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Spaceward Bound Australia 2011:
Expedition to the Pilbara Western Australia: "The Dawn of Life".

Contents

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1.0 Introduction

Spaceward Bound Australia (SBA) in collaboration with 'NASA Spaceward Bound' in July 2011 undertook a 'Planetary and space science' expedition, SBA 2011, to the Pilbara visiting locations at The "Dawn of Life" Nullagine, Shark Bay, Western Australia. The theme of the expedition was to compare the recently discovered large conical stromatolites in Lake Untersee, Antarctica with the conical stromatolites in Shark Bay and the 3.45 billion year fossils in the Pilbara. The primary focus was on the 3.45 byr old fossils.

'Spaceward Bound Australia' is organized by the Mars Society Australia (MSA) with aims that are in alignment with NASA Spaceward Bound. NASA Spaceward Bound is an educational program organized at NASA Ames Research Centre in partnership with the Mars Society (US).

The focus of Spaceward Bound is to inspire and train the next generation of space explorers by having students and teachers participate with scientists in the exploration of scientifically interesting but remote and extreme environments on Earth as analogues for human exploration of the Moon and Mars. 2006 was the first year of the program, with the work expeditions in the United States.

SBA expeditions undertaken prior to the Pilbara expedition SBA 2011 are:

- 2007, two Australian teachers participated in a NASA Spaceward Bound expedition to the Mojave Desert, California; and,
- 2008, a small SBA expedition to Arkaroola and Woomera that included two teachers/educators, two students, and NASA representatives.
- 2009, three Australian teachers to participate in a NASA Spaceward Bound expedition to the Mojave Desert;
- 2009, A Spaceward Bound Australia and NASA Spaceward Bound expedition to Arkaroola and Sturts Stony Desert North of the Flinders Rangers.
- 2009, three Australian teachers participated in a NASA Spaceward Bound expedition to the Mojave Desert;
- 2010, Two Australian teacher participated in a NASA Spaceward Bound expedition to the Namibian Dry Deserts;
- 2011, one Australian teacher participated in a NASA Spaceward Bound expedition to the Mojave Desert; and now,
- 2011, Spaceward Bound Australia and NASA Spaceward Bound, Expedition to the Pilbara Western Australia: "The Dawn of Life".

1.1 Sponsors

The sponsors for the Pilbara expedition are:

- Space Sciences and Technology CSIRO Astronomy and Space Science, Building 108, North Road, ANU Campus, Acton, ACT 2601 Postal address: GPO Box 664, Canberra, ACT 2601 http://www.csiro.au
- Western Australian Government, Department of Regional Development and Lands, Royalties for Regions Program administered by the Pilbara Development Commission.

http://www.royaltiesforregions.wa.gov.au and http://www.pdc.wa.gov.au

- Geological Survey of Western Australia, Department of Mines and Petroleum, Minerals House, Perth WA, http://www.dmp.wa.gov.au

- Dave's Hobby Centre, 10940 Great Eastern Highway, Sawyers Valley, WA 6074 – Ph 08 9295 6466, http://www.hobbycentre.com.au

2.0 Expedition Aims and Program

The SBA 2011 expedition aims were in order of priority:

- Comparisons of stromatolites, past and resent, including living stromatolites in Lake Untersee, Antarctica and Shark Bay and fossilised stomatolites in the Pilbara;

- Mapping The "Dawn of life Trail" and undertaking a flora and fauna study to support the long term preservation of the site.

- Measuring organics in clays from the Pilbara region including those associated with inverted channels as support for future Mars missions such as the soon to be launched 'Mars Science Laboratory'.

- Undertaking field observations of early life fossils in a space suit, assessing the performance of scientist astronauts doing off-world field science.

- Education for Educators, as part of the spaceward bound educational program organized at NASA Ames Research Centre.

Locations visited to accomplish these aims were:

- The Dawn of Life Trail near Nullagine;
- The North Pole site south of Port Headland;
- Mesa A Mine south of Karatha;
- The Bonny Downs Station near Nullagine;
- Shark Bay; and,
- Geological Survey of Western Australia to examine their extensive stromatolite fossil collection.

The expedition took place from the 10th to 21st July 2011 starting and finishing in Perth. Table 1 lists the program completed covering places visited, the travel times and science activities. A map of the region route and locations visited is also shown in figure 3.1.

3.0 The Expedition Team

The expedition team scientists and teachers from the US and Australia numbered 23 people and one non travelling person.
In summary:

- There were 13 US participants including 1 educator; and,
- 10 Australians including 4 teachers and one student.

The participants, their affiliation, work and expedition roles are listed in Table 2.

Table1:Program

Date	Travel	Distance Kilometre	Travel Time Hrs	Accomodation Venue
Sun 10th July	Perth (New Norcia) Mount Magnet	582	9 hrs	Mt Magnet Camp
Mon 11th July	Mount Magnet Nullagine	797	9 hrs	Nullagine Camp Ground
Tue 12th July	Nullagine (Dawn of Life) Nullagine	112	8 hrs	Nullagine Camp Ground
Wed 13th July	Nullagine (Bonny Downs Station - MESA's) Nullagine	120	8 hrs	Nullagine Camp Ground
Thu 14th July	Nullagine Port Hedland	120	8 hrs	Cook Point Caravan Park
Fri 15th July	Port Hedland (North Pole) & Outreach in evening Port Hedland	500	8 hrs	Cook Point Caravan Park
Sat 16th July	Port Hedland Outreach in evening Karratha	242	3 hrs	Pilbara Aspen Caravan
Sun 17th July	Karratha (Mesa A Mine) Carbla Station	496	6 hrs	Carbla Station Station
Mon 18th July	Carbla Station side Trip to Coral Bay Carbla Station	338	5 hrs	Carbla Station Station
Tue 19th July	Carbla Station Geraldton	408	5 hrs	Belair Gardens Caravan
Wed 20th July	Geraldton (Pinnacles) Perth	474	6 hrs	UWA Trinity college
Thursday	Inspect Stromatolite Collection at Geological Survey of Western Australia,			UWA Trinity college
Friday	Outreach at SciTech			UWA Trinity college

Table 2: The Expedition Participants: 6 June 2011

Name	**Role**	**Affiliation**	**Email**
Chris McKay	Principal Investigator	NASA Ames CA	chris.mckay@nasa.gov
Dale Andersen	Scientist	SETI CA	dandersen@carlsagancenter.org
Sasha Andersen	Scientist	SETI CA	dandersen@carlsagancenter.org
Matt Reyes	Engineer	NASA Ames CA	motorbikematt@gmail.com
Jon Rask	Scientist/Teacher	NASA Ames CA	Jon.C.Rask@nasa.gov
Rosalba Bonaccorsi	Environ Scientist/ Astrobiologist	NASA Ames/SETI CA	Rosalba.Bonaccorsi-1@nasa.gov
Alfonso Davila	Astrobiologist	NASA Ames/SETI CA	adavila@seti.org
Shannon Rupert	Biologist/teacher	Uni of New Mexico,	shannonmarie_99@yahoo.com
Carol Stoker	Planetary scientist	NASA Ames CA	Carol.stoker@nasa.gov
Daniel Valerio	Teacher/videographer	New Mexico	valerio_daniel@hotmail.com
Larry Lemke	Engineer	NASA Ames CA	llemke@mail.arc.nasa.gov
Jen Blank	Geologist	SETI CA	jblank@seti.org
Lucinda Land	Educator	NASA Ames/Mars Soc CA	lucinda@marssociety.org
Jon Clarke	Geologist/Scientist	MSA ACT	jon.clarke@bigpond.com
Mark Gargano	Teacher Coordinator	Curtin Uni. WA	Mark.Gargano@curtin.edu.au
Monika Bell	Environmental Scientist	BHP WA	monika.bell@bhpbilliton.com
Dave Cooper	Leader	MSA WA	mdghobby@vianet.net.au
Maureen Cooper	Librarian and Expedition Cook	MSA WA	maureen.cooper@audit.wa.gov.au
David Willson	Engineer	MSA TAS	dtaswillson@gmail.com
Simon George	Earth Scientist	Macquarie Uni NSW	simon.george@mq.edu.au
Ken Silburn	Head Science Teacher	Casula High School, NSW	Kenneth.Silburn@det.nsw.edu.au
Janine Slocomb	Biologist/Teacher	NAMIG SA	janineelizabeth9@gmail.com
Harry Steel	Student		duncansteel@grapevine.com.au
Kath Grey	Scientist remaining in Perth	Geological Survey WA	Kath.GREY@dmp.wa.gov.au
Guy Murphy	Media relations remaining in Melbourne	MSA VIC	gmmurphy@ozemail.com.au

The map in figure 1 shows the route taken by the expedition, the day and location camped (denoted by a circle with the expedition day) and the rough locations of the fossil sites, the "Dawn of life trail", "South Pole" and Shark Bay, the location of modern day stromatolite and microbial mats.

Figure 3.1 Reference Map

4.0 The Science Activities

A summary of science activities undertaken at the various locations on the expedition is:

- **"Comparisons of Stromatolites, Past and Present"**: To compare the recently discovered large conical stromatolites in Lake Untersee, Antarctica with the conical stromatolites in Shark Bay (W.A.), refer figure 4.3, and the 3.45 billion year fossils in the Pilbara. The primary focus was on the 3.45 byr old fossils at the "Dawn of life Trail" near Nullagine and the fossil collection located at the Geological Survey of Western Australia, Department of Mines and Petroleum in Perth.

- **"Mapping The Dawn of life Trail"**: To survey the 3.45 byr old fossils at the "Dawn of life Trail" for the purpose of providing documentation to support the long term preservation of the site. A flora and Fauna survey was also undertaken as a basis of a future environmental plan for visitors to the site. Shortened summaries of the 'Mapping the Dawn of Life Trail', (Clarke *et al*. 2011) and 'Dawn of Life Trail Flora and Fauna Survey', (Bell 2011) are in section 4.1 and 4.2 in this report and the full reports will be ultimately available on http://spacewardbound.nasa.gov/australia2011/index.html and http://www.marssociety.org.au/

- **"Organics in Clays"**: To collect samples of clay deposits from Mesas and any other accessible deposits of the oldest clays in the Pilbara region as part of a long term study to assess environments and geological materials where organic bio-signatures and bulk organic carbon is preferentially concentrated, preserved and detectable. This is to support future

Mars missions, such as the soon to be launched ‘Mars Science Lab’, in the search for habitable environments and evidence of life on Mars. This work is in section 4.3 and will be ultimately available on http://spacewardbound.nasa.gov/australia2011/index.html and http://www.marssociety.org.au/ when complete.

- “**Field observations of early life fossils.” in a Space suit**: To undertake ‘Field observations of early life fossils’ while wearing a pressurised space suit with the aim to assess: What is seen and what is missed; and, The ability for scientists astronauts to characterize their findings. The report of this work is listed in section 4.4. and will be ultimately available on http://spacewardbound.nasa.gov/australia2011/index.html and http://www.marssociety.org.au/ when complete.

Left and Middle. Shark Bay: Swimming with Stromatolites
Right: © Western Australian:
Police arresting man in space suit harassing innocent stromatolite fossils. Harry Steel in suit, Police officer unnamed.

Figure 4.3

4.1 Mapping the Dawn of Life Trail

By Jonathan Clarke, Carol Stoker, Chris McKay, Dale Anderson, Simon George, Alfonso Davila, Jennifer Blank. Refer Table 2 for affiliation and contact details.

4.1.1 Rationale

The rational for the geological reconnaissance of the Dawn of Life Trail (DLT) were three-fold:

1. To map and photo-document the distribution of stromatolites and associated lithologies in the proposed Dawn of Life Trail to Dr Kath Grey and Dr Arthur Hickman of the Geological Survey of Western Australia.

2. To familiarise the expedition scientists with the ~3.4 billion year old stromatolites of the Pilbara in their geological context as a prelude to possible future work on them and to increase their skills and knowledge base in the search for life on Mars.

3. To show educators and students some of the earliest evidence for life on Earth and explain its importance to astrobiology, in particular the search for evidence of life on Mars.

4.1.2 Mapping the Dawn of Life Trail

The discovery of about half a dozen key sites showing evidence of early life in the Pilbara of Western Australia in the 1970s led to an explosion of interest in visiting the sites by a broad cross-section of the community, including scientists, educators, media, tour operators, and the general public. These small, highly vulnerable sites cannot sustain large numbers of visitors or the removal of samples (Grey et al., 2002), and the sites were declared Geoheritage Reserves by the Western Australian Government (Grey et al., 2010). At the same time a site that could satisfy public curiosity was still needed, if possible at a more accessible location. Such a site was discovered by Geological Survey of Western Australia geologists in 2000, about 1 km west of the Marble Bar and Nullagine Road, some 60 km south of Marble Bar and 50 km north of Nullagine and therefore roughly mid-way between the two townships (Figure 4.1.1). This site was named the "Dawn of Life Trail" (Grey et al., 2002; Grey and Caldon, 2008) and has featured in guidebooks to the region (Van Kranendonk and Johnson 2009).

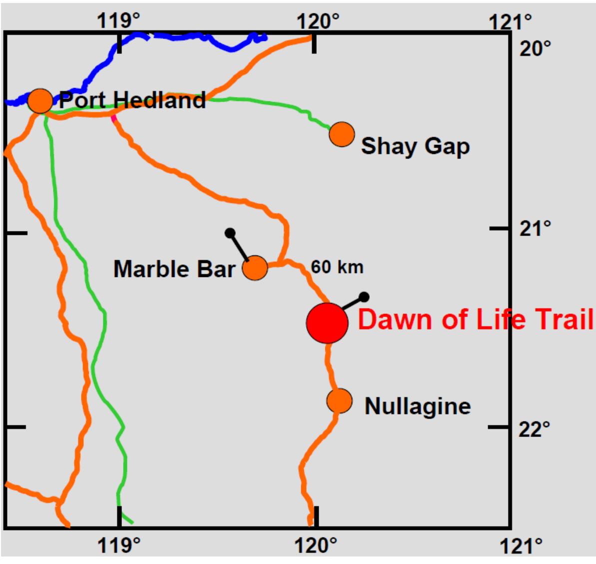


Figure 4.1.1. Location of Dawn of Life Trail (from Grey and Caldon, 2008)).

To map the area several groups criss-crossed the area of the DLT, which measures about 1 km by 0.5 km. The outcrops were walked in all directions until no more stromatolites could be located. Each occurrence was photographed using a camera with a linked GPS and the positions were plotted as a .kmz file in Google Earth. Clusters of images defined the outcrops hosting stromatolites. The position of other features that might of interest to tourists, such as pillow basalts and spinifex texture, were also recorded. A detailed report was prepared and submitted to the Geological Survey of Western Australia for publication. A summary of this report has been prepared for the Pilbara Development Council (Clarke *et al.* 2011). Two days were spent at the DLT by the Spaceward Bound expeditioners: the first day was reconnaissance and the second day was spent on mapping and field trials of instruments.

4.1.3 Science at the Dawn of Life Trail

The Pilbara region, with its record of ~3.4 billion year old surface environments and life has also been used as an analogue for features found on Mars (Brown *et al.* 2005). The DLT was recognized as having significant potential as an accessible site for testing mission-related tools and instruments and training planetary and astrobiology researchers in the recognition of 3.4 billion year old habitable environments and fossil structures similar to those that might be found in rocks of similar age on Mars (Brown *et al.* 2004). While there has been regional mapping at 1:100,000 scale (Figure 4.1.2) no detailed analysis of the local geology or distribution and diversity of the stromatolites present at the DLT had been carried out. The Spaceward Bound expedition, with an abundance of manpower and range of expertise, provided an ideal opportunity to carry out the much needed documentation of the site as a preliminary to future work.

The Spaceward Bound scientists who took part in the preliminary investigation of the stromatolites at the DLT possess a considerable range of expertise and experience. They include:

- Dr Chris McKay and astrobiologist fromof NASA Ames, a global leader in astrobiology, which extensive experience in the Arctic, Antarctic, the Atacama Desert, the Middle East, Spain, Namibia, and elsewhere, and has been an principle investigator on several planetary missions including the Phoenix Mars mission in 2008.

- Dr Carol Stoker, a planetary scientist from NASA Ames, who also has extensive experience Arctic, Antarctic, and the Atacama Desert, Spain and elsewhere, and has been an investigator in several planetary probes including Voyager, Mars Pathfinder, and the Phoenix mission.

- Dr. Dale Anderson, an astrobiologist from the SETI Institute, with considerable experience in the recognition of stromatolites from many locations in the world and in marine and lake research, including in the Antarctic

- Dr Simon George of the University of New South Wales whose main research experience is in the chemistry of organic matter associated ancient stromatolites, including those of the Pilbara, and what these information can tell us about ancient life and its history.

- Dr Jonathan Clarke of the Mars Society Australia and the Australian centre for Astrobiology, who has worked extensively in Archean rocks between Kalgoorlie and Norseman, and on Mars analogue rocks and landscapes in Australia, Utah and the Atacama Desert.

- Dr Alfonso Davila, astrobiologist, from NASA Ames/SETI CA with extensive experience in the Antarctic and with microbes in salts and salty-acidic lakes.

- Dr Jennifer Blank Geologist, from NASA Ames/SETI CA a planetary scientist and part of the Mare science Lab team.

These researches took the lead in the mapping and documentation of the DLT and providing training the other expeditioners in field methods, stromatolite recognition, and interpretation of their significance.

There is considerable diversity of stromatolites at the DLT, representative examples of these are shown in Figure 4.1.3.

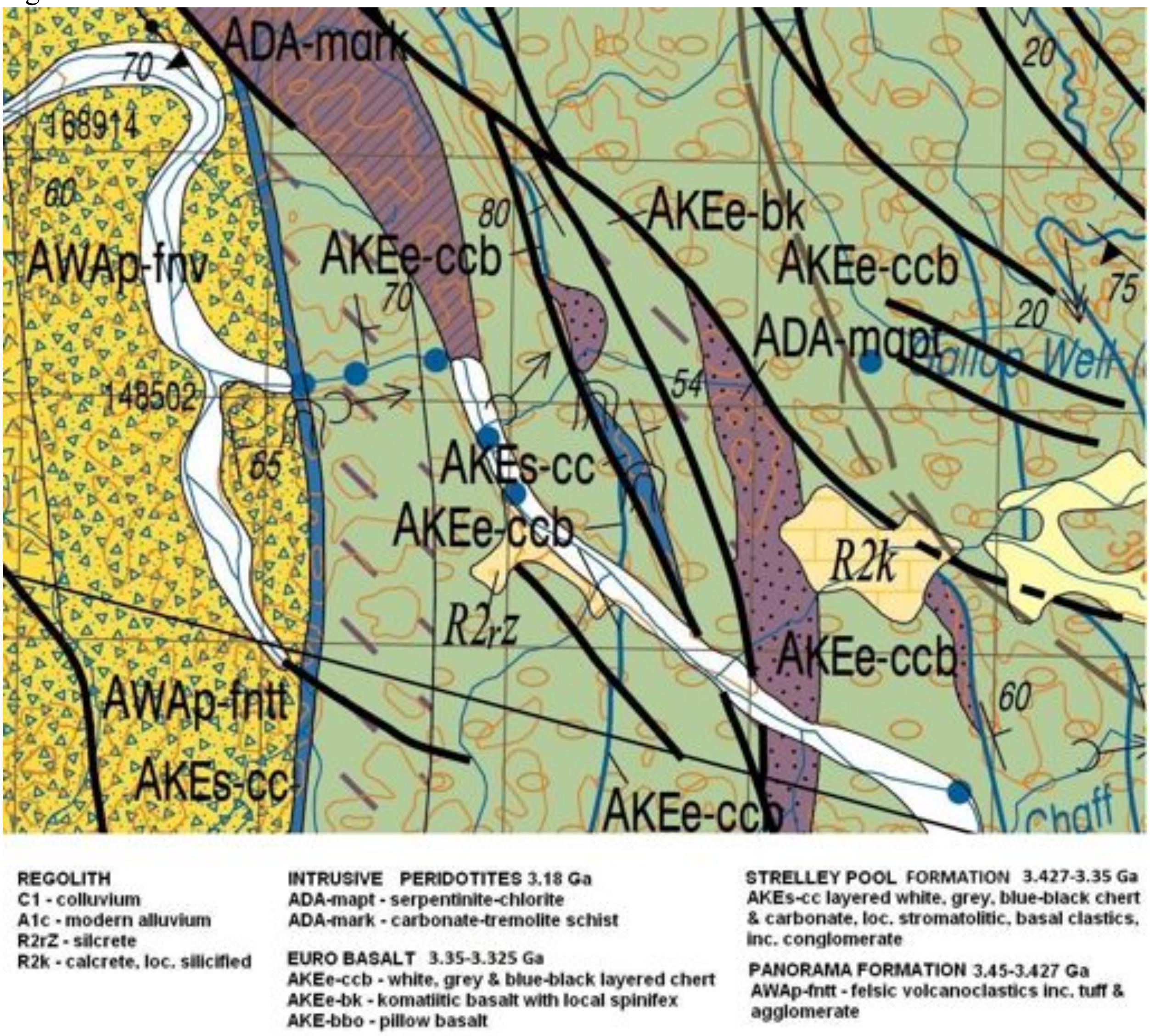


Figure 4.1.2. Geology of the DLT area (approximate position red box), after Williams and Bagas (2007). Grid squares are 1 km

Samples of rocks at the DLT were analysed using the Integrated Spectronics (Inc.) Portable Infrared Spectrometer (PIMA). This instrument operates in the Short Wavelength Infrared band and readily identifies minerals associated with hydrous alteration, including sulphate, carbonates, clays and micas (Thompson 1999). Further work is planned for the samples in laboratories in Canberra and at NASA Ames, including thin sections for petrography, XRD, XRF and organic mass spectroscopy.

Further details of the mapping and analytical work can be found in Clarke *et al.* (2011)

4.1.4 Education on Spaceward Bound Pilbara

All the educators and students in the group were exposed to the different stromatolites in the area and their field context explained to them. They formed part of the mapping teams and collected the field data. The experience they gained would assist in the development of astrobiology and planetary science components within the framework of the Australian Curriculum (AC) documentation, which is to mandated for all Australian schools by 2013. Particular aspects of this new curriculum have a direct link to the type of activities that could be undertaken in the three AC areas; Science Understanding, Science as a Human Endeavour, Science Inquiry Skills.

As one example, within Middle School, at Year 8, a module about 'Astrobiology' could be developed and taught that connects with the Pilbara expedition, the Dawn of Life trail and the meaning and relevance of stromatolites. This is discussed further in the accompanying education report (Gargano 2011).

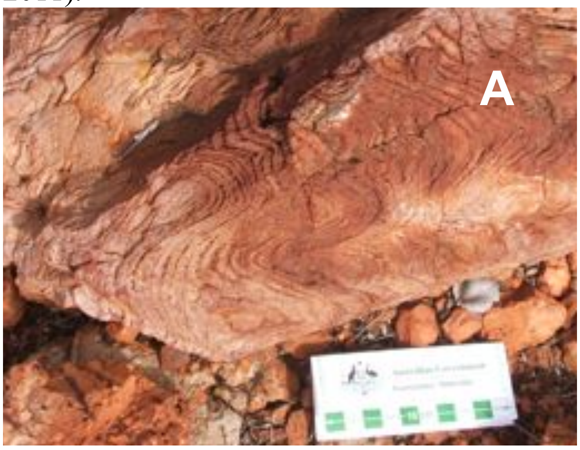


Figure 4.1.3. Representative stromatolite morphologies at the DLT.
A – twinned laterally linked conical or ridged stromatolites .
B – oblique profile of conical or ridged stromatolite.
C – 3D "egg carton", small conical stromatolites.

4.2 'Dawn of Life Trail' Ecological Survey

By Monika Bell. Refer Table 2 for affiliation and contact details.
The full report will be available on http://spacewardbound.nasa.gov/australia2011/index.html and http://www.marssociety.org.au/.

Pilbara Biogeographic Region

Spaceward Bound Australia 2011 took place in the Pilbara, North Western Australia, bordered by the Indian Ocean to the west and Great Sandy and Gibson Deserts on its east. The region receives much of its annual rainfall in the summer month (January – March) due to cyclonic events moving inland. Both Nullagine and Marble Bar lie in the Chichester subregion (IBRA PIL 1; Thackway and Cresswell, 1995), which comprises the northern section of the Pilbara Craton and has an overall area of 9,044,560ha. There is high faunal biodiversity with overlapping elements from the Kimberley and South-West, as well as contributions from the adjacent desert and Murchison regions (Kendrick and McKenzie, 2003). The Pilbara with its ancient geology, soil formations and large north-flowing river systems contains biodiversity values such as species-rich, refugial gorge, watercourse and ridge top ecosystems, grassland savannas and tropical woodlands in the inland areas to mangroves along the coast. Given the industrial nature of the region much of its 98.8% pre-European vegetation is under threat from land degradation, overgrazing, feral animals, weeds and pests.

Historical Background

The north-west coast of Australia was first visited by Dutch ships in 1616. The English followed in 1688. William Dampier explored the coast from Shark to Roebuck Bay eleven years later. Land-based exploration of the Pilbara became possible after the establishment of the Swan River Colony (now Perth) in 1829. Good grazing lands (2.4 million hectares) surrounding the Ashburton, Fortescue, de Grey and Oakover Rivers were placed under pastoral lease from 1866. Most of these early leases are still in operation today (Beard, 1975) and grazing remains the most common land use, limited only by the availability of reliable water for livestock. In 1888 gold was discovered in Pilbara Creek, tin was found in 1899. Asbestos was mined around Wittenoom adjacent to Karijini National Park between 1943 and 1966. The mining of copper, manganese and various other minerals began in the latter part of the 19th century. Vast capital investment poured into iron ore mining in the 1960's, with the construction of railways and port facilities at Dampier and Port Hedland, and a new town at Newman.

Local Flora

We saw several Acacia during the Spaceward Bound field excursion and cannot forget our encounters with the prickly spinifex (photo 10). *Triodia wiseana* (hard spinifex) and *T. pungens* (soft spinifex) are hummock-forming, perennial grasses endemic to inland Pilbara. The former grows forming concentric rings that die off in the centre, with dead fibres harvested by termites. The latter forms hummocks up to 2m high and 3m diameter where there is moisture or nutrient rich soil. Such natural structures provide cooler, relatively humid microhabitats for small mammals, reptiles and numerous invertebrates. Other spinifex which may be present include *Triodia basedowii*, *T. brizioides*, *T. lanigera*, *T. longiceps*, *T. epactia* and *T. plurinervata.* The Acacias differ in form, flower colour and shape and leaf structure. Top row left to right are: *Acacia inaequilatera, A. pyrifolia*, *A. bivenosa, A. hamersleyensis* and *A. aphanoclada.* Other showy flowers were the red Sturt's Desert Pea *Swainsona formosa* (photos 6 & 7) and Wickham's Grevillea *Grevillea wickhamii* (photos 8 & 9). Purples were represented by *Gossypium robinsonii* Robinson's Desert Rose (photo 16), and several Ptilotus or Mulla Mulla species. In between the stromatolites, white clumps of *Polycarpaea holtzei* (photo 17) were spotted. The trees we observed were *Eucalyptus leucophloia* (photo 14) and *Corymbia hamersleyana* (photo 12) on hillsides, ridges and open flats, *Eucalyptus camaldulensis* and the smaller Coolibah or *Eucalyptus victrix* (photo 11) along the river banks and floodplains, together with the paperbark *Melaleuca argentea* (photos 13 & 15).

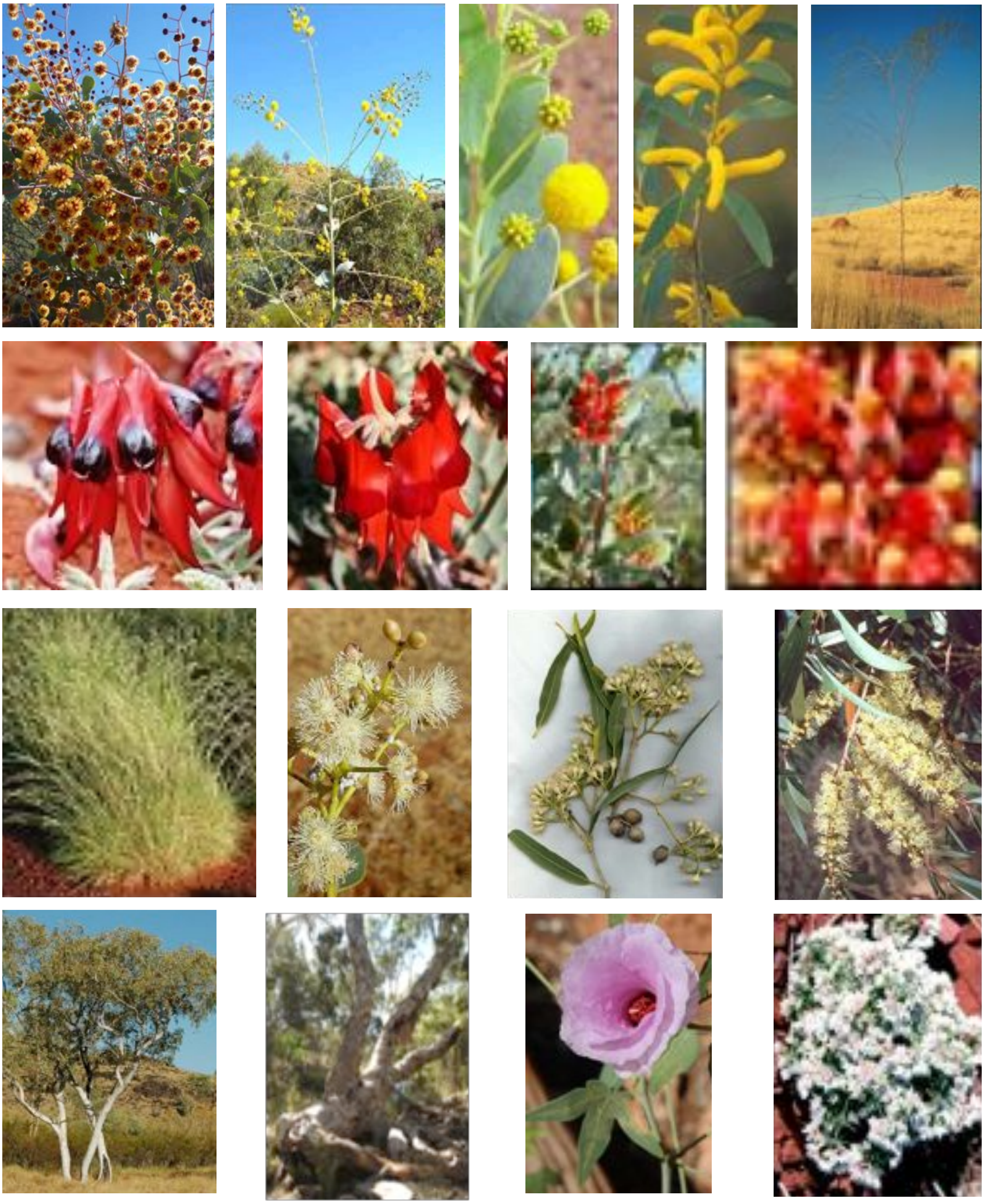


Figure 4.2.1. Photos are numbered left to right:
1 *Acacia inaequilatera, 2 A. pyrifolia*, 3 *A. bivenosa,* 4 *A. hamersleyensis,* 5 *A. aphanoclada;*
6 & 7 *Swainsona formosa;* 8 & 9 *Grevillea wickhamii*; 10 *Triodia* or spinifex sp.; 11 *Eucalyptus victrix;*
12 *Corymbia hamersleyana;* 13 & 15 *Melaleuca argentea;* 14 *Eucalyptus leucophloia;*
16 *Gossypium robinsonii;* 17 *Polycarpaea holtzei*
Flora information and pictures can be found at http://florabase.dec.wa.gov.au

Rare Pilbara Vertebrates

Mulgara (*Dasycercus cristicauda*), Pilbara Pebble-mound Mouse (*Pseudomys chapmani*), the tiny carnivorous marsupial - Pilbara Ningaui *(Ningaui timealeyi),* Spectacled Hare-wallaby (*Lagorchestes conspicillatus leichardti*)*,* Bilby (*Macrotis lagotis*)*,* Northern Brushtail Possum *(Trichosurus vulpecular arnhemensis),* Orange Leaf-nosed Bat (*Rhinonicteris aurantius*)*,* Ghost Bat (*Macroderma gigas*)*,*Northwestern Long-eared Bat (*Nyctophilus bifax daedalus*) and Little Northwestern Free-tailed Bat (*Mormopterus loriae cobourgensis*), Princess Parrot (*Polytelis alexandrae*), Major Mitchell's Cockatoo (*Cacatua leadbeateri*)*,* Peregrine Falcon (*Falco peregrinus*), Pilbara Olive Python (*Liasis olivaceus barroni*), Pilbara crevice-skink (*Egernia pilbarensis*) and *Ctenotus rubicundus, Ctenotus* affin. *robustus, Lerista zietzi, Lerista flammicauda, Lerista neande*

4.3 Clays in Western Australia

By Rosalba Bonaccorsi, Simon George & David Willson: Refer Table 2 for affiliation and contact details.

4.3.1 Why are we hunting for clays in WA?

The Mars Science Laboratory (MSL) rover mission to mars (to be launched in late November 2011) will search for potentially habitable ancient geological environments as a key step toward future life detection (e.g. the ESA 2016/18 Pasteur ExoMars Mission) and sample return missions. MSL landing sites candidates such as Eberswalde (Figure 4.3.3) and Gale Crater show evidence of hydrated clay minerals (phyllosilicates) as indicators of past aqueous activity as well as of interest to scientists for their potential to preserve organic compounds. These sites have been evaluated in terms of accessibility to a rover, geological context, diversity, habitability, and preservation potential (Golombek et al., 2007) and (http://marsoweb.nas.nasa.gov/landingsites/ index.html).

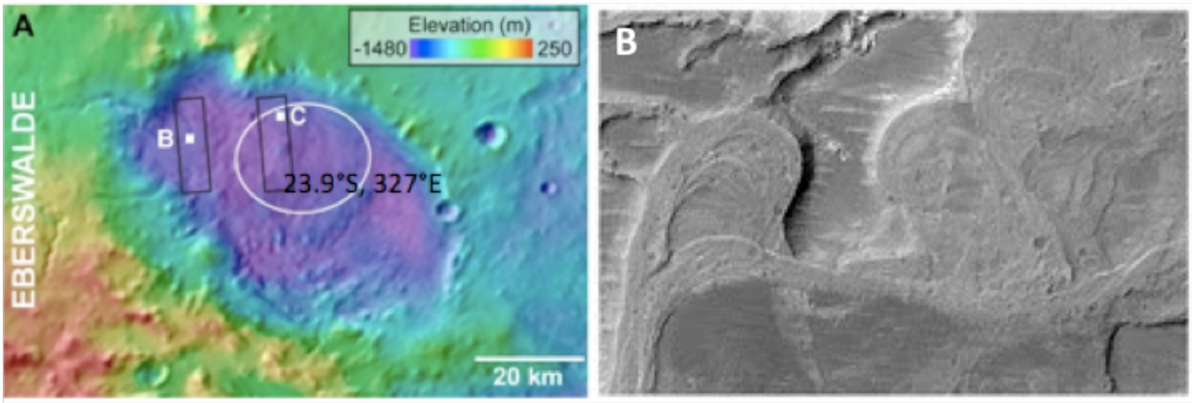


Figure 4.3.3: A) Eberswalde Crater landing ellipse. B) An Inverted relief, part of the Eberswalde Crater on Mars

Science return from the MSL mission will depend critically on strategic decisions about where to drive the rover, what geological type to select, and when to move on to a new site. Key targets will be those rock types and sediments where organics of biological origin might have been once produced, concentrated, and preserved.

In this context, we have been analyzing clay samples collected worldwide and ranging from extremely arid to semi-arid environments to test hypotheses for preferential preservation of organics and colonization of mineral surfaces by microorganism. These environments represent a plausible climatic analog model of a past "wet and warmer" mars surface, possibly more conducive to the colonization by microbial life and organic compound concentration than today ("cold and dry" Mars).

During the SBA expedition our group is exploring and assessing sites with geological and mineralogical features analog of those seen at MSL (Gale and Eberswalde landing sites).
For instance, the proposed landing ellipse in Eberwalde Crater includes a Fe/Mg smectite-bearing alluvium recording episodes of transport and deposition of fine-grained materials in a fluvial Martian environment (Figure 3). One exciting opportunity we have for accessing a sedimentary environment with similar features is offered by mesa systems with exposed fine-grained clay-rich lithologies underlying caps of oxidized ironstone (Figure 1).

4.3.2 Visit to the Bonny Downs Station

On day five we visited an ironstone mesa, a remnant of an inverted channel, on the Bonny Downs Station near Nullagine in the Pilbara region. We collected paired samples of an inferred 15 - 25 Ma old clay-rich weathered profile of late Archean basalt below the ironstone cap (Figure 4.3.2).

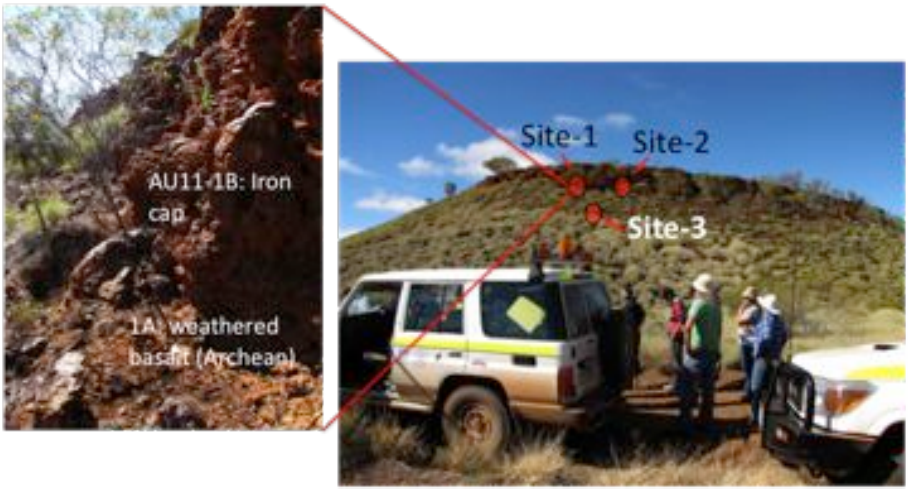


Figure 4.3.2: View of a mesa at Bonny Downs Station. Red dots indicate the three sampled sites. Paired sample for Sites 1 and 2 were taken from the ironstone cap above and the weathered basalt soil profile below (5-10cm-depth below contact). At Site 3 we collected a light toned weathered rock exposed at the surface.

The main objective is to use these samples as relevant mineralogical/sedimentary analog materials at the MSL landing site (Gale Crater), and analyse them to find out where organic compounds and biosignatures are preferentially concentrated and preserved.

We analysed the samples for biological activity (within 15 hours) with an adenosine triphosphate (ATP) assay. This assay uses a sampling swab device operating with a hand-held luminometer. This instrument translates bioluminescence-induced outputs into Relative Luminosity Units (RLUs) raw values as a semi-quantitative proxy for total (living) biomass colonizing soil and rocks substrates. Bulk samples were processed at a field lab set up in Port Headland (the laundry room! Figure 4.3.3) using a portable life detection instrument. Five samples were run with the appropriate positive and negative controls for a total of 30 assays. Overall, the assay yielded values ranging from 10^6 to 10^7 RLUs, which roughly correspond to a total biomass of ~10^7 to 10^8 cells/gram.

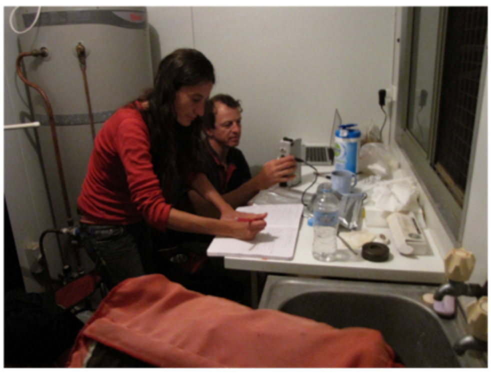


Figure 4.3.3 – Laboratory/Laundry room. Analyzing biological activity in samples with an ATP Luminometry assay. Prior. Rosalba Bonaccorsi and Simon George.

Once the samples will be back to our labs, they will be analysed by organic geochemical techniques to establish the organic content. Some of these techniques will be the same as per the MSL SAM instrument on Mars.

Laboratory analyses of the organics sequestered in mesas clays are a part of our effort to test hypotheses on preferential concentration and preservations of organic compounds in a variety of clay mineral types as well as genetic and depositional environments.

We will also analyze samples for detailed clay analysis (in collaboration with the University of Bologna, Italy) and for abundance of lypopolysaccharide (LPS), a general type of biomarker present in the cellular wall of gram negative-like microorganisms. With these efforts we hope to refine and improve the protocols for sample selection and analyses we applied during SBA 2009 in the Flinders Ranges (Southern Australia).

4.3.3 Trip to Mesa A

By Rosalba Bonaccorsi, Simon George & David Willson, Jon Rask and Chris McKay: Refer Table 2 for affiliation and contact details.
On day eight we visited an ironstone mesa mined for iron ore by the Rio Tinto Mine Company. Due to safety restriction we were unable to acquire samples direcly from the cut surface. We collected paired samples of 15 - 60 Ma old materials thru a weathered profile of late Archean basalt below the ironstone cap (Figure 4.3.4).

Blue asterisks indicate material sampled at this site. For each site three lithotypes, or types of materials were sampled. They are a grey mud, a dark yellow altered rock, and background coarse grained fines mainly consisting of ironstone materials. Based on their color material samples here can be related to the original stratigraphy seen across the cut. Paired sample for Sites 1 and 2 were taken from the ironstone cap above and the weathered basalt soil profile below (5-10 cm-depth below contact). At Site 3 we collected a light toned weathered rock exposed at the surface.

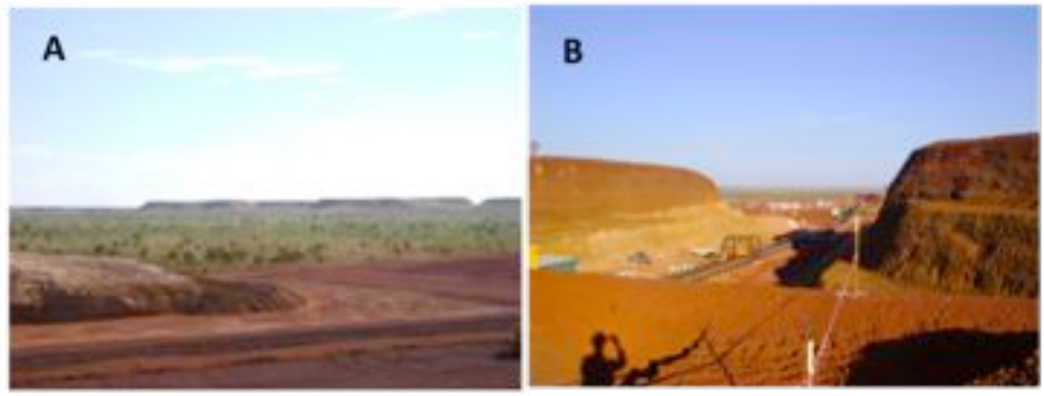


Figure 4.3.4: A) View of an inverted channel mesa system as seen from the Rio Tinto Mine at Pannawanica (200km south from Karrata). B) machinery access cut through inverted channel at the Mesa A.

The main objective is to use these samples as relevant mineralogical/sedimentary analog materials at the MSL landing site (Gale Crater), and analyze them to find out where organic compounds and biosignatures are preferentially concentrated and preserved.

Finally Rio Tinto provided a core of the Mesa to the Geological Survey of Western Australia, Department of Mines and Petroleum, Minerals to undergo spectral analysis by their CSIRO HyLogger. The review of the hyperspectral results for the Mesa A mine mesa core is in progress.

4.3.4 Mars Science Lab (MSL) Mars Rover Support from the SBA 2011 Expedition

Science return from the MSL mission will depend critically on tactical and strategic decisions about where to drive the rover, what samples to select, and when to move on to a new site. Work on analog materials, testing for habitability potential in a suite of different mineral types and depositional analog environments, will help finalize tactical decisions. The results of our field and laboratory work will be integrated through MSL mission goals into concrete contributions to MSL science objectives, support to science operations, and science instruments.

In support of CheMin, we are analyzing samples with the Terra XRD/XRF instrument (figure 4.3.5) provided to us by David Blake (CheMin PI) at NASA Ames. The Terra XRD/XRF is a commercial version of the flight instrument manufactured by InXitu Corporation (Sarrazin et al. 2008).and can characterize the mineralogical and elemental composition of powered samples by combining X-ray diffraction (XRD) and X-ray fluorescence (XRF). With Terra just a few minutes of a single XRD/XRF experiment are necessary to unambiguously identify a single mineral phase such as phyllosilicates, iron-bearing minerals, olivine, or ferric iron oxides. Fine-grained sediment samples from the mesas contain complex mineral assemblages, including clays, which identification requires to integrate 4-8 of these experiments e.g., over ~1 hour (200-250 runs). The portable Terra instrument consists of a power supply/X-ray tube, sample holder, CCD detector, control electronics, computer and battery/power management system. The CheMin instrument is a key component of the analytical payload on MSL.

Figure 4.3.5: Left: the miniCheMin field instrument displayed during an EPO event organized at the art gallery in Port Headland. Autonomous operation 14.5kg with embedded batteries and computer (45x32x12cm); Right Rosalba Bonaccorsi foreground.

The transmission sample holder consists of a 5mm diameter wafer-shaped cell, bounded by 7µm mylar windows held apart by a 175µm spacer. Powdered sample material is flowed into the cell through an opening at the top. The sample holder employs a sonic frequency piezoelectric shaker system, which causes the powdered sample material to flow with a convection pattern similar to a liquid, exposing all mineral particles to the beam in random orientation.

The Terra detector consists of a commercial a thermoelectrically cooled 1024 X 256 deep-depleted direct detection CCD.

4.4 Testing and Operation of the NDX Space suit: "Field observations of early life fossils."

By David Willson, Jon Rask, Simon George, Pablo De Leon, Jenifer Blank, Rosalba Bonaccorsi, Janine Slocombe, Ken Silburn, Harry Steele & Mark Gargarno. Refer Table 2 for contact details.

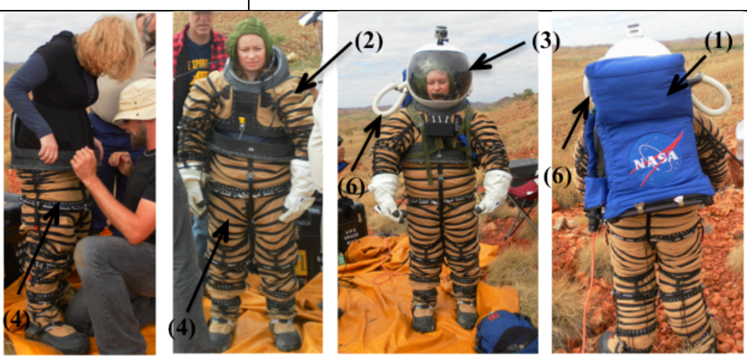
4.4.1 The NDX-1 Space Suit

The objective of the space suit trials for the Spaceward Bound Pilbara Expedition was to perform fField observations of early life fossils while wearing the space suit.

The NXD-1 space suit system, North Dakota Experimental-1, (De Leon et al, 2006) is a pressurized planetary space suit concept demonstrator for analog Moon and Mars testing, provided by the University of North Dakota. The suit development was funded by NASA's EPSCoP program. Prior to the Pilbara expedition trials undertaken include, Manual core sample drilling in an Esker, North Dakota in 2010 (Rask et al, 2010) and manual drilling, Antarctic in 2010.
Table 1 and Figure 4.4.1 lists the NDX-1 technical description.

Table 1: NDX-1 Space Suit Technical Description As Used in the Pilbara Field Trials

General Description	A high fidelity planetary pressurized test-bed space suit for analog Moon and Mars operations and hardware testing.
Mass	Suit mass = 23 kg. PLSS mass = maximum 9 kg. Total mass = 31 kg.
Construction	A separable two piece suit consisting of a lower trouser assembly and upper composite hard torso assembly coupled at chest level on a dual-plane composite enclosure ring. The upper torso has a neck dam assembly and coupling ring for a removable helmet. The trousers and arm sections are fabric with adjustable straps for different body sizes. Gloves are shuttle standard.
Materials	All restraint layer joints and fabric are sewn Milennia fabrics, 60% Para-aramid and 40% PBO (polybenzoxazole) fibres, The pressure bladder is a sewn fabric garment coated with latex.
Operating pressure	26.2 kPa above ambient air pressure (As per the Apollo Space Suit).
Gas Supply	Atmospheric air pressurized by two compressors located in the PLSS.
Primary Life support Subsystem PLSS (1)	Contains two 12 Volt DC compressors each with an independent umbilical line to the suit or helmet driven from rechargeable batteries with 20 min life.
PLSS (2)	Contains two 12 Volt DC compressors each with independent umbilical lines to the suit driven from rechargeable batteries with 20 min life.
Communications	A cable and headsets for 'astronaut' and external supervisor communications.



NDX-1 Space Suit in the Pilbara Western Australia 2011

(1) PLSS: Two 12 V compressors & power cable. Mass = 9 kg.
(2) Upper Torso
(3) Dual Plane composite enclosure coupling
(4) Lower Torso
(5) Removable Helmet clamped to neck dam assembly ring
(6) Air lines

Janine Slocombe donning space suit with assistance from Jon Rask.
Figure 4.4.1

'Field observations of early life fossils' used the NDX-1 space suit to assess the success of five 'scientist astronaut' (teachers and geologists) in looking for 3.45 Billion year old stromatolite and bio-mat fossils on rock units at the 'Dawn of Life Trail' near Nullagine. The aim was to find and characterize as many fossils possible while wearing the space suit over a limited time period, simulating an EVA, and compare this result to doing the same task in the same area without a space suit. The quality of information was also recorded. David Willson (MSA) and Jon Rask (NASA Ames) and conducted the field trial and Simon George (Macquarie Uni) was our 'scientist astronaut trainer'.

The data from the field trials has yet to be assessed in detail but it was noted during the trials that our 5 "scientist astronauts" had difficulty in using their normal "field skills" while operating the space suit due to limited vision, lack of dexterity and physical fatigue. Also this was the fist time they had worn the suit and lack of familiarity with its capabilities and liminations may have been a factor. All of our 'scientist astronauts' needed to view the rock structures at very close proximity, occasionally on their knees, to characterize and verify the fossil rock structures. Refer figure 4.4.2.

As such the assessment of the changes and limitations of scientist field skills while operating a pressurized space suit and the identification of space suit technology and field science skill changes needed to improve scientist astronaut EVA performance while on Mars or the Moon is now being planed for future space suit trials in the US.

A Scientist in space suit attempting to get close to a boulder to identify a 3.45 Byo Stromatolite fossil. **Figure 4.4.2**

4.4.2 Outreach

The Space suit field trials lasted a full day and was attended by class aboriginal children of Nullagine school, see fig 3 and at least one family who had traveled 4 hours to see the field tests.
Finally, the Space suit was operated at outreach venues in Port Headland, Karratha, SciTech in Perth, and at the Australian Mars Exploration Conference attracting considerable interest and questions.

Figure 3: Children of Nullagine participating in the space suit testing. Right: Jenifer Blank in space suit mid back row. Left: Jon Rask.

5.0 Education implications for Spaceward Bound Australia: Pilbara

By Mark Gargarno, Lucinda Land, Janine Slocombe, Ken Silburn, Harry Steele, Monika Bell, Shannon Rupert. Daniel Valerio Refer Table 2 for affiliation and contact details.

The inclusion of science teachers in the process of mapping is of relevance and importance to the Spaceward Bound theme. A fundamental principle of Spaceward Bound when first proposed was to incorporate Middle and Senior School educators in authentic field research in areas that are analogous to off-world locations, such as Mars.

It was apparent to the Spaceward Bound planning team that the next generation of astronauts that would be conducting missions on the Moon, Mars and beyond were still currently in Middle School. In order to fulfil NASA's mission, these students need to learn about exploration science. This training consists of both STEM (science, mathematics, engineering, and technology) education, as well as education that leads to the understanding of exploration concepts and skills. Planned education activities were guided by the motivation to train teachers to inspire students to be the next generation of explorers. (Heldmann, McKay and Coe, 2007)

The Spaceward Bound concept provides a unique experience for teachers to contribute to field science research and to enhance their own knowledge of science skills, processes and practices. (McKay et al, 2007). The latest expedition provided an opportunity for teachers to understand field science that supports previous events in the South America, North America, the Arctic, Africa and Australia, with the emphasis for the Pilbara placed on the early Earth through identification and studying stromatolites.

It was suggested within the key document, 'The Status and Quality of Teaching and Learning of Science in Australian Schools', through recommendation 8 it is outlined that a national focus be encouraged to promote collaborative approaches to research, data collection, innovation, and development of curriculum and professional development resources for science education. (Goodrum, Hackling and Rennie, 2000). It was further outlined that new scientific concepts and ideas should be introduced using issues that are meaningful in students' lives. Integrating science activities and content with other learning areas may serve to make the process of learning science more relevant to students.

Under the banner of Spaceward Bound professional development opportunities for teachers to learn from world-leaders in specialist fields, to get first-hand experience using technical equipment and to liaise with other educators in designing methods to implement this in science classrooms occurs, leading to individuals creating a cutting-edge curriculum that is inter-disciplinary, student research focussed and linked to future science courses and careers.

With Spaceward Bound, science is not developed as discrete areas, but as a holistic study embracing the research, bringing in the skills of biology, chemistry, geology and physics when required. In modern schools, curriculum and pedagogy are ill-equipped to embrace the synthesis of the sciences, and much less able to develop the content, concepts, and skills to teach it. (McKay et al, 2007).

Through the link of scientists and teachers in Spaceward Bound, opportunities and experiences are gained that promote a connection with current research and techniques of utilising science content and skills to cover defined areas of the curriculum. With the release of the Australian Curriculum (AC) documentation, which is mandated for all schools by 2013 (http://www.australiancurriculum.edu.au/Science/Curriculum/F-10), it is apparent that certain aspects of this new curriculum have a direct connection for teachers involved with this program.

Areas discussed throughout Spaceward Bound cover the three AC areas; Science Understanding, Science as a Human Endeavour, Science Inquiry Skills. As an example, within Middle School, at Year 8, a topic about Astrobiology could be developed and taught that connects with the Pilbara expedition, and the Dawn of Life trail and the meaning and relevance of stromatolites. The proposed topic would link with the Australian Curriculum areas of Biological Sciences (Cells are the basic units of living things and have specialised structures and functions-ACSSU149), with Earth and Space Sciences (Sedimentary, igneous and metamorphic rocks contain minerals and are formed by processes that occur within Earth over a variety of timescales ACSSU153), linked under the theme of Science as a Human Endeavour (Science knowledge can develop through collaboration and connecting ideas across the disciplines of science-ACSHE226) where students would apply aspects from each of those content areas mentioned assisting with understanding what these scientists do, but then apply practical skills in Science Inquiry Skills, where students could plan, conduct and process data from their own experiment.
In addition to curriculum development, teachers participating in Spaceward Bound are being surveyed about their experiences. Teachers are provided with 2 surveys (a Pre-expedition and Post-expedition) each take approximately 20 minutes to complete (A delayed survey is issued around 12 months after participation in the expedition), where levels of confidence, motivation, interest and knowledge are identified as well as levels of links and implementation in the delayed survey. This new development is linked with a Doctoral Thesis at Curtin University examining changes in teachers' motivation, practices and classroom pedagogy through participation in a specialist professional learning opportunity. Though early days, much data analysis and interpretation of interview data will be occurring in the near future and Mark Gargano intends to submit a number of papers relating to this topic to international peer-reviewed journals.

Preliminary research being analysed on 20 teachers that have participated in the 2011 field opportunities in the United States and Australia are indicating a number of interesting results that will be further investigated as a part of this study. Even with this group of highly motivated educators, a number of teachers have indicated on the pre-expedition survey that they are 'confident' in teaching Earth and Space Science concepts, which compared with general science, often is rated as 'quite confident' or even 'highly confident'.

From examining the initial data, it appears that there is some reluctance for teachers to incorporate practical skills in these areas in their classroom, one US Teacher even mentioning that they do not complete any practical work in a 4-week Earth and Space Science module. A number of other teachers stated that laboratory work is used about once a week, highlighting reasons such as a perceived lack of available practical work, difficulty accessing equipment, not enough specialist teachers or knowledge, or all the practical work for a 4-week module, being placed into a one day field-trip experience covering a range of skills in a single hit.

Left: Teachers Mark Gargano, Lucinda Land & Ken Silbourn. Middle: Meeting the Rover. Left Lucinda Land & Rover drivers.

Figure 5.1

From the Post-Expedition survey it appears that there is much learning and modifications in attitudes, with comments including:

It was good to have interaction with the researchers and being able to speak to them how their work could be used in the classroom (US Teacher)

Ideas for field survey techniques will now be used in my classrooms (US Teacher)

I am more confident and the experiences will influence my classes (Australian Teacher).

The analysis of this research will continue with further NASA Spaceward Bound expeditions, as well as delayed surveys for all groups and interviews for teachers. It is envisaged that results will highlight best practice techniques as schools move towards implementation of the Australian Curriculum and engage students proactively in authentic research projects (figure 5.1) with a genuine research culture that promotes the growth and acceptance of courses and careers in science, technology, engineering and mathematics. What is also evident is that through professional development, creating of class materials and instructions, teachers and students will gain a greater understanding of the early Earth with particular connections to the Pilbara and the importance of the Dawn of Life trail itself.

6.0 Outreach

The expedition was active with outreach.
Public outreach presentations were given at Nullagine (20 people), Port Headland (30 people), Karatha (10 people) and Perth. The Perth presentations were at the Planetarium at Scietech (200 people) and a 'meet the scientists' afternoon at the Scietech science display centre (2,500 people). Refer figure 6.1

I addition media interviews were given at all locations. Media web references are listed in the Appendix.

Outreach: at Scietech, Perth. Right: Jon Clark.

Figure 6.1

7.0 Financial Summary

The summary of the expedition expenses and income are listed in the table 7.1 below.

Table 7.1: Expedition Expenses and Income

		% of Overall Total
Expenses:		
Vehicle hire and fuel	$21,000	59 %
Camping and accommodation	$8,850	25 %
Food and kitchen equipment	$4,200	12 %
Miscellaneous	$1450	4 %
Total	**$35,500**	
Income:		
CSIRO	$5,000	14 %
Pilbara Development Commission	$10,000	28 %
Expedition participants	$12,650	36 %
MSA Internal funds	$7850	22 %
Total	**$35,500**	

We note that the expedition participants provided 36% of the income. The cost charged per person was $550.

Overall the expedition cost nominally $1,550 per person. This contrasted with the SBA 2009 expedition to Arkaroola and Marie, South Australia, which cost nominally $850 per person.

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