.

7. During the Pilbara trials the weather was very warm, and all participants experienced over-heating leading to fogging and misting to greater or lesser degrees, which significantly hampered the ability to make geological observations. Similar issues were not experienced with the VSSEC suit, due to cooler weather and the different suit design.

*Fig. 5: The high flexibility of the VSSEC suits enables the wearing to easily crouch down while inspecting rocks on the ground.*

## Further Work

Further work with the VSSEC suit will be needed to test the seven possibilities above, and assess the validity and implications of the trials. We recommend that several further trials should be carried out to test these hypotheses.

1) As a minimum more unsuited trials in the same area with a similar mix of skill sets should be carried out to establish a baseline.

2) If the VSSEC or similar suits are available, the trials should be repeated, but this time with the suited test last. This would allow the possibility of fatigue to be explored and determine whether similar patterns are observed. Together these would test hypotheses 1-4 proposed above to explain the data.

3) A repeat of the NDX test with experienced wearers who more closely match the size requirements of the suit should be carried out to test hypothesis 5 above; and

4) Trials at a different, more rugged stromatolite site at Arkaroola with the VSSEC suits (or similar) and a less difficult stromatolite (or equivalent) site with the NDX-1 suit would assess whether rougher terrain impacts significantly on performance.

We are currently planning on carrying out trials 1) and 2) in a further expedition to Arkaroola in July 2016.

## Applications to Mars

Any Mars mission will consist of a small team, perhaps numbering six, of cross-trained astronauts, some with more specialised training in field science than others (Ref. 1). This regard they will not be dissimilar to Apollo astronauts, who were mostly from test-pilot backgrounds with formal training in engineering with some cross-training in geology, and only one geologist (Ref. 4). As with Apollo, astronauts will be under time constraints forced by EVA logistics, to a degree rare on Earth (Ref. 23). Unlike Apollo, astronauts on Mars will have the ability to revisit sites of interest during their 500-600 day surface mission (Ref. 1). The superior performance of the geologists in the trial underlies the importance of having trained field expertise on Mars, however it is neither possible nor desirable to have a crew made up entirely of such people. However the fact that motivated and informed, if not with formal training, could also make useful observations highlights the importance of cross-training of astronauts of other specialisations. The success of that cross-training will be partly dependent on the breath and realism of that training, for example it is unlikely that any of our non-geologists would have recognised stromatolites without the briefing they previous received and exposure to examples elsewhere in the Arkaroola region.

## Conclusions

This study showed that, as expected, VSSEC (and similar) analogue suits allow useful trials of crewed exploration of planetary surfaces within the limitations of their abilities to represent actual EVA suit performance. In particular they show that wearers, both geologists and non- geologists, are able to make the required observations despite wearing a helmet.

As per the predictions based on Ref. 5 and recommendations of Ref. 2, performance of geologists was measurably greater than non-geologists, as determined by accuracy of observations. This was irrespective of whether or not the VSSEC suit was worn, however the performance differential between the two increased when suits were worn.

However, contra predictions in Ref. 5, the VSSEC analogue EVA suit did not appear to degrade observational performance, but enhance it.

Multiple hypotheses were generated as possible explanations of these differences between what was predicted and was measured. Further trials are recommended to test these using VSSEC (or similar suits) and, if possible the NDX-1 suit.

Finally, and perhaps most importantly, as per the Mars scenario that framed the experiment, suited geologists and appropriately briefed and trained non-geologists appear to have no difficulty in correctly identifying stromatolite-like features on Mars, should they be encountered.

## Acknowledgements

We thank the Victorian Space Science Education Centre for the loan of their suits. Funding for the expedition was provided by CSIRO, the Australia-India Council, and Australian Geographic, and Saber Astronautics. In-kind support was provided by Saber Astronautics, UNSW, Macquarie University, Murdoch University and the Arkaroola Resort. David Willson of NASA Ames Research Center also provided much useful commentary on the paper.

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