# MAPPING THE DAWN OF LIFE TRAIL STROMATOLITES

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## SUMMARY

This report is submitted to the Pilbara Development Commission as part of the requirements for that body's grant to Mars Society Australia for the July 2001 "Spaceward Bound Pilbara" expedition. It summarises results from a field reconnaissance and preliminary mapping of a c. 3.4 billion year old stromatolite locality in the Strelley Pool Formation between Marble Bar and Nullagine. The location is referred to as the 'Dawn of Life Trail', a site being proposed for geoheritage and geotourism purposes in recognition of the significance of the Pilbara region to the understanding of the earliest inhabited environments on Earth and the search for life elsewhere in the solar system. The site was discovered by geologists from the Geological Survey of Western Australia (GSWA) in 2000. Mapping of the site and documentation of significant features was carried out as part of the Mars Society Australia's Spaceward Bound Pilbara expedition in partnership with the NASA Ames Research Centre and was funded by grants from CSIRO, the Western Australian Government (through the Royalties for Regions program), and the Pilbara Development Commission, in addition to the expedition partners. Reconnaissance and mapping delineated many stromatolite occurrences in the area, together with possible evidence of near-surface hydrothermal activity. Most of the stromatolites are simple domes, but cones and low relief domes are also common, branching stromatolites are much rarer. Much of the non-stromatolitic carbonate and chert was laminated, suggesting a microbial role in its formation also. All occurrences found were photographed and documented and their coordinates logged by Global Positioning Systems (GPS) and will be described in more detail in a forthcoming Geological Survey of Western Australia Record. The positions of well preserved structures were plotted on aerial photographs of the area using Google Earth imagery. Future work options, a possible trail location, and site protection issues, as outlined here, require consideration before the site development can be advanced further.

## Introduction

Stromatolites in the Strelley Pool Formation at the Dawn of Life Trail (DLT) locality, between Marble Bar and Nullagine, were mapped by Spaceward Bound Australia participants in July 2011. This report provides examples of the range of stromatolite morphologies and other features of interest, makes recommendations of features for incorporation into a heritage trail (Grey et al. (2010) and the design of that trail, proposes procedures for site protection, and suggests possible future activities. The work was made possible by a grant from the Pilbara Development Commission and this report is prepared to meet the requirements of the grant.

## Rationale

Following the discovery of about half a dozen key sites showing evidence of early life in the Pilbara of Western Australia, interest in visiting the sites has been considerable and comes from a broad cross-section of the community, including scientists, educators, media, tour operators, and the general public. It soon became obvious that these small, highly vulnerable sites could not 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 and access to them is subject to various conditions (Grey et al., 2010). At the same time it was recognized that 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 Mar and 50 km north of Nullagine and therefore roughly mid-way between the two townships (Figure 1). Subsequent reconnaissance studies suggested that the DLT site had the potential for development as a geoheritage trail to educate the public about the global significance of the Pilbara region for the history of life on Earth (Grey et al., 2002; Grey and Caldon, 2008). The accessibility of the DLT would serve to reduce pressure on the highly protected and extensively studied State Geoheritage Reserves elsewhere in the Pilbara. Subsequently, the DLT site was listed as location 5.2 in a geotourist guide book to the Marble Bar area by Van Kranendonk and Johnson (2009).

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). However, to date, no detailed analysis of the local geology or distribution and diversity of the stromatolites present at the DLT had been carried out. Such an undertaking is labour intensive and an attempt to document the site in 2008 had failed because of adverse weather conditions. 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 determining its future potential.

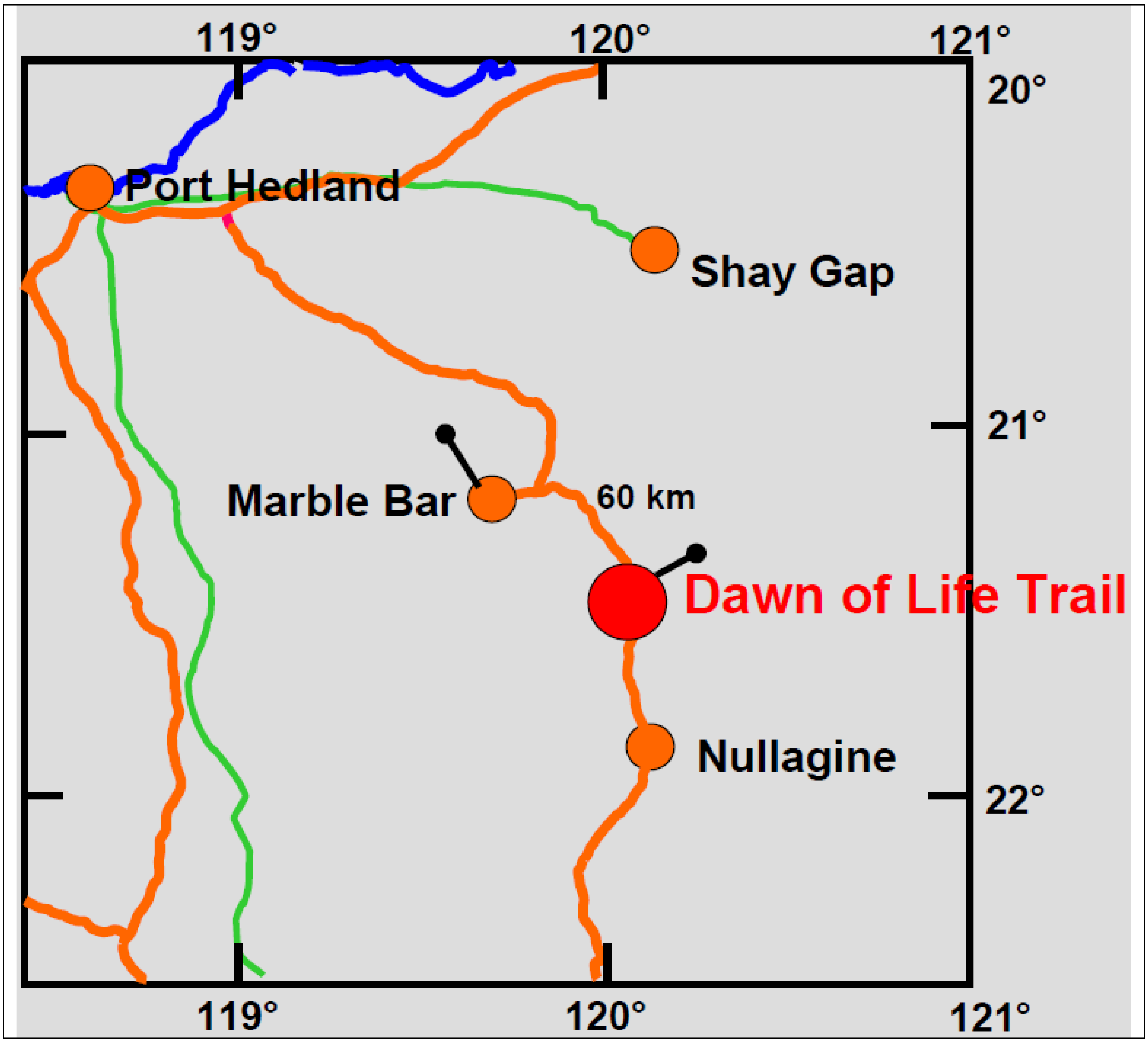



*Figure 1. Location of Dawn of Life Trail (from Grey and Caldon, 2008)).*

In July 2011 the Mars Society Australia (MSA), in conjunction with researchers from NASA Ames Research Centre in the United States and elsewhere, undertook the Spaceward Bound Pilbara expedition to the Pilbara and Shark Bay regions. This was part of the longer term Spaceward Bound Program (Heldmann et al. 2007) run by NASA Ames with MSA as it's Australian partner. The aims of the Spaceward Bound Pilbara expedition were:

1. Scientific reconnaissance of the region for future research by planetary scientists and astrobiologists.
2. Testing of space related hardware (e.g. the NDX-1 prototype space suit and the Terra XRD-XRF) in an environment analogous to what might be found by the forth coming Mars Science Laboratory Mission.
3. Collect data on the DLT.
4. Training of educators in planetary science, aerospace education, and astrobiology.
5. Engagement with the public through media contacts, public lectures and schools.

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. The data collected on these two days forms the basis of this report.

**Geological Context**

The Strelley Pool Formation (Hickman, 2008), formerly the Strelley Pool Chert of Lowe (1983) and Van Kranendonk and Morant (1998), has been geologically mapped over about 30 000 $km^2$ of the east Pilbara. Outcrops of the formation are regionally discontinuous due to folding, faulting, and locally being concealed by unconformably overlying formations. In most areas, the succession of the Strelley Pool Formation is less than 50 m thick and is composed of siliciclastic and volcaniclastic units, laminated grey-white chert mainly representing silicified carbonate rocks, carbonate rocks with only minor silicification, and minor primary black, white, and jaspelitic chert with crystal fans (pseudomorphs after aragonite, gypsum, or barite). Although the formation is extremely thin compared to other >3.2 billion year old geological formations of the east Pilbara, which have a combined thickness of >15 km, its scientific importance is exceptional because it contains the most diverse and abundant early Archean fossil assemblage on Earth, and because it provides unique evidence on c. 3.4 billion year old depositional environments and early Archean processes of crustal evolution (Hickman et al., 2011). The Strelley Pool Formation was deposited during a 75-million-year break in volcanic activity (Hickman, 2008), which gave early life the first known lengthy opportunity to flourish on Earth.

In the DLT area, the succession of the Strelley Pool Formation dips predominantly to the east, but local dip reversals indicate some structural complexity related to faults that separate the DLT outcrop from the main outcrop of the formation 1.5 km to the west (Fig. 2). Low-angle quartz veins which intrude the succession at DLT were formed by hydrothermal activity along these faults. Stromatolites comprise only a small part of the overall succession at DLT, and this may be a consequence both of their limited primary depositional distribution and post-deposition destruction of primary fabrics by silicification and various other types of alteration. Outcrop thickness at DLT is highly variable, from 5 to 100 m, and a basal conglomerate is locally present (Van Kranendonk and Johnson, 2010).

Paraconformably to disconformably underlying the Strelley Pool Formation is the 3.45-3.427 billion year old Panorama Formation of the upper Warrawoona Group. The Panorama Formation consists of flow-banded, fine-grained and porphyritic rhyolite, fragmental felsic volcanic rocks, and minor banded and black chert.

Disconformably to paraconformably overlying the Strelley Pool Formation is the 3.35-3.325 billion year old Euro Basalt of the lower Kelly Group. The Euro Basalt is a thick, predominantly basalt succession also containing dolerite and komatiitic basalt, with minor chert, komatiite, clastic and volcaniclastic sediments, all metamorphosed to greenschist facies.

Some local ultramafic rocks forming units parallel or sub-parallel to bedding in the Strelley Pool Formation and the Euro Basalt are most likely the same age as the Euro Basalt, but larger intrusions probably belong to the 3.18 billion year old Dalton Suite (Van Kranendonk *et al.* 2006). The ultramafic rocks have been metamorphosed to form serpentinite-chlorite and carbonate-tremolite schists.

Residual bodies of calcrete and silcrete are present in the area (Williams and Bagas 2007a). These locally fill deep fractures in the bedrock.

An extract from the 1:100 000 Mount Edgar sheet (Williams and Bagas 2007b), shows the regional geological setting of the DLT (Figure 2).

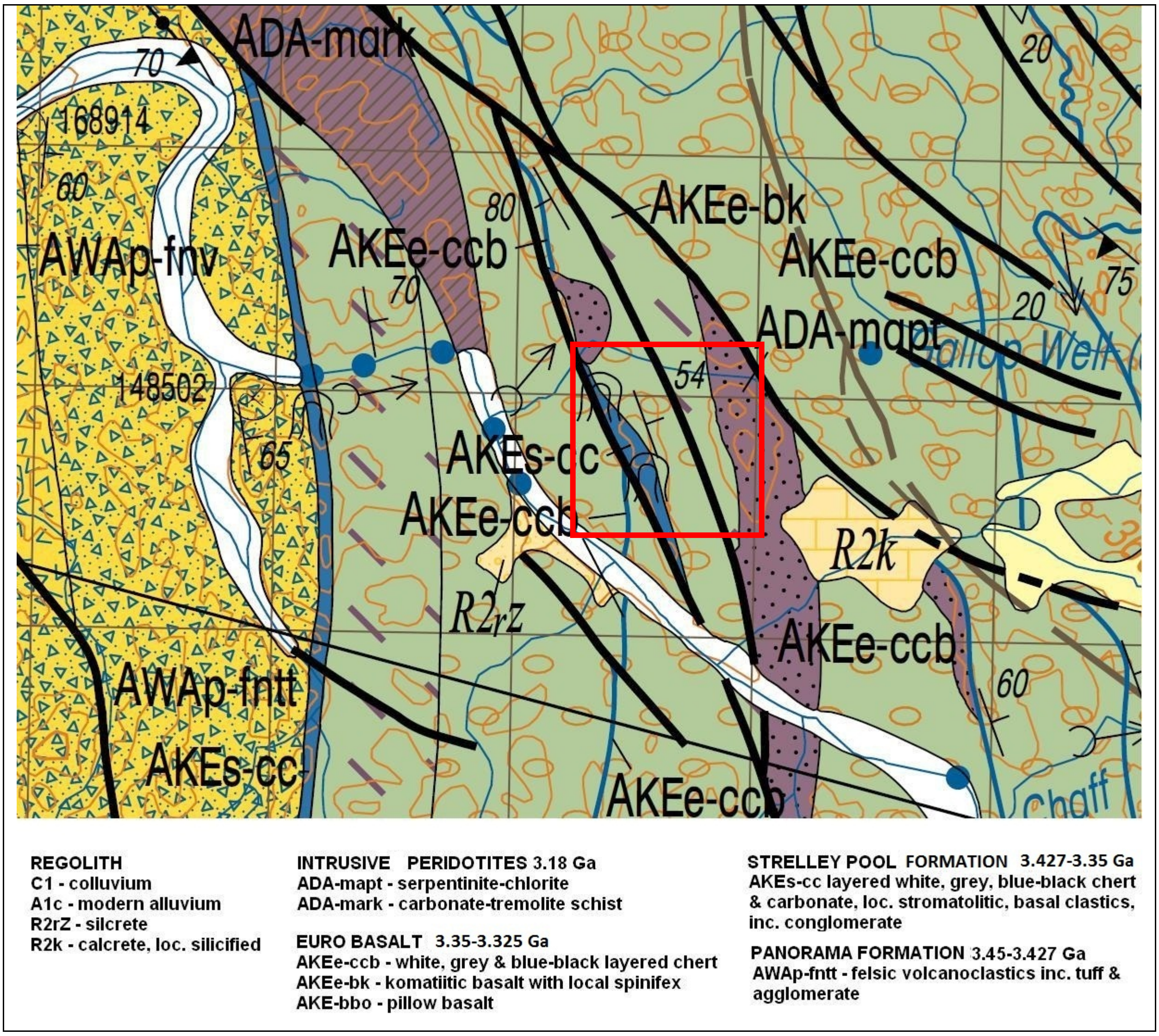



*Figure 2. Geology of the DLT area (approximate position red box), after Williams and Bagas (2007b). Grid squares are 1 km*

## Exposure

The main silicified portion of the Strelley Pool Formation at the DLT forms a low hill, with individual chert beds forming small steep outcrops that shed siliceous fragments (Figure 3). This scree mantles the surface, obscuring the intervening lithologies. Other lithologies occur as exposures in the banks and beds of small gullies and creeks. Approximately 25-30% of the surface is covered by low spinifex (*Triodia sp.*)

*Figure 3. Typical outcrop at the DLT from the top of the ridge and looking south. Note partial Spinifex cover, silicified rocky outcrops, and siliceous scree between outcrops.*

**Methods**

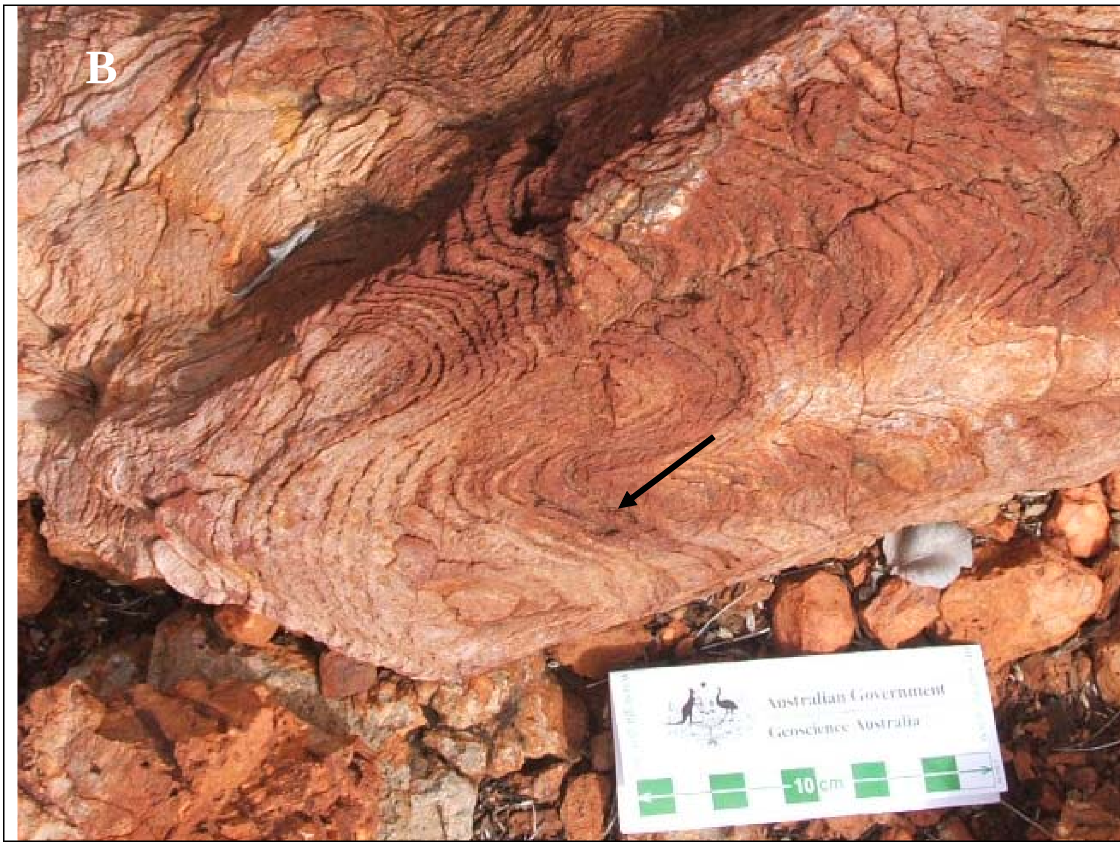
Several multi-person parties traversed an area measuring about 1 km by 0.5 km surrounding the area where stromatolites had been recorded previously. The chert outcrops were walked in all directions until no more stromatolites could be located. Each occurrence was photographed using a camera with a linked 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.

The stromatolitic outcrops consisted mainly of low ridges of silicified limestone, and could be readily correlated with features visible in the Google Earth image. Polygons showing the main stromatolite localities were defined based on the photograph coordinates and topographic features.

Stromatolitic cherts are fine-grained and preserved fine laminations, and locally clearly replaced carbonate rocks. Elsewhere the chert is coarser grained and did not preserve fine detail. We suggest that this is due to either a different depositional environment or diagenetic, hydrothermal or metamorphic overprinting. Diagenetic alteration is common in Pilbara successions, but it is often below lower greenschist facies, which is one reason for the exceptional preservation found in some areas. The limited occurrence of stromatolites may therefore either reflect original distribution patterns, such as those caused by limited habitats, or be a preservational feature.

## Stromatolite morphologies

The range of stromatolite morphologies is shown in Figure 4.  In total 97 different stromatolitic features were imaged. The most common stromatolites were convex stromatolites (45 imaged – 46%).  These were followed by low relief convex stromatolites (26 imaged – 27%) and cones (24 imaged – 25%).  Least common branching stromatolites (“Micky Mouse ears”, 2%).  We suspect than the parallel laminated chert and carbonate through the area is also originally microbial in origin, however these are not included in the statistics.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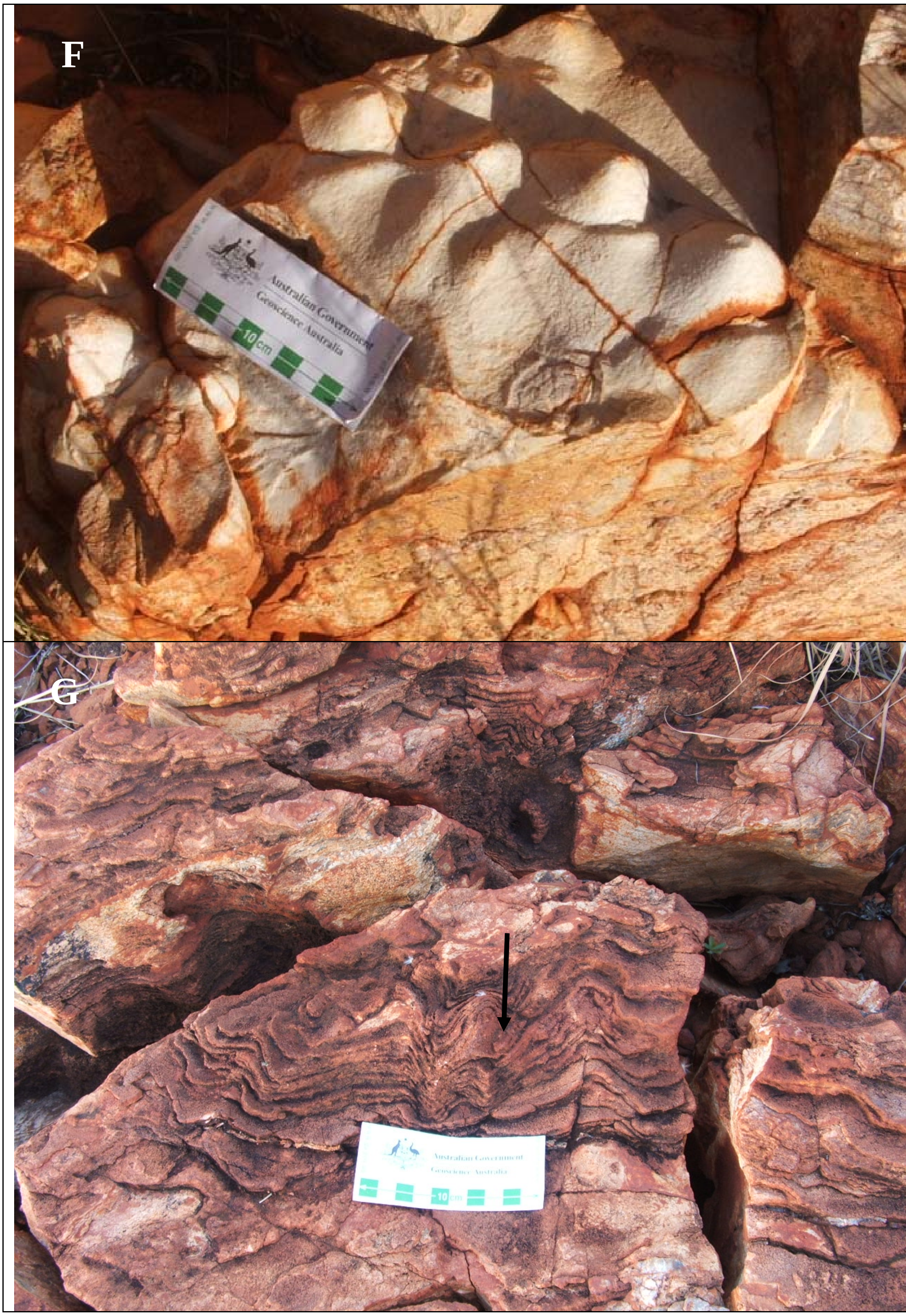
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*Figure 4. Representative stromatolite morphologies at the DLT. A – conical stromatolites passing up into near-horizontal laminae (laminae recrystallized). B – twinned laterally linked conical or ridged stromatolites . C – undulating conical or ridged stromatolites with vertical profile of a cone arrowed, only partly silicified. D – layered stromatolites with plan view of a conical stromatolite (arrowed). E – oblique profiles of conical or ridged stromatolites. F – 3-D "egg carton", small conical stromatolites. G – weathered surface of small conical stromatolite demonstrating that the 3D shape is conical (arrowed) H – Plan view of conical 'egg carton' stromatolites showing lateral linkage between the cones.*

## Site Description

Thirty eight stromatolite locations were identified and photographed. Of these, seven small outcrops in two clusters were composed of black chert, suggesting preserved carbonaceous matter. Five outcrops had evidence for exhalative activity, two had mounds of nail hole bladed quartz, carbonate, and barite, often forming cavity filling textures, two had horizontal laminated to low amplitude yellow-stained (probably goethitic after pyrite) stromatolites. A fifth site had platy quartz and euhedral cavity filling quartz, suggestion deposition in the boiling zone of a hydrothermal systems (Dong *et al.* 1995).

**Table 1**
PIMA results

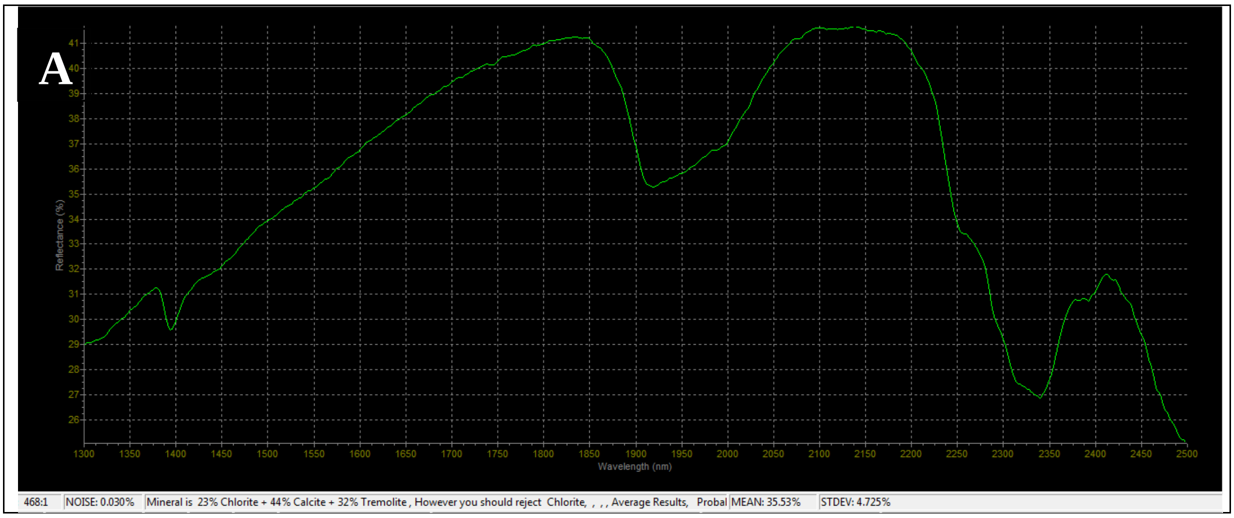
| ID | Location | Unit | Lithology | Mineralogy | Comments |
|---|---|---|---|---|---|
| 1a | Exterior | Komatiitic Euro Basalt | Weathered ultramafic schist | Tremolite, calcite, tr. chlorite | Primary mineralogy |
| 1b | Interior | Komatiitic Euro Basalt | Ultramafic schist | Tremolite, calcite, chlorite | Primary mineralogy |
| 2a | Exterior | Euro Basalt | Fine-grained | Chlorite, siderite | Primary mineralogy & |

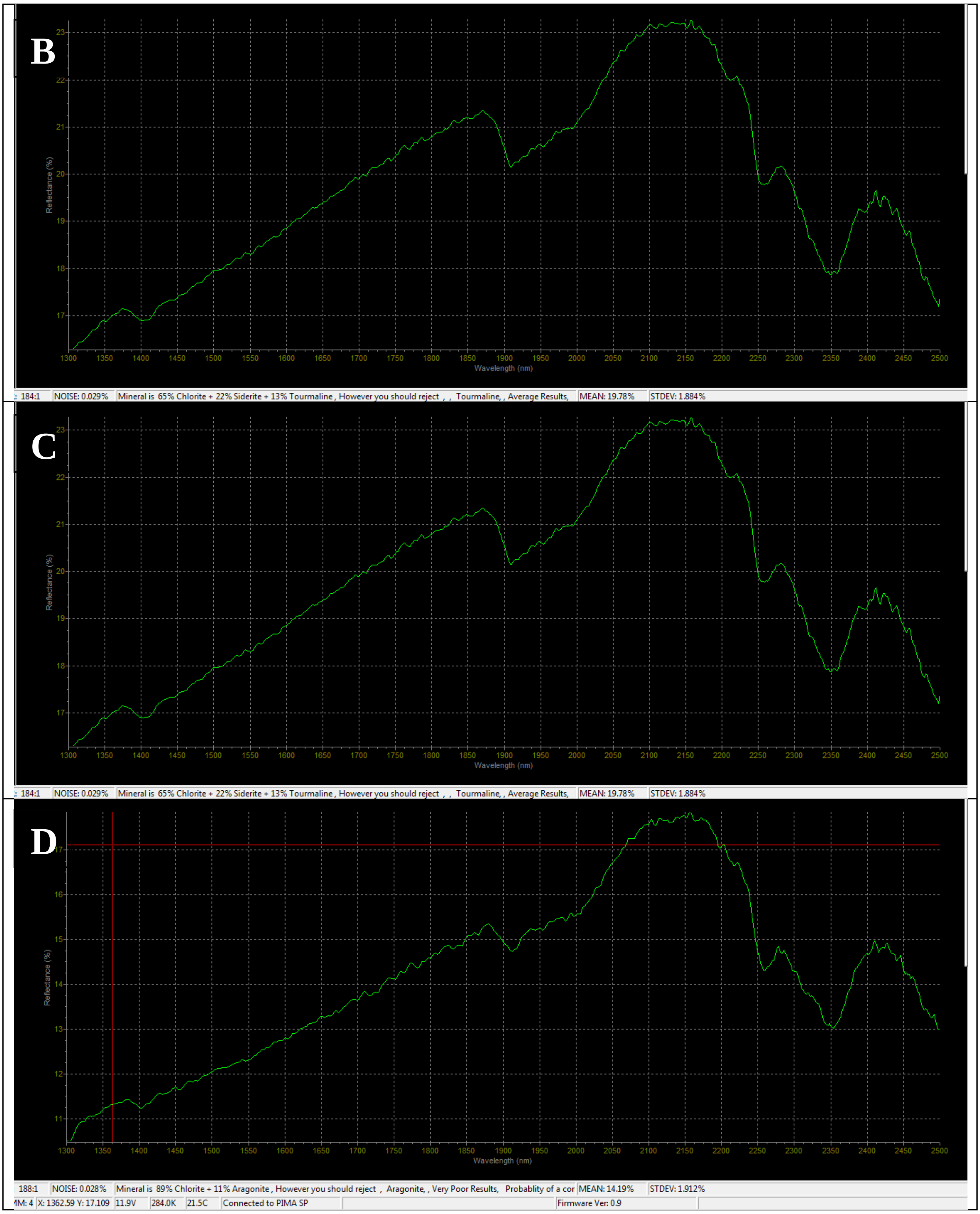
| | | | | | |
|---|---|---|---|---|---|
| | | | amphibolite | | 2ndary siderite |
| 2b | Interior | Euro Basalt | Fine-grained amphibolite | Chlorite | Primary mineralogy |
| 3 | Exterior | Strelley Pool Formation | Stromatolitic carbonate | Weak carbonate signal | Poor results from rough surface |
| 4 | Interior | Strelley Pool Formation | Limestone marble | calcite | Primary mineralogy |
| 5a | Exterior | Strelley Pool | Mafic schist | Kaolinite, nontronite | No primary mineralogy detected |
| 5b | Interior | Strelley Pool | Mafic schist | Nontronite, phengite | Nontronite weathering, phengite original |
| 6a | Exterior | Komatiitic Euro Basalt | Weathered ultramafic schist | Talc? | Poor results from rough surface |
| 6b | Interior | Komatiitic Euro Basalt | Ultramafic schist | Talc, tremolite | Primary mineralogy |
| 7a | Exterior | Euro Basalt | Fine-grained amphibolite | Gypsum, kaolinite, montmorillonite? | No primary mineralogy detected |
| 7b | Interior | Euro Basalt | Fine-grained amphibolite | Chlorite, calcite | Primary mineralogy |

**PIMA results**

The PIMA collects short wavelength infrared (SWIR) spectra in the 1300 to 2500 nm wavelength range (Thompson *et al.* 1999). These wavelengths are optimised to detect the products of hydrothermal alteration, in particular hydrated or hydroxyl-bearing minerals, sulphates and carbonates.

Representative PIMA spectra are shown in Figure 5 and the results tabulated contained in Table 1. Most measurements were made of the mafic rocks overlying or interlayered with the Strelley Pool Formation to determine their mineralogy. They show that the carbonate rocks of the Strelley Pool Formation are composed of calcite and that the dominant alteration assemblage of the mafic and ultramafic rocks is consistent with aqueous alteration (chlorite and tremolite) with minor signature minerals of $CO_2$ alteration (talc and calcite) (Powell *et al.* 1991).

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Reflectance (%)
Wavelength (nm)
184:1 NOISE: 0.029% Mineral is 65% Chlorite + 22% Siderite + 13% Tourmaline, However you should reject , , Tourmaline, , Average Results, MEAN: 19.78% STDEV: 1.884%
C
Reflectance (%)
Wavelength (nm)
184:1 NOISE: 0.029% Mineral is 65% Chlorite + 22% Siderite + 13% Tourmaline, However you should reject , , Tourmaline, , Average Results, MEAN: 19.78% STDEV: 1.884%
D
Reflectance (%)
Wavelength (nm)
188:1 NOISE: 0.028% Mineral is 89% Chlorite + 11% Aragonite, However you should reject , Aragonite, , Very Poor Results, Probablity of a cor MEAN: 14.19% STDEV: 1.912%
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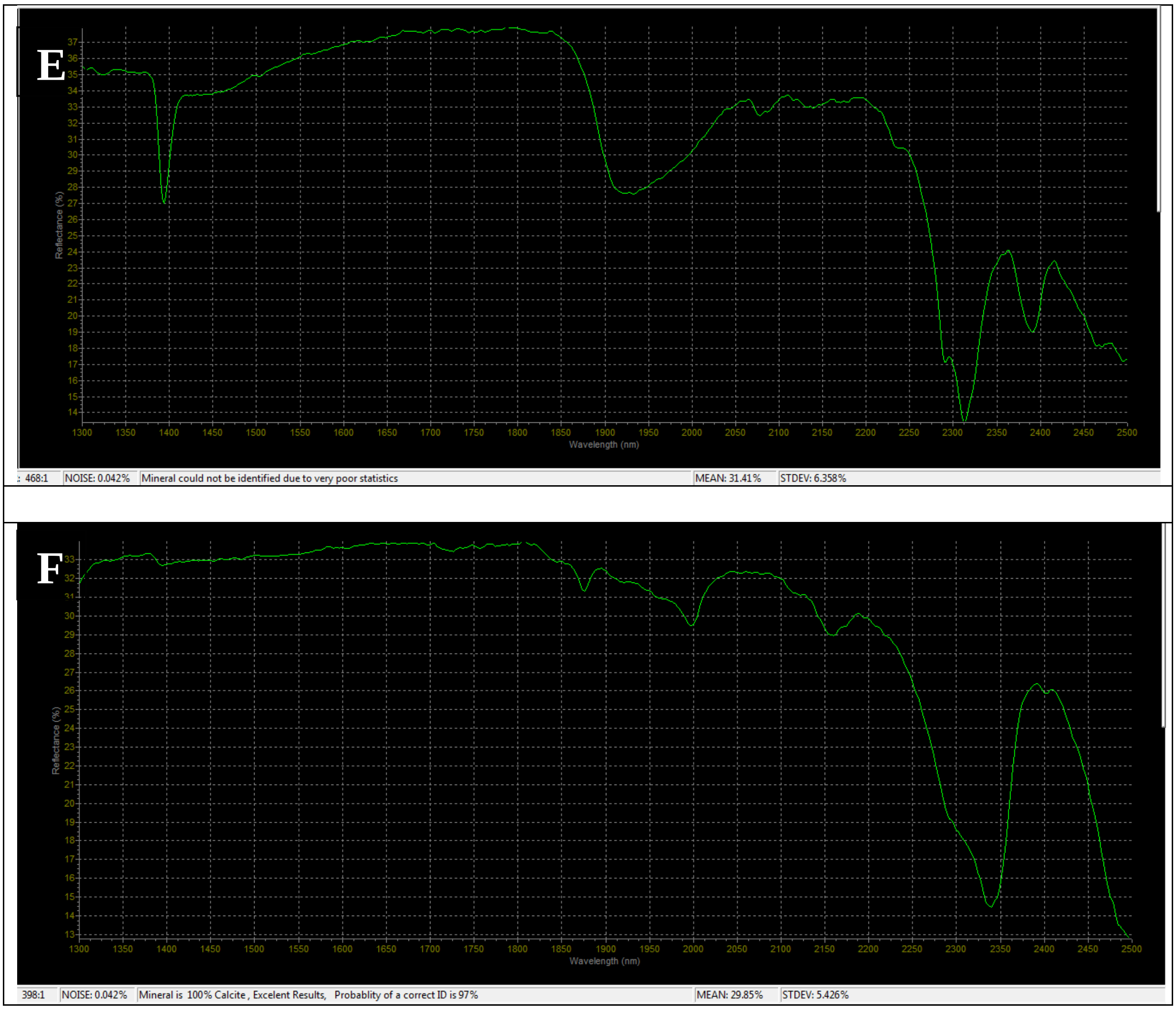


*Figure 5. Selected PIMA spectra. A - Exterior of altered ultramafic schist (komatiitic Euro Basalt). Tremolite and calcite detected, with weak chlorite signal because of weathering. B - Interior of altered ultramafic schist (komatiitic Euro Basalt). Tremolite, calcite detected, with stronger chlorite signal because of less weathering. C- of fine-grained ambibolite (Euro Basalt). Chlorite and siderite detected. D- Interior of fine-grained ambibolite (Euro Basalt). Chlorite detected. E - Surface of stromatolitic limestone in Strelley Pool Formation. Carbonates not detected by software because very rough surface gave poor signal. F - Interior of limestone Strelley Pool Formation. Excellent detection of calcite.*

## Other features of interest

A location showing pillow structures of the Euro basalt reportedly occurs on the track into the site. This was not examined because of time constraints. These should be photo documented on a future visit.

Spinifex-textured komatiites are similarly shown close to the nominal parking spot. This also was not visited because of time and because the track now extends much closer to the outcrops. These should be photo documented on a future visit.

Several chert localities show signs of near surface hydrothermal activity. These include quartz pseudomorphs after platy quartz, euhedral quartz (Figure 6A), goethite-stained laminated to low-relief stromatolitic chert (possibly relacing sulphides, Figure 6B), nail hole bladed quartz, carbonate, and barite, often forming cavity filling textures, (Figure 6E). These features are consistent with the suggestion (Van Kranendonk 2006) that the stromatolite locations are associated with areas of hydrothermal activity. Some cross-cutting quartz veins are associated with silification of basalts inter-layered with the cherts (Figure 6F and 6G).

A range of conglomerates have been reported in the area. These include volcanic conglomerates of lithic lapelli (Figure 6H) and polymict conglomerates containing sedimentary detritus (Van Kranendonk and Johnson 2009).

Crystal fans after either aragonite or sulphate evaporates have been reported and illustrated by van Kranendonk and Johnson (2009). These were not documented on this visit; we hope to do so on a future occasion.

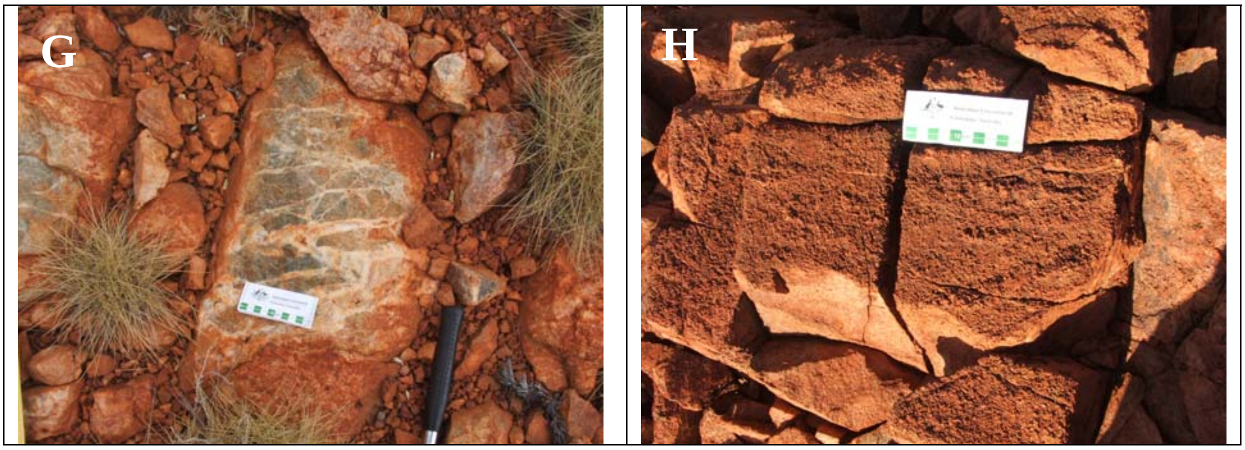


*Figure 6. Other features of interest. A - euhedral quartz filling a cavity. B - goethite-stained laminated to low-relief stromatolitic chert, possibly relacing sulphides. C – possible hydrothermal breccias. D - botryoidal cavity-filling quartz (arrowed), location 5. E - hollow nail hole bladed quartz, carbonate, and barite, often forming cavity filling textures. F - cross-cutting, low angle bucky quartz vein connecting two stromatolite horizons in foreground, and middle distance). G – quartz-veined and silicified basalt H - volcanic conglomerate of lithic lapelli.*

**Suggestions for a heritage trail**

A suggested heritage trail is outlined below and shown in Figure 7. Total distance traversed is 0.86 km. Total climb is 22 m.

1. Pillow lavas - on way in (21°28'2.49"S 120° 4'34.15"E)
2. Trail head - suggested parking area (21°28'6.27"S 120° 4'21.33"E). Location 3 of Grey and Cadon (2008).
3. Spinifex textures in komatiite - next to parking area (21°28'6.89"S 120° 4'22.05"E)
4. Stromatolite location A – partially silicified carbonate stromatolites of varying morphology (21°28'11.42"S 120° 4'19.15"E)
5. Stromatolite location B – silicified stromatolites of varying morphology and exposures (21°28'14.33"S 120° 4'18.92"E) Location 1 of van Kranendonk and Johnson (2009) and Location 9 of Grey and Caldon (2008).
6. Crystal fans and conglomerates (21°28'15.66"S 120° 4'19.24"E). Location 2 of van Kranendonk and Johnson (2009) and Location 10 of Grey and Caldon (2008).
7. View from top of hill - Stromatolite location C – stromatolites in black chert, view across site (21°28'13.75"S 120° 4'16.69"E)
8. Hydrothermal vent – low amplitude stromatolites, goethite-stained laminated silica (21°28'10.22"S 120° 4'15.35"E).

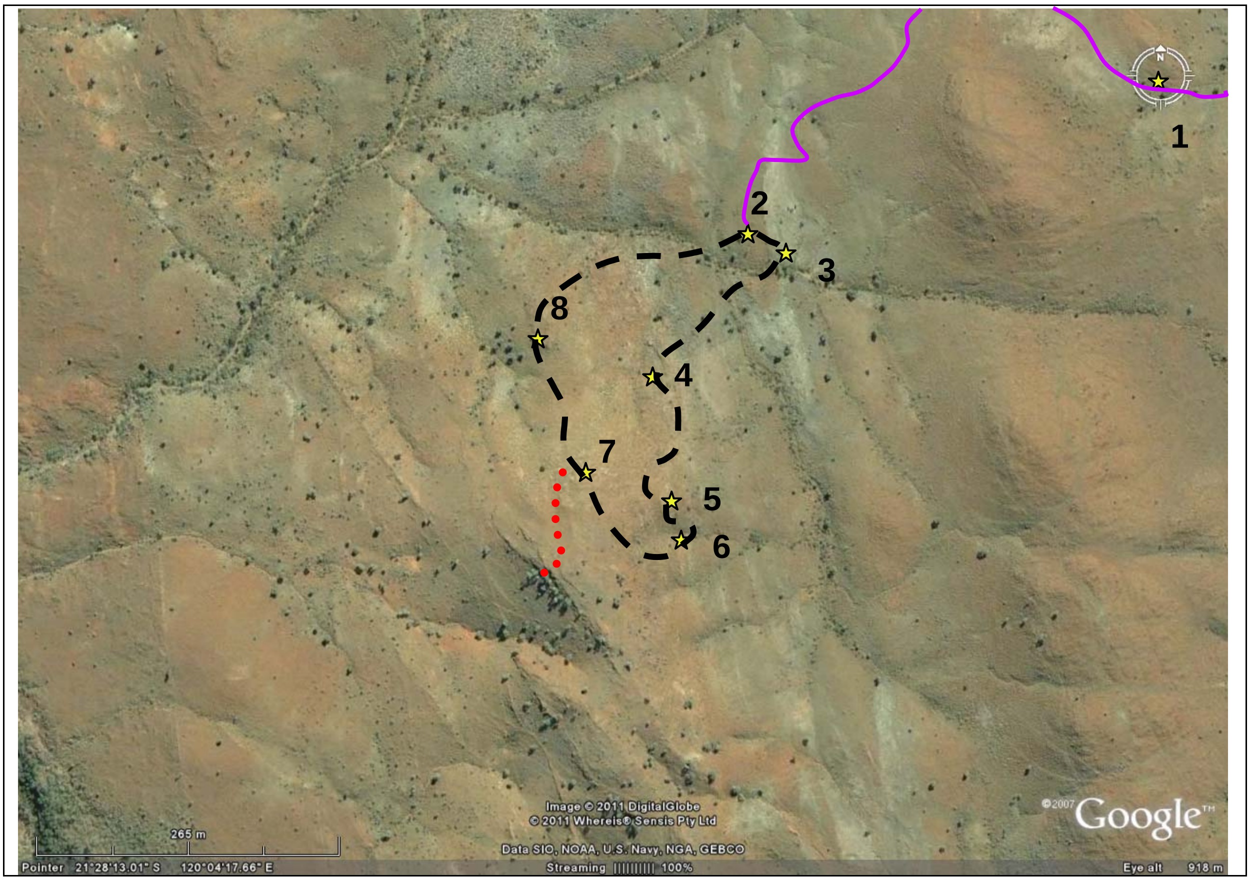


Figure 7. Proposed "Dawn of Life Trail" and features of interest. Purple line is access track in, black marks proposed walking trail. Red marks possible track extension to lookout.

**Future work**

MSA and the Spaceward Bound Pilbara Team hope to continue activities at the DLT trail. Of immediate relevance to the development of the area is further mapping to extend and infill the data presently available. In particular specific features, including quartz veins, hydrothermal vents, conglomerate and faults need to be located with greater confidence. These data will be used to further develop the case for development of a formal geoheritage trail at the site, expand knowledge about the early habits for life in the Pilbara, test instruments for use in planetary science and astrobiology, and provide field training for researchers.

**Education**

The mission of Spaceward Bound is to train the next generation of space explorers by having students and teachers participate in the exploration of scientifically interesting but remote and extreme environments on Earth as analogs for human exploration of the Moon and Mars (NASA Spaceward Bound 2011). The Pilbara region examined falls into this category and provides the basis for teachers to gain specialist science knowledge and to work with scientists in a field environment. The DLT is a great location to develop an integrated field experience for teachers and students from all levels of education that embraces the skills and knowledge of biology, chemistry, geology and physics when required. With the release of the Australian Curriculum (AC) documentation, which is to mandated for all Australian schools by 2013 (see http://www.australiancurriculum.edu.au/Science/Curriculum/F-10), it is apparent that 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. The proposed topic would incorporate 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).

A series of modules are planned that focuses the students' attention to what is life, beginning with a series of discussions about the characteristics of living organisms, this would include investigations into cells and cell structure. An integral area would be to examine our understanding of life within a geological timeframe, with information about early life processes-making reference to the Pilbara with examples of these biotic structures that we now see as fossilised stromatolites. Students would be able to handle rock and mineral types and then observe the characteristic layering structure that indicates microbial action. Discussions and activities would then occur that link the stromatolites to space science, with connections between the conditions on early Earth, with that on Mars, adding the reasons why space science researchers are investigating these areas.

Students would need to utilise 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.

A very important teaching resource would be areas clearly marked along the DLT itself, with class materials designed to generate thoughts and discussions about the significance of this region and life on Earth, along with reasons why these areas are a part of our heritage. This would enable an enriching Earth and Space Science field-trip experience to occur.

Using the DLT linked to the AC would provide an opportunity for students to learn about scientists working in this field, and gain a greater understanding of science careers in fields of geology that promote an understanding of the early Earth, particularly in locations such as the DLT.

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