Field Robotics, Astrobiology and Mars Analogue Research on the Arkaroola Mars Robot Challenge Expedition

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Summary: Mars Society Australia's Arkaroola Mars Rover Challenge Expedition was an initiative of Saber Astronautics and Mars Society Australia. The expedition was based round a program of field trials of robots developed by students from Murdoch University, the University of New South Wales, Mars Society India and Mars Society Australia. This was the first time such an expedition had been attempted in Australia. Robot performance, remote operations, simulated extra-vehicular activities and simulated space suit evaluations were accompanied by geobiological research and training in field geology and media relations. The successful conclusion of the expedition paves the way for further expeditions of this type for Australian and international students and researchers.

Keywords: field robotics, planetary exploration, astrobiology, analogue research, Mars, Arkaroola.

Introduction

The Arkaroola Mars Rover Challenge Expedition, a collaboration with Saber Astronautics and Mars Society India (MSI), is the latest in a series of expeditions run by Mars Society Australia (MSA) since 2001. Destinations of previous expeditions have included the Pilbara [1], the Mars Desert Research Station [2] in Utah as well as Arkaroola [3].

The goal of the expedition was to conduct research across several fields relevant to Mars exploration in a Mars-like environment side by side with educational and public engagement programs. A Mars analogue is an environment or a region that has analogous characteristics to Mars [4].

The Arkaroola region (Fig. 1) was selected by MSA on the basis of 1) its many scientific features of interest to planetary geologists, geomorphologists, and astrobiologists; 2) a diversity of different terrains, materials and surfaces ideal for engineering tests; 3) the education and outreach

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[1] K. Abetz, W. Andrews, M. Cooper, A. Dahl, P. Gatkine, S. George, G. Hobbs, S. Hobbs, S. Houlahan, Y. Kabaran, A. Kotwal, A. Kshirsagar, J. Lai, G. Mann, S. McArthur, G. Murphy, R. Prajapat, A. Rajagopal, K. Silburn, N. Small, T. Smith, P. Spinks, V. Sudarsanan, A. Tandi, M. Tanner, N. Wheaton, and T. Wheaton.

potential supplied by this diversity; 4) the logistic support available through the Arkaroola Resort [5], and 5) a heritage of Mars analogue and astrobiological research by MSA, the Australian Centre for Astrobiology and others [6, 7].

Fig. 1: Location of Arkaroola in the Flinders Ranges (Google Earth Image).

The expedition was conducted over a two week period in July 2014 and involved 28 participants. They included students from four universities in Australia and India (Murdoch, UNSW, Macquarie and IIT Bombay), researchers from two Australian universities (Murdoch and Macquarie), MSA volunteers, two researchers from Saber Astronautics and a representative from Fairfax Media. Several researchers and volunteers located in Sydney, Canberra and Melbourne were also tasked by MSA and Saber Astronautics to provide expedition support.

This paper summarises the expedition rationale and activities, providing a context for other papers, including some those elsewhere in these proceedings, which will detail expedition results (e.g. [8, 9, 10]).

Rationale

Purpose of Mars analogue research

Analogue research is an invaluable step in space research and development between the laboratory and an actual mission. Mars (and other Solar System) analogues are also very useful in education and outreach as they place educators and students in environments that resemble aspects of those found on Mars and elsewhere in the Solar System.

Three types of analogue research were outlined by Persaud [4]. These were programs of discovery, opportunity, and investigation. Programs of discovery are those that consist of holistic and realistic simulations (which may none the less be of low fidelity in some aspects) that set up a situation and make qualitative observations of the problems and challenges that arise, both anticipated and unanticipated. Programs of opportunity are those where engineering and scientific research (e.g. geology, biology) is carried out of the analogue region or environment. Programs of investigation carry out experiments of specific parameters and make qualitative observations on operational problems, usually connected to the design and operation of engineering items and instrumentation. Under this classification, the research undertaken on the Arkaroola Mars Rover Challenge Expedition fell into the category of programs of opportunity and investigation with respect to field robotics and operations research, and of opportunity with respect to geobiology.

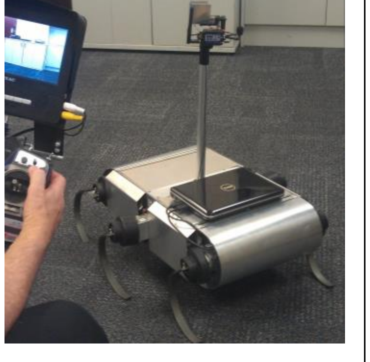
Expedition aims

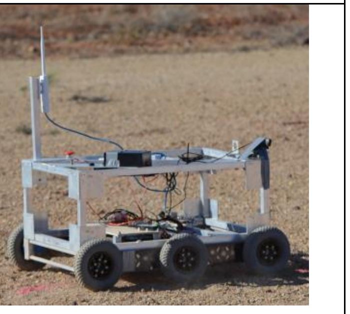
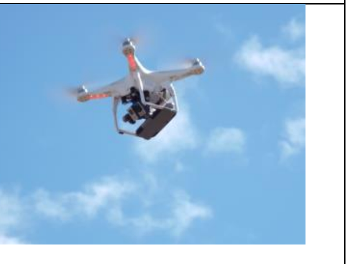
The Arkaroola Mars Rover Challenge Expedition had the following objectives (terminology of Persaud [4]):

- To investigatively test a range of field robotic systems under standardised conditions with goal of developing concepts for planetary operations, especially Mars.
- To opportunistically test robots in the field against conditions and features that approximated in one or more aspects those that might be found on Mars and other Solar System bodies.
- To opportunistically test control of remote robotic and human field operations at Arkaroola from Saber Astronautics' control centre in Sydney.
- To opportunistically conduct a series of simulated extra-vehicular-activities (EVAs), utilising observational data of human-robot systems to model mission performance
- To opportunistically explore effectiveness of field science while wearing simulated space suits.
- To opportunistically explore geobiological features relevant to astrobiology, testing hypotheses regarding the presence of fossil bacteria in veins and presence of sponge biomarkers in sediments.
- To provide instruction to participants into astrobiology, astrogeology, and science communications, and encourage interaction and cross-stimulation between students, researchers and volunteers.
- Enable public outreach via lectures and media contacts as to the importance of planetary science, field robotics, and astrobiology, and
- Inspire and equip STEM teachers via the Spaceward Bound program through exposure to science & engineering related to planetary exploration.

These goals were all met during the expedition, as detailed in the following sections.

Table 1: Arkaroola Mars Robot Challenge Expedition robots.

Robot	Operator	Description	Investigations	Other features	Illustration
MSI rover	MSI	Custom 6X6 rover bogie rover with skid and 4-wheel steering	Remote operations tests	Power: 11.1V LiPo 56Ah Batteries. Sensors: 3 FPV colour cameras 180 degrees FoV, 1 forward, 1 navigation (rear mount) and 1 on the arm; compass and GPS. Comms: 250mW 900MHz RS-232 serial command and control link (ruuning at 19200 bps); 500mW 2.4GHz wireless data link for camera feeds. Other features: 3 DoF (degrees of freedom) arm, with soil sampling scoop attachment or optional gripper attachment.	
Corobot	Murdoch	Modified OTS 4X4 rover	Rover trials	Power: 2 x 6V 5Ah NiMH batteries. Sensors: fixed camera, 2 IR detectors, GPS, force sensors, bump switches. Comms: 802.11n WiFi to laptop. Other features: 5 DoF manipulator with joint angle sensors, power screwdriver	
Mascot	Murdoch	Custom hexapod rover with drive revolute spring legs for tripod walking	Rover trials	Power 2 x 18v 5Ah motors, 1x 11 Ah LiPo batteries. Sensors: Pan-tilt 380 line PAL camera with 1.4 Ghz 1 W video transmitter, microphone. Comms: 900 MHz analog RC (control). Other features: 5 DoF Still camera mount	

Robot	Operator	Description	Investigations	Other features	Illustration
UNSW	UNSW	Modified OTS 6X6 skid steer rover	Rover trials	Power: 2 x 18Ah SLA batteries. Sensors: 1 pan tilt camera, 1 fixed camera, GPS, pitch-roll inclinometers. Comms: 0.63W 2.4Ghz 802.11n WiFi to laptop. Other features: custom 4Dof manipulator, lidar	
Miner	MSA	Custom 8X4 in rocker bogie pairs, skid steer rover	Rover trials & remote operations tests	Power: 1 x 12V 12Ah SLA batteries, 1 x 12.2V 2.4Ah LiPo. Sensors: pan-tilt camera with 750mW 5.8Ghz video transmitter, 2 x sonar detectors. Comms: 0.75W 2.4Ghz analogue RC. Other features: 20W solar panel	
Little Blue	MSA	Custom 4X4 skid steering rover	Rover trials & remote operations tests	Power: 1 x 14.8V 5Ah batteries, 1 x 12.2 Ah LiPo battery. Sensors: pan-tilt camera with 750mW 5.8Ghz video transmitter, 2 x sonar detectors. Comms: 0.75W 2.4Ghz analogue RC. Other features: custom spectrometer using filer wheel, 40W solar panel, LED lighting option	
Phantom 2	MSA	OTS quadcopter	Rover trials & remote operations tests	Power: 5.2 Ah LiPo batter/balancer. Sensors: pan-tiltcamera with 600mW 5.8GHz transmitter to 177.8 mm HDMI video receiver, GPS. Comms: 2.4 GHz analogue RC control. Other features: Helical and omni-directional antennae for video, PC on-screen display	

Expedition Activities

Field robotics

Expedition robots

Seven robots (Fig. 2) were tested on the expedition, their descriptions and operations are summarised in Table 1.

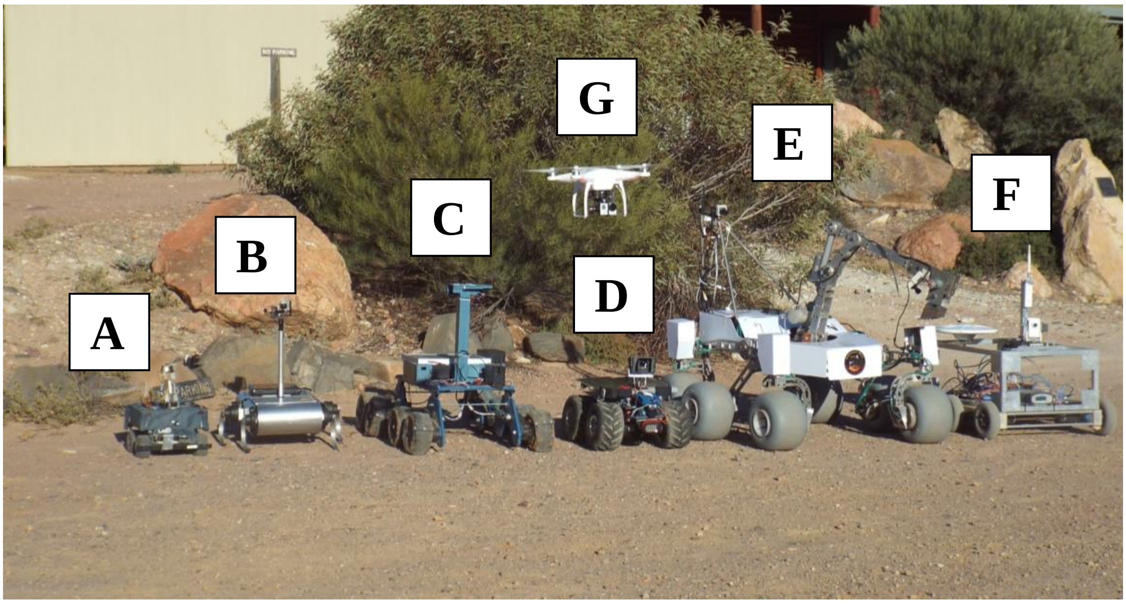


Fig. 2: The seven robots that took part in the Arkaroola Mars Robot Challenge Expedition. A – Corobot, B -Mascot, C-Miner, D- Little Blue, E – MSI Rover, F – UNSW rover, G – Phantom 2.

Robot field trials

Planetary robots can be considered to be a specialised sub-type of field robots. Controlled testing using standard tasks within standard environments allow meaningful comparison of the performance of different designs and guide both improvement of particular designs and design selection for specific tasks. The participating robots in the Arkaroola trials were not envisaged as autonomous explorers such as the current generation of planetary rovers like Yutu on the Moon and Curiosity on Mars. Rather they were conceived as supporting human activity on the surface. Therefore they can be controlled locally, rather than over interplanetary distances. This means that issues of latency and autonomy were not considered in these trials. Such robots could be used for remote activities, required to perform routine maintenance tasks or support astronaut EVAs.

The trials (Fig 3) were devised by Graham Mann of Murdoch University to evaluate the performance of six of the seven robots on the expedition in these areas. Six different standardised tasks, based on those developed by the National Institute of Standards (DHS-NIST-ASTM) in the United States, were performed. Three operational tasks were also developed to evaluate the robots in tasks approximating their intended purpose [8]. The standardised tests were:

1. **Logistics: Robot Test Configuration & Cache Packing.** The process required the completion of forms for every participating machine to capture details of the physical properties, equipment specifications, configurations, toolkit, packing and transport logistics. The information includes specific photographs of a robot, in different poses and from various angles, against a calibrated background. The information is particularly important for managing the configuration of robots from one test to another.

2. **Energy/Power: Endurance: Terrains: Pitch/Roll Ramps.** A test rig consisting of 15° wooden ramps measuring 1200 x 600mm was laid out in a specified alternating sawtooth pattern to repeatably measure the robots' performance on discontinuous terrain. Operators guided the robots around a 15m figure-eight path on the ramps around two vertical pylons. Distance and time from full battery charge to inoperability are measured. It turned out to be impractical to bench test sets of batteries through multiple charge-recharge cycles in the field.

3. **Mobility: Terrains: Flat/Paved Surfaces (100m).** Two pylons were placed 50m apart on a flat surface. The ground around each was marked with a circle 2m in diameter. The robots were to make 10 timed figure-of-eight laps around this course, without deviating from the circumscribed path. Thus both speed and control are important. Average speeds in metres per second were recorded. `

4. **Mobility: Towing: Grasped Sleds (100m).** The robots dragged an aluminium sled, carrying an operator-designated payload, around 10 figure-of-eight laps on the 100m course specified in the third test. Average velocities and maximum achieved weights were recorded.

5. **Radio Communications: Line-Of-Sight Environments.** The robots were tested for navigation control and video feed on a straight course with pylons at 50m and then every 100m thereafter. The robot circumnavigated each station at a radius of 2m, imaging a 35 x 35mm bold letter and a 100 x 100 mm figure on the four faces box atop the pylons. The distance of last station at which both navigation control and video were perfectly reliable (complete circle and all four visual tests correct) was recorded.

6. **Sensors: Video: Acuity Charts and Field of View Measures.** The robots were placed on a 15° ramp 6m from a far-field Landolt-C vision chart. The operator viewed the chart at their control station via the robot's camera and read down the chart to the smallest line at which the orientations of the C shapes were discernible. No more than two errors were permitted on a line. This is reported as a percentage of the 6-6 (20:20) vision standard. The same procedure was used for the near-field Landolt-C chart, except that the distance was then 40cm. The horizontal field of view was calculated by measuring the distance between the chart and the camera.

The three operational tests were carried out at an abandoned road metal quarry. Terrain included slopes of 20 to 40 degrees, loose sand, and large irregular rocks. The operational tests evaluated:

1. **Irregular Terrain Traversal.** A 106m course consisting of four gates (1.2m pylons spaced 2m apart) was arranged over rough, natural, Mars-like terrain. It included slopes of between approximately 20° - 40°, loose sand, and large irregular stones. Operators were

allowed to walk the course before robot testing. The robots were video recorded and timed during their traversal of the course.

2. **Context Imaging.** A small, brightly painted 100g target object was placed at a random locations on roughly level ground at distances of between 43 and 76m from the starting point. The operator was given the object's GPS coordinates. The operator was to locate the object as quickly as possible, then photograph it in context. Time to locate the target and distance to target were recorded. Each operator chose his best four images to be rated for quality. Each image was made anonymous, then examined by three expert field geologists who rated each according to five criteria: object in context (shows surrounding structure), image composition, brightness and contrast, sharpness of focus and image resolution. The mean rating over all images, experts and criteria was then computed from the ratings and expressed as a percentage of the perfect score.

3. **Sample Return**: Robots equipped with a manipulator had the option to use it in a variation of the Context Imaging task. The robots had to carry a small geologist's scale, place it alongside the located target object, photograph the object in context, collect the object then return it to the starting location. Time to return was reported.

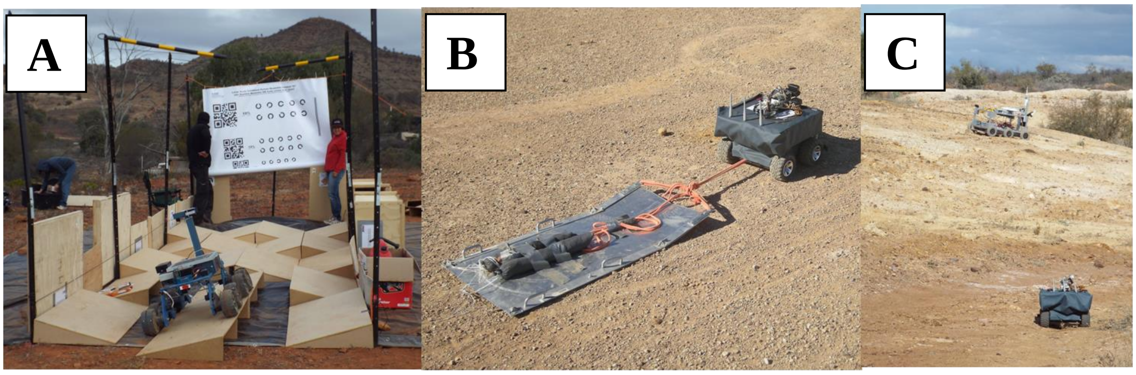


Fig. 3: Robot trials. A – Miner rover in pitch and roll ramps test area undergoing visual acuity test. D – Corbot pulling sled. C- UNSW robot and Corbot in quarry test area.

Remote operations

Space operations centre trials

Control of space assets is a major challenge to space operations. The Saber Astronautics has developed the "Responsive Space Operations Centre" (RSOC) which implements new techniques in diagnosing faults in space systems. These techniques are novel in that they consider space systems and space environments together in the same *global* probabilistic model, allowing operators the ability to rapidly respond to problems that can occur. This is an advantage over current methods which are limited by frequent retraining and a high degree of domain knowledge.

The same principles can be applied to surface operations on other Solar System bodies and to both manned and un-manned missions. They can also include mission analysis and performance optimisation. For example, optimising a human-robotic team, or tracking consumption logistics and workload, can increase the science output of the team. The Responsive Space Operations

Centre provides the tools to tackle the important research question of how the performance of the Mars base as a whole, EVA teams, or indivuaal astronaut or robotic systems can be measured during actual or simulated missions: during analogue missions such quantification is a way to better assess what impacts success or failure in field science.

Throughout the Arkaroola Mars Rover Challenge Expedition, Saber Astronautics tested the performance of the Responsive Space Operations Centre in supporting a simulated Mars mission. A communications link was established between Arkaroola and the Responsive Space Operations Centre at the Saber laboratory at Chippendale NSW. This enabled transmission of rover telemetry and GPS tracking data from the field and Mission support actions such as weather monitoring and remote scientist support. All communications with the expedition were subject to a 20 minute time delay representative of the latency of Mars operations. Live data streams from space weather protection services were also included into the service as part of the operational modelling.

Saber Astronautics also conducted a series of simulated missions, collecting observational data toward further research into global, probabilistic mission performance models. Simulated missions included robot-only scenarios utilising the MSI rover, human-only EVA teams, and human-robot EVA teams utilising the Phantom 2 quadcopter, Miner and Little Blue rovers. Several missions were conducted with both a surface rover and the quadcopter. Robot components were operated both directly and remotely from mission control. EVA personnel (in addition to mission control) consisted of pairs of Expeditioners, who wore simulated space suits loaned from the Victorian Space Science Education Centre (VSSEC) but originally manufactured by MSA to its own design.

Table 2: Key simulated missions conducted at Arkaroola by Saber Astronautics.

# Experiments	Assets	Mission Type
Two	2 astronauts, Little Blue, Phantom 2	Geological sortie
Two	2 astronauts	Maintenance (weather station; rover)
One	2 astronauts, Phantom 2	Geological sortie
Six	2 astronauts, Phantom 2	Exploration
Five	MSI Rover	Exploration

Missions were conducted over a wide range of terrains from smooth dust to extremely rocky creek beds with typical deployment duration of around 60 minutes. Mission goals fell into three main categories: exploration, geological ‘sorties’ or sample collection, and equipment maintenance. Rover-only mission goals included both acquisition of visual data via a video link and surface sampling with a robot arm. The arm was able to collect a range of materials, for example aeolian dust, fine alluvial sand, and alluvial gravel.

A range of specific tasks (Table 2) were attempted in astronaut-only, robot-only and mixed astronaut-robot EVA missions. These included a geologist monitoring non-geologist EVA teams via a video link and directing them over UHF radio to carry out specific geological tasks such as observation and sample collection. Other tasks in exploration EVAs involved multiple deployments and recoveries of the quadcopter. Perhaps the most notable EVA was the servicing of a weather station at one of the observatories behind Arkaroola (Fig. 4).

Data collected during each mission included biometric, GPS, motion and other data from sensors deployed on robots and personnel. In addition, human-to-human communications via UHF radio were collected, as well as local weather conditions via a weather station deployed on site.

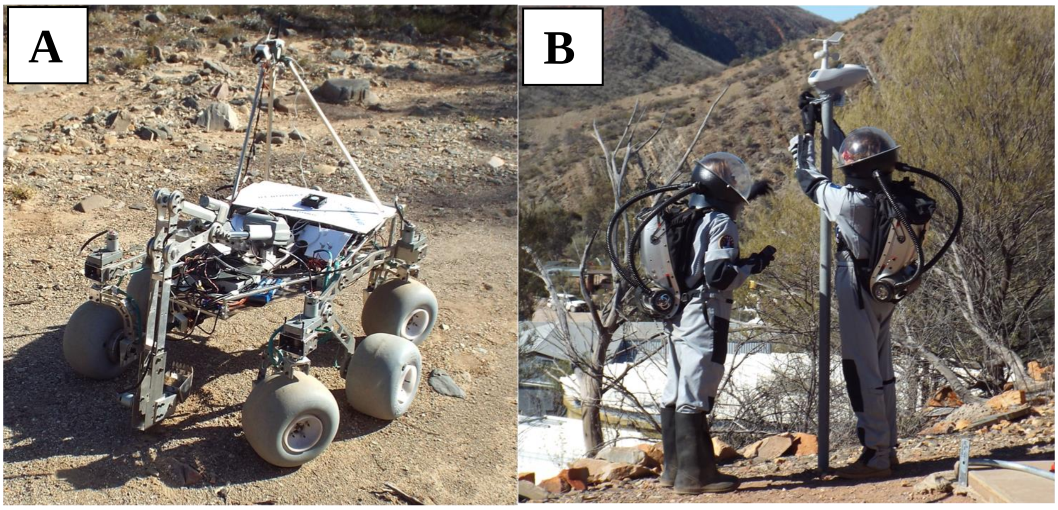


Fig. 4: Remote operations trials. A –MSI rover sampling alluvial gravel under remote control. B –Simulated EVA installing automatic weather station at Arkaroola Old Observatory.

Suit trials

Understanding the constraints of field work while in a space suit is critical when considering the capabilities and limits of crewed exploration on the surface of the Moon, Mars and other accessible Solar System bodies. The impact of a pressure suit was studied during a previous MSA expedition to the Pilbara. The Pilbara study used the University of North Dakota's NDX-1 suit and investigated the ability of geologists and non-geologists to recognize stromatolites despite the physical and temporal limitations of wearing the suit [1].

A follow up investigation using the same methodology was carried out on the Arkaroola Mars Robot Challenge Expedition (Fig. 5). A VSSEC simulated space suit was used. While not pressurized, the suit impaired sensory awareness and mobility to some extent analogous to an actual suit. A number of volunteers, both geologists and non-geologists, were asked to walk along a limestone outcrop and identity features that they considered as possible and probable stromatolites over a period of 20 minutes. Analysis is in progress and it is expected to present results at the 2015 ASRC.

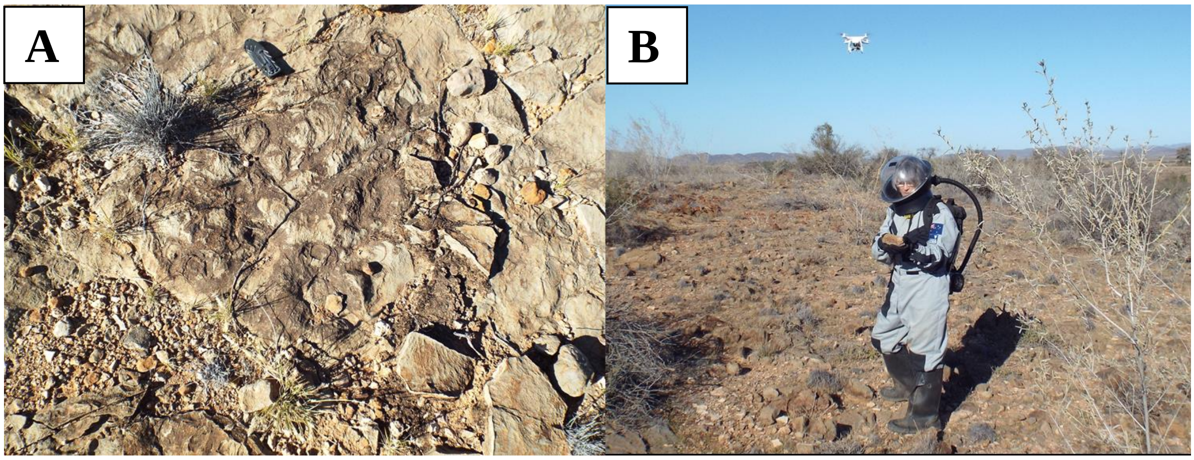


Fig. 5: Suit trials. A – bedding plane exposure of stromatolites of the Trenzona Limestone. B – geologist in VSSEC suit assesses whether a hand specimen contains a stromatolites. Experiment is being recorded by the Phantom 2 quadcopter.

Geobiology

Geobiological research, led by Simon George and Sarah Houlahan on the expedition focused on the testing hypotheses regarding the evidence for ancient biospheres found in Cryogenian (850 to 635 Mya) rocks the Arkaroola area (Fig. 6). The first hypothesis was regarding the biogenicity of possible microfossil structures found in veins within the Tapley Hill Formation which have been postulated to represent evidence of a deep hot biosphere living in basin fluids of Neoproterozoic age [11]. The second hypothesis was whether or not the carbonates of Balacanoona Formation and the contemporaneous siltstones of the Tapley Hill Formation contain organic compounds or biomarkers, specifically 24-*n*-isopropylcholestane [12], that may be indicative of the fossil sponges that some researchers have identified in these rocks [13].

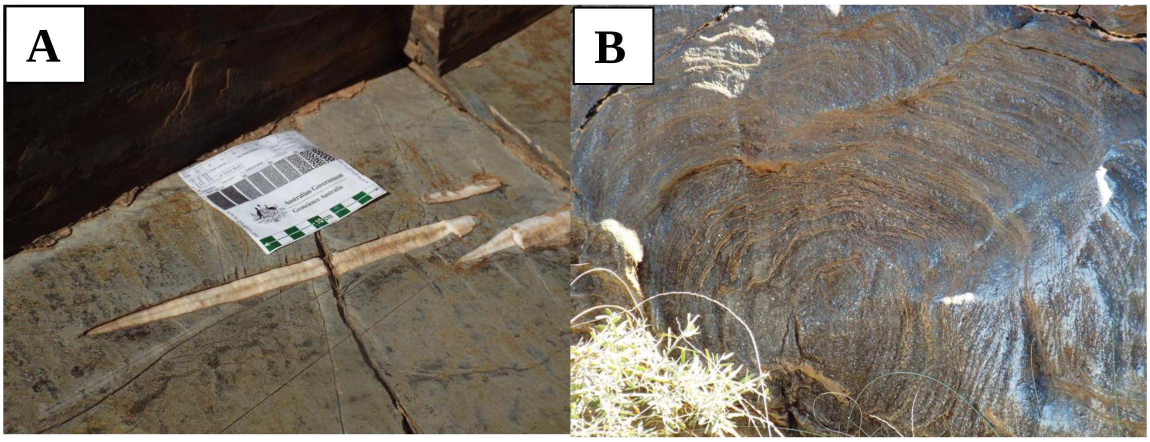


Fig. 6: A -Fibrous calcite veins in the Tapley Hill Formation that host possible microfossils of a deep hot biosphere. B - Stromatolite of the Balcanoona Formation, ~1.5 m high.

In addition to the importance of terrestrial geological of understanding the antiquity of the deep biosphere and Metazoa (complex animals) this research is relevant to astrobiology. The putative microfossils resemble structures found in some martian meteorites e.g. ALH84001 [14], testing their biogenicity refines tools for the interpretation of these martian structures. Likewise biomarkers are potentially the best tool to search for past or present life [15] in martian meteorites, samples being analysed on the surface of Mars or material returned by space missions.

Teacher experience

Three school teachers were among the Expeditioners. They contributed resources, including radios, vehicles, and the Phantom 2 quadcopter, took part in the experiments, gave talks and collected information for their classes. Their participation was part of their professional development as defined by the Australian Professional Standards for Teachers [16], specifically Standard 2, "Know the Content and How to Teach It" and Standard 6, "Engage in Professional Learning". As a result of their participation the teachers were able to demonstrate that they were able to select and organise geology, Mars and space exploration content in a rich and authentic context following the expedition to Arkaroola (Standard 2) and had taken part in a high quality learning opportunity to improve our teaching practice by enriching our knowledge and understanding of the connection between geology, Mars and space exploration (Standard 6).

Training and outreach

Workshops and field trips

The geological framework of the Arkaroola area is an important part of its analogue value. The diverse rocks and landscapes provide diversity of surfaces for robot tests, counterparts for the types of landscapes and targets studied by planetary robots, and numerous astrobiologically interesting niches. As most of the expeditioners had not been to Arkaroola before and had no background in geology, the first full day was spent on a geological tour of the area, introducing them to the principles of field geology, the geological and geobiological highlights, the challenges facing designers of planetary rovers, and providing spatial orientation.

Part of the conditions of the Australia-India Council grant was the provision of media training for the expeditions. Peter Spinks, a science journalist with Fairfax Media provided a two-day workshop that gave an introduction to the different new media, how it works and its priorities, and how to write releases and articles for it. Expeditioners wrote test releases and received feedback. This training proved most helpful when post-expedition releases were made.

Public engagement

Educating the public about Mars and spacde exploration generally is a core goal of MSA. Consequently public engagement occurred throughout the Expedition. They included planned public lectures at Arkaroola, media coverage from arising from previous alerts, media visits, casual engagement with the public, and post-expedition reporting. A series of evening public lectures were delivered at Arkaroola by several expeditioners, covering topics such as Space Camp (K. Silburn), life on Mars and the history of Life on Earth (S. George), planetary robotics (G. Mann) and human missions to Mars (the lead author). The talks were attended by between 20 and 60 people. Melbourne University students who happened to be on a field camp in the area, attended two of the lectures. A group of students from Mitcham Girl's High School in

Adelaide visited with the MSI and UNSW students and Saber Astronautics, watching the robots being put through their paces and talking about science and engineering opportunities for women.

There was extensive coverage over the expedition in the Indian media, including a report in the Times of India. Eloise Fuss of ABC Regional South Australia visited Arkaroola during the Expedition and several stories appeared subsequently on the ABC Regional SA web site. Peter Spinks of Fairfax Media wrote a number of excellent online articles and webcasts on TheAge.com.au blog “Science Matters” about the expedition.

Lastly, the presence of the expeditions and their numerous robots, people in simulated spacesuits the advertised public lectures generated a considerable number of casual interest and questions from other people visiting Arkaroola at the time.

Conclusion

The Arkaroola Mars Robot Challenge was a very successful expedition, with all the pre-expedition goals being met. The Expedition showed the value of multi-goal expeditions for both research and training in an analogue setting. Preliminary results are being published [8, 9, 10] and more publications are expected. Mars Society Australia plans future events to follow up on the success of this expedition, including possibly a field robotics student competition similar to the University Rover Challenge run by the US Mars Society in Utah [17].

Acknowledgments

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