Department of
Mineral and Petroleum Resources

RECORD
2002/17

3.45 BILLION YEAR-OLD STROMATOLITES IN THE PILBARA REGION OF WESTERN AUSTRALIA: PROPOSALS FOR SITE PROTECTION AND PUBLIC ACCESS

by K. Grey, A. H. Hickman, M. J. Van Kranendonk, and M. J. Freeman

Geological Survey of Western Australia

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

RECORD 2002/17

3.45 BILLION YEAR-OLD STROMATOLITES IN THE PILBARA REGION OF WESTERN AUSTRALIA: PROPOSALS FOR SITE PROTECTION AND PUBLIC ACCESS

by
K. Grey, A. H. Hickman, M. J. Van Kranendonk, and M. J. Freeman

Perth 2002

REFERENCE
The recommended reference for this publication is:
GREY, K., HICKMAN, A. H., VAN KRANENDONK, M. J., and FREEMAN, M. J., 2002, 3.45 billion year-old stromatolites in the Pilbara region of Western Australia: proposals for site protection and public access: Western Australia Geological Survey, Record 2002/17, 11p.

National Library of Australia Card Number and ISBN 0 7307 8904 7

Grid references in this publication refer to the Geocentric Datum of Australia 1994 (GDA94). Locations mentioned in the text are referenced using Map Grid Australia (MGA) coordinates, Zone 51. All locations are quoted to at least the nearest 100 m.

Published 2002 by Geological Survey of Western Australia

Copies available online at: www.mpr.wa.gov.au
Hardcopy available on request from:
Information Centre
Department of Mineral and Petroleum Resources
100 Plain Street
EAST PERTH, WESTERN AUSTRALIA 6004
Telephone: (08) 9222 3459 Facsimile: (08) 9222 3444
Information about publications of the Geological Survey of Western Australia is available through the Department's website at www.mpr.wa.gov.au

Contents

Figures

Tables

3.45 billion year-old stromatolites in the Pilbara region of Western Australia: proposals for site protection and public access

by

K. Grey, A. H. Hickman, M. J. Van Kranendonk, and M. J. Freeman

Abstract

Since announcing the discovery of some of the oldest stromatolites in the world in the eastern part of the Pilbara Craton of Western Australia in 1999, the Geological Survey of Western Australia has received an increasing number of requests to view 'the oldest fossils on Earth' in situ. Enquiries range from how to set up research projects to holiday plans for curious tourists. The Pilbara is an exceedingly remote area located some 1800 km northeast of Perth and travel to this region requires careful planning, special equipment and supplies, as well as a sturdy vehicle (generally a 4-wheel drive vehicle). The fragile fossil sites also require protection from indiscriminate collecting.

This report reviews the status of known stromatolite sites, offers suggestions for their protection, and discusses the advantages of making one location that is readily accessible from Marble Bar (the Gallop Well locality) available as a public viewing site.

KEYWORDS: Pilbara Craton, stromatolites, Archaean, microorganisms, biosphere, geological monuments, national heritage, field excursions

Introduction

Since announcing the discovery of some of the oldest stromatolites in the world in the eastern part of the Pilbara Craton in 1999, the Geological Survey of Western Australia has received an increasing number of requests to view 'the oldest fossils on Earth in situ'. Enquiries range from how to set up research projects to holiday plans for curious tourists. Proposals are rarely feasible and most visitors have no concept of the logistics involved. One tour company wanted to coach in 300 visitors in one day, staying at Port Hedland. Someone with no outback experience planned to drive alone from Marble Bar to the North Pole area to look at the stromatolites, and return to Marble Bar in a single day in late November. Apart from the risks inherent in such proposals, fragile sites are threatened through indiscriminate collecting. Protection is required for key sites and access to them has to be limited to well-prepared researchers with good scientific credentials.

The Geological Survey of Western Australia will continue to help and advise appropriate geoscientists to visit significant locations. Wherever possible, parties should be accompanied by a suitable Australian geologist, preferably with costs met by the visitors. Visitors should be aware of regulations governing fossil collection and export, and agree to abide by these restrictions, before the Geological Survey of Western Australia or anyone else provides them with assistance. Some unprotected sites should be vested as Crown Reserves to allow conditions to be placed on visits. It would be appropriate for such reserves to be vested with the Minister for State Development (who has responsibility for the Department of Mineral and Petroleum Resources). Currently, some sites are reserves vested with the Minister for Planning and Infrastructure (who is responsible for the Department of Land Administration). In order to monitor site usage appropriately, and for ease of administration, it would be better if all sites were vested in one authority that had an expert understanding of why each site has been vested with the Crown.

Demand from non-specialists could be met if a more accessible location for viewing the stromatolites and their typical host rocks were available. This would channel

interest away from vulnerable sites, and provide an opportunity to educate the public at large about aspects of geology and the conservation of geological sites. With this in mind, geologists from the Geological Survey of Western Australia working in the Pilbara region have identified a potential site near Marble Bar that could become a viewing area for non-specialists. A location near Gallop Well, about 1 km west of the Marble Bar – Nullagine road (60 km and about 50 minutes drive from Marble Bar), meets most public access site requirements, although the fossils are only moderately preserved. Investigations of alternative sites known to contain patches of well-preserved material are in progress, but access is difficult, and the area is at present unsuitable for tourism.

This report reviews the status of known sites, offers suggestions for their protection, and discusses the advantages of making the Gallop Well locality available to the general public.

Significance of 3.45 billion year-old Pilbara stromatolites

The Warrawoona Group of rocks in the Archaean Pilbara Craton contains volcanic and sedimentary rocks in which ancient stromatolites have been preserved. Stromatolites are laminated organosedimentary structures built mainly by the activities of microorganisms, principally bacteria and cyanobacteria. Stromatolites of Archaean age are important because they demonstrate the nature and antiquity of the Earth's biosphere, whereas most fossils commonly found in rocks around the world are the remains of creatures that lived over the past 600 million years.

The Earth formed about 4 600 million years ago (4.6 billion years, or 4.6 Ga), and the record of life demonstrated by actual fossils can be traced back to about 3.45 Ga. The oldest part of this record in the early Archaean (that is, in rocks older than 3.0 billion years) is sparse, and consists mainly of stromatolites and rare microfossils. These provide the most tangible evidence of early biological activity on Earth, although chemical traces from rocks in Greenland indicate possible organic material older than 3.8 Ga. About 30 Archaean stromatolite occurrences have been reported worldwide, but the biogenicity of structures in rocks older than 3.2 billion years is often disputed, and their origins attributed to non-living processes, such as chemical precipitation of sedimentary rocks or soft-sediment deformation. The rare microfossils that have been found in these ancient rocks are also the subject of disputes, such as whether the microfossils are in situ or represent contaminants introduced much later.

The 'egg-carton' stromatolites discovered in carbonate rocks in the Archaean Warrawoona Group at the 'Trendall locality' (Table 1) in the eastern Pilbara in 1997 provide the most convincing evidence to date that structures of biogenic origin were growing about 3.45 billion years ago. The 'Trendall locality' is particularly significant because of the exceptional preservation that occurs over just a few square metres of outcrop, and which demonstrates a morphological development consistent with biological construction. Formation by means such as soft-sediment deformation is ruled out by the presence of the complex structures discovered at this site. These include cones arranged in an 'egg-carton' pattern, as well as branching columns that grow on the sides of cones.

Once such well-preserved material had been identified, many of the more doubtful structures could be re-interpreted, and are now also considered to be biogenic in origin. Preservation is poor at many localities, but stromatolites appear to have been much more widespread in the Warrawoona Group than previously reported. Distribution of stromatolites appears to be closely associated with a hot-spring environment, often the site for gold and other mineralization. The value of the stromatolites is further demonstrated by the interest shown in them as a model in the search for fossilized life on Mars.

Volcanic rocks associated with the stromatolites were dated using uranium–lead isotopes from zircons, a method that gives very precise ages. Stromatolites at the Trendall locality are about 3.458 billion years old. Previously discovered North Pole stromatolites and microfossils are 3.49–3.46 billion years old, and microfossils from Chinaman Creek are about 3.46 billion years old. These Pilbara Warrawoona Group stromatolites and microfossils are currently the oldest fossils known on Earth. (See '**Further reading**' for papers discussing the finds at these various localities.)

Key scientific sites

Assessment of individual sites

Tables 1(†) and 2 list the individual sites and attempt to assess their significance on the basis of four criteria:

- preservation
- access
- significance or uniqueness
- and vulnerability.

The need for protection has been prioritized based on these criteria. Sites that are already protected are indicated by an asterisk (*). Sites with highest priority for protection comprise North Pole 2* (in a reserve that also incorporates North Pole 1* and 3*), and Trendall (which does not currently have any form of protection). Other sites with a high protection priority consist of Awramik*, Chinaman Creek, Spinaway Creek, and Strelley West.

Strelley Pool, Strelley West, North Pole stromatolite locality 2*, and the Awramik microfossil locality* were nominated for National Heritage Listing by the Australian Heritage Commission, and North Pole* and Awramik* have just gained interim listing status. These two sites are unvested Crown Reserves. Written permission from the

† In the interests of protection for these sites, specific details of their locations have not been included in the tables.

Table 1. List of significant stromatolite sites

Site		*Comments*
1	Awramik microfossils*	Two small hills with black chert containing microfossils. The age of the chert is between 3.49 and 3.46 billion years. Access is good. About two hours drive from Port Hedland
2	Chinaman Creek (Schopf microfossils)	Black chert with microfossils visible in thin section. The age of the chert is between 3.46 and 3.45 billion years. This site is inaccessible by 4WD vehicle, and requires a 2 km walk from the nearest access point. About one and a half hours drive from Marble Bar
3	Doolena Gap	Broad, domical stromatolites up to 2 m long × 60 cm wide in grey and black layered chert; some small conical stromatolites. These are morphologically similar to the Panorama 2 locality stromatolites. About one and a half hours drive from Port Hedland
4	Gallop Well	The site is at MGA 0196557 E, 7622919 N. Small domical and conical stromatolites in partly silicified laminated carbonate rock. Stromatolites are preserved in cross section, but bedding plane exposures are less common. The stromatolitic horizon on the eastern slopes of a chert ridge is traceable for about 1 km southward along strike. The age of the stromatolites is between 3.43 and 3.34 billion years. Access is from Highway 138 at MGA 0197753 E, 7622467 N. Distance westward from the highway to the stromatolite locality is about 1.2 km. One hour drive from Marble Bar, three and a half hours drive from Port Hedland
5	Miralga Creek	A single, broad (40 cm), domical, wrinkly stromatolite is in a 2 m-thick chert horizon within the Euro Basalt at the top and northern end of the North Pole Dome stratigraphy. Three hours drive from Port Hedland, then access on foot
6	North Pole 1*	This is the original site visited by the Precambrian Palaeobiology Research Group in the late 1970s. Now collected out. The stromatolite illustrated on the front cover of 'Earth's earliest biosphere' (Schopf, 1983) is from here. About two and a half hours drive from Port Hedland
7	North Pole 2*	Good examples of domical stromatolites. Age of the stromatolites is about 3.49 billion years. Access is 4WD only. About two and a half hours drive from Port Hedland
8	North Pole 3*	A broad, domical stromatolite is growing near the vent of a hydrothermal vein. Uphill, there are three large domical stromatolites. About two and a half hours drive from Port Hedland
9	Panorama northeast	Locality is in the Strelley Pool Chert above the Panorama Formation, containing silicified conical stromatolites with 'egg-carton' geometry, as at the Trendall locality. About three and a half hours drive from Port Hedland, then access on foot
10	Sandy Creek	Carbonate domes and flat-laminated stromatolites, strongly recrystallized. Volcanic rocks immediately underlying the stromatolite horizon have been dated at 3.43 billion years. Site is at the same stratigraphic horizon as Spinaway Creek (Hickman, 1980). About two hours drive from Marble Bar. Access by 4WD vehicle, then on foot
11	Shark Gully	Poorly preserved carbonate stromatolites at the top of felsic volcanic rocks near Glen Herring Creek. The volcanic rocks immediately underlying the stromatolites have been dated at 3.43 billion years. About two hours drive from Marble Bar. Access by 4WD vehicle, then on foot
12	Spinaway Creek	Silicified cones up to 150 mm high lie near the top of a chert ridge, close to Spinaway Creek. Site is at the same stratigraphic horizon as Sandy Creek. 4WD access is difficult, even in dry conditions. Tracks in the area are disused, washed out, and partly overgrown. About two and a half to three hours drive from Marble Bar
13	Strelley West	Silicified conical stromatolites in two small gorges. Host rock is Strelley Pool Chert, dated in other areas at 3.43 billion years. About two and a half to three hours drive from Port Hedland. Access by 4WD vehicle, then on foot
14	Trendall	Excellent exposures of several different types of stromatolites — including small conical stromatolites ('egg-carton' types, which are now on display in the Western Australian Museum), large cones, and multiple-branching columnar stromatolites — in carbonate laminites and their silicified equivalents. Also examples of fine-laminated domical stromatolites in black chert and thin-bedded black chert stromatolites in sandstone. About three hours drive from Port Hedland. Access by 4WD vehicle in dry conditions only, then on foot

NOTES: * currently protected by a Reserve
MGA Map Grid of Australia
4WD Four-wheel drive vehicle

Table 2. Assessment of site quality

Site		*Preservation*	*Access*	*Significance/ uniqueness*	*Vulnerability*	*Protection priority*[†]
1	Awramik microfossil locality*	poor	easy	highly significant	vulnerable to commercial collecting	2
2	Chinaman Creek microfossils	good	difficult	highly significant	not very vulnerable	2
3	Doolena Gap stromatolites	very good	difficult	moderate — mainly domes	moderately vulnerable	4
4	Gallop Well stromatolites	moderate	easy	not very significant or unique	moderately vulnerable	2[‡]
5	Miralga Creek stromatolites	moderate	good	not very significant or unique	vulnerable	5
6	North Pole stromatolites 1*	poor	difficult	significant, first stromatolites found, photograph of these fossils on the cover of a text book	not very — most material has already been removed	3
7	North Pole stromatolites 2*	good	easy	highly significant — illustrated in many publications	very vulnerable	1
8	North Pole stromatolites 3*	good	fairly easy	highly significant because of field relationships	vulnerable	1
9	Panorama northeast stromatolites	good	poor	significant — confirms observations at Trendall	not very vulnerable	3
10	Sandy Creek stromatolites	moderate	difficult	moderate — recrystallized domes	not very	5
11	Shark Gully stromatolites	moderate–poor	difficult	moderate — recrystallized	not very	4
12	Spinaway Creek stromatolites	very good	difficult	highly significant — cones with preservation close to that of Trendall	vulnerable	2
13	Strelley West stromatolites	good	easy	highly significant — illustrated in literature	vulnerable	2
14	Trendall stromato lites	excellent	moderately easy	highly significant — well-preserved cones and a variety of other morphologies, relationships to sedimentary rocks	extremely vulnerable	1

NOTES: * currently protected by a Reserve
† 1 is highest protection priority, 5 is lowest
‡ if made accessible to public

Minister for Planning and Infrastructure is required before sampling within the reserves. Strelley Pool* (not included in the list because details are sketchy) is a Water Reserve, so permission to sample is required from the Minister responsible for the Water and Rivers Commission (Minister for Environment and Heritage). Stromatolites have not been found at this locality, although microfossils from this site are mentioned in a report by Schopf and Packer (1987).

North Pole stromatolite locality 1* was more or less collected out during investigations in the early 1980s, although there are still good examples of stromatolite mats and small, low-amplitude domical stromatolites in the vicinity. The small extent of the outcrop at North Pole 2* and the fact that the stromatolites are probably the oldest known, makes it imperative that there be no collecting at that locality. Any hammering would totally destroy the context, and there has already been material removed from the site since 1997 (Fig. 1). The Awramik microfossil locality* and the Schopf Chinaman Creek microfossil locality are more suitable for sampling, but this should be kept to a minimum. Localities along the ridge near Strelley Pool* and Strelley West have moderately abundant stromatolites, but care has to be taken to ensure they are not over exploited. A greater degree of protection is required for the well-preserved stromatolites exposed in the walls of two small gorges at Strelley West.

The Trendall locality is not currently protected by reserve status and requires careful management. The most convincing-looking structures were removed from the site and placed in the Western Australian Museum in Perth for safekeeping. However, there are exceptionally well-preserved vertical- and bedding-plane faces that need protection. Damage to the site, including the removal of a large conical stromatolite in carbonate, the decapitation of some of the largest conical stromatolites at the outcrop, and unauthorized sample collection occurred during the winter of 2000 (Fig. 1).

Land tenure and site protection issues

The Pilbara fossil sites are of international importance, attracting increasing attention from scientists and the public throughout the globe. The sites are subject to a variety of land tenure, ranging from Reserve for Management of Significant Geological Feature to unallocated Crown land. Those in reserves have some degree of protection from inappropriate use, but those on pastoral lease or unallocated Crown land are vulnerable to damage or misuse. When the locations of sites of comparable scientific significance overseas became known, they were included in mining titles and the fossils mined for sale. A few Pilbara sites have such exceptional geoscientific value that they should not be mined for profit (Western Australian meteorites are similarly protected from commercial activities because of their high scientific value). However, mining of minerals (if any are located) nearby could be justified in some cases, and might even be of benefit to a site because mining activity could expose additional high-quality specimens. Existence of a Crown Reserve over a site, vested in the Minister for State Development, will allow the Director, Geological Survey of Western Australia, to have input to any appropriate tenement conditions or mining approvals.

Creation of Crown Reserves

Creation of Crown Reserves is warranted because:

- the international geoscientific community recognizes these outcrops as invaluable for understanding the early evolution of life on Earth. Any deterioration through lack of management by the State will reflect badly on the State's reputation for valuing scientific endeavour and could lead to criticism by the international scientific community and consequential adverse media comment regarding our scientific reputation;
- critically, it will allow the Geological Survey of Western Australia, through its Director, to have major input to the ongoing management of these sites. Management by authorities with little or no geological expertise is considered inappropriate;
- it will legitimize the Director, Geological Survey of Western Australia, as having authority over activities incompatible with the ongoing management of these vulnerable sites to ensure their value is retained for future researchers and the community at large;
- it will facilitate appropriate advice being provided to mineral explorers holding tenements over the reserves to ensure they are aware of the value and vulnerability of the small outcrops (mineral resource companies are most likely to be highly supportive of protective management of geological sites);
- it will ensure that the Director, Geological Survey of Western Australia, has input over any mining proposal over the sites, and allow for protection of the sites from commercial dealings;
- increasing numbers of high-calibre geoscientists from around the world want to visit the sites. Continued erosion through geological sampling will progressively destroy those sites that are small or vulnerable. The Director, Geological Survey of Western Australia, must have some way of controlling the extent of such visits, perhaps in consultation with a panel of experts;
- as visitor numbers rise, the Geological Survey of Western Australia is increasingly called upon to provide advice and assistance. If such support is not given by the State's custodians of its geoscientific heritage, it will lead to inappropriate visitations and progressive destruction of the sites.

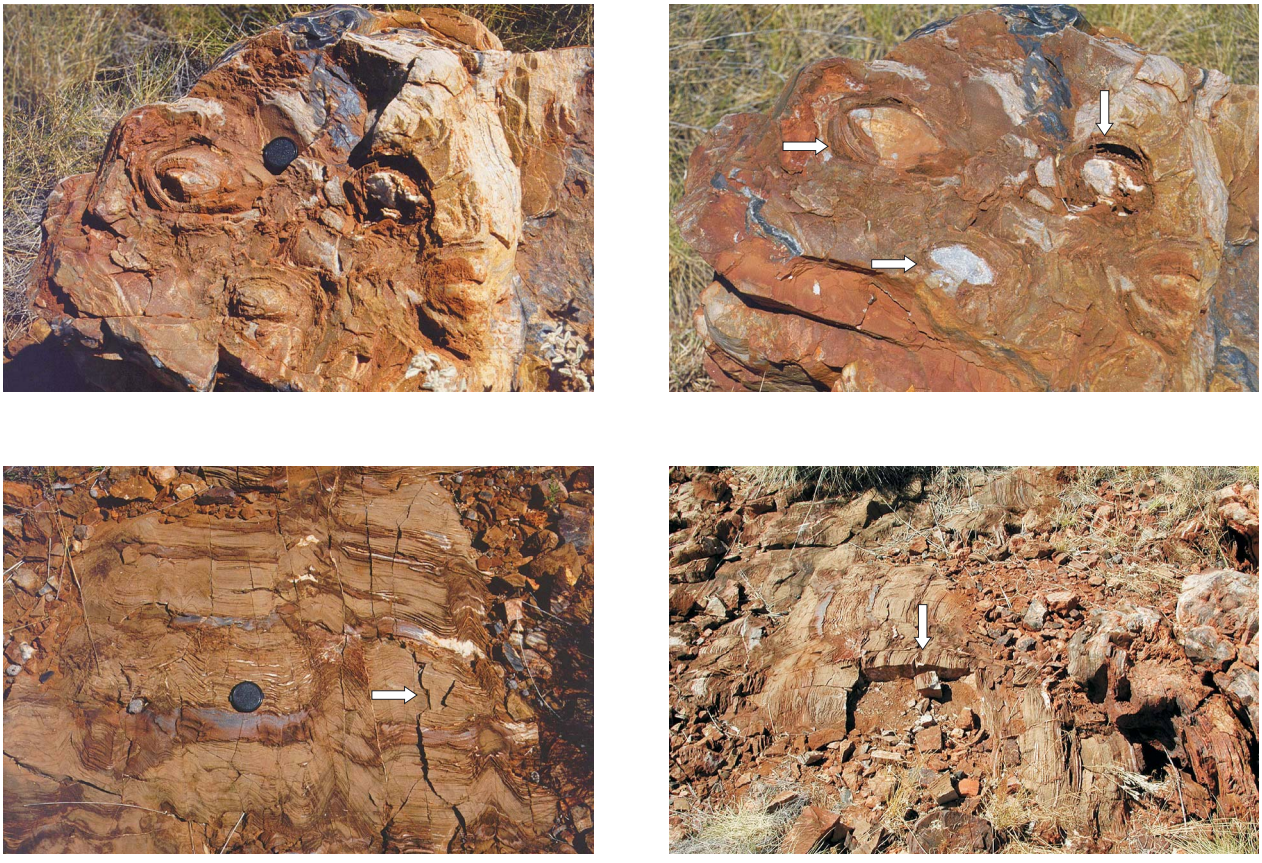
Financial implications are not seen as being significant. Little has been consumed by the four existing Geological Reserves since they were created in the early 1990s. Any ongoing expenses for management of visiting researchers should be nominally at their own expense. Erection of advice signs and any signage at the entries would not be unduly expensive. Reserves and locations should be labelled with suitable plaques pointing out that they are reserves and that it is illegal to collect and export without a permit. It may be possible to obtain funding for

A.

MVK434 18.10.02

B.

BEFORE AFTER



MVK433 18.10.02

Figure 1. Examples of damage caused to sites by indiscriminate hammering and removal of stromatolites

A. Damage at the North Pole locality 2 includes the removal of blocks of sandstone beneath a stromatolite mat (left) and a large part of the stromatolite mat itself (right)

B. Damage at the Trendall locality includes the decapitation of large conical stromatolites on a boulder (top) and the removal of a carbonate block with a conical stromatolite in cross-section (bottom)

this purpose from local mining companies, relevant professional societies, or other interested parties.

The Australian Customs Service and federal police, which enforce the Australian Protection of Moveable Cultural Heritage Act 1986 (APMCHA), would welcome any additional protection of sites that might strengthen their grounds in any prosecution that is undertaken.

Development of sites would not be appropriate. Hence costs for management, such as road maintenance and visitor infrastructure, are not considered an issue in the foreseeable future, except at the proposed public viewing area as discussed below.

Proposed management strategy

Management of the sites is premised on the following:

- sites are of international significance;
- exposures with important features are extremely vulnerable to destruction, and the removal of material from its context will significantly decrease its scientific value;
- the key sites are vulnerable to commercial collecting and would not be able to sustain legal or illegal exploitation for either the Australian or overseas markets;
- although few visitors would wantonly damage the sites, numerous, cumulative small-scale impacts — including 'legitimate' research sampling — would ultimately produce the same effects; and
- equivalent strata are available along strike away from these key exposures.

Management in the foreseeable future will consist of:

- creating Crown Reserves over the nominated key sites, to be vested with the Minister for State Development, to allow the government to insist that visitors adopt appropriate measures for the long-term protection of the rocks. (As an interim measure, an exemption under Section 19 of the Mining Act can be used to prevent mining at certain sites until reserves can be created);
- initiating a formal Management Plan once the reserves are created, to allow prosecution for intentional damage to the outcrops;
- including in the Management Plan a requirement to notify the Geological Survey of Western Australia of intent to enter any of the reserves, and a statement of purpose. If the purpose is the collecting of samples, written approval must be obtained from the Director, Geological Survey of Western Australia, who (after consultation with appropriate experts) will only sanction minimum sampling and may impose conditions on how the sampling is to be undertaken;
- monitoring the appearance of key sites by requiring a 'before' and 'after' photographic record of sampling by visitors to be submitted to the Director, Geological Survey of Western Australia, so that removal of material can be monitored and those responsible for damage can be identified;
- placing low-key signs on access tracks advising visitors of their responsibilities;
- taking no action to improve accessibility of the sites, to dissuade casual visitors;
- consider placing a locked gate across a narrow part of the access track to the Trendall locality;
- publicizing the protection and management strategy internationally through communications with Geological Surveys, Geological Societies, other stakeholders, such as heritage bodies and the Customs Service, and commercial marketers of fossil specimens.

Designation of a public viewing site

Designation of a public viewing site is warranted because:

- there is significant demand from the general public for the provision of a location where the fossils can be viewed in the field;
- it would direct interest away from the more vulnerable sites of significant scientific interest, increasing protection for them from casual collecting;
- a few well-chosen illustrations and explanations could point out significant features (and overcome the fact that the structures are not of the highest quality), help the non-specialist understand the significance of the site, and emphasize the need to protect geological sites as part of our heritage;
- it would reduce the risks created by having inexperienced travellers attempting to visit remote locations;
- it would benefit the tourism industry in places such as Marble Bar;
- tour operators, especially those running safari and eco-tours, would be interested in including a public viewing site in their itinerary, and would take an interest in conserving such a site because site damage would be detrimental to their operations;
- on a broader scale, exposure of the community to some of the geological wonders of the State could assist in creating better recognition of the intrinsic importance of the science, and not just its relationship to mining.

Various stakeholders were approached to test their reactions to the concept of opening up a public, readily accessible site. All welcomed the idea in principal, and offered enthusiastic support.

With these considerations in mind, it is proposed that the Gallop Well locality (Figs 2–4) be developed as a public viewing site. The reasons for favouring this location are discussed below.

Gallop Well locality

Location: MGA 0196557 E, 7622919 N, approximately 1.5 km west of Gallop Well, 59.5 km from Marble Bar on Highway 138 (Figs 2, 4).

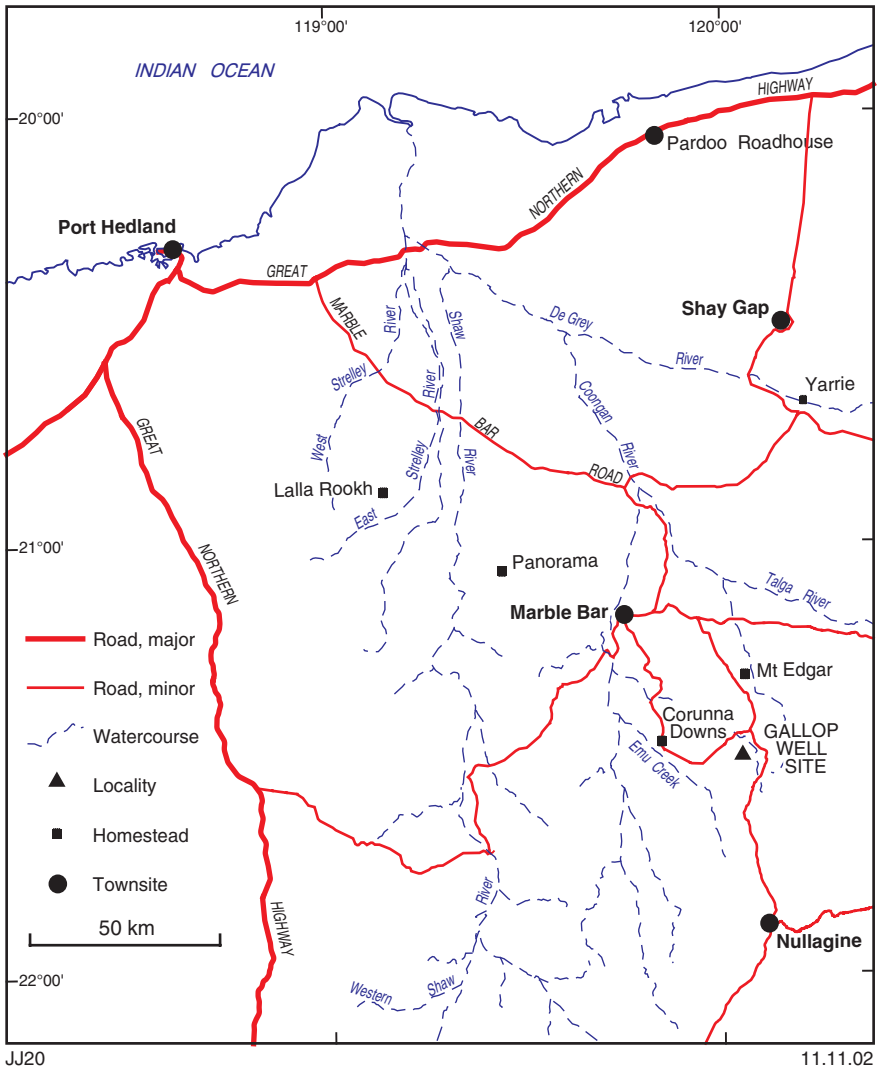


Figure 2. Regional map showing the location of the proposed Gallop Well public-access site

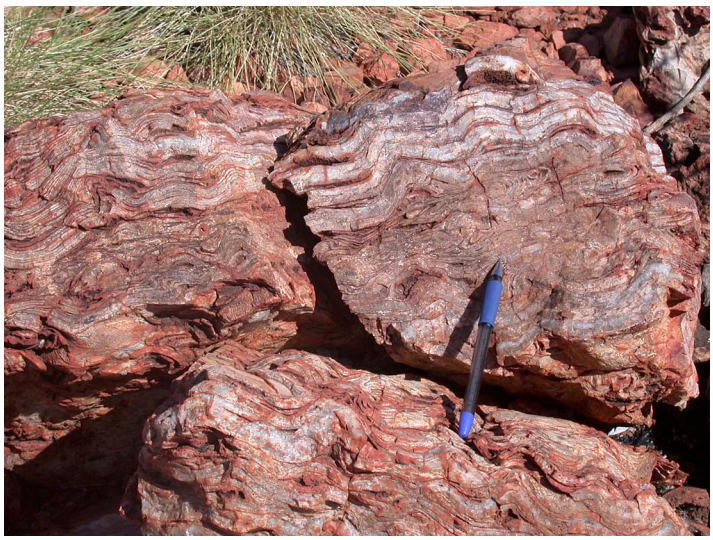
Geological setting: A stromatolitic horizon lies on the eastern slopes of a chert ridge, traceable for about 1 km along strike to the south. The stromatolites and carbonate rocks are restricted to the stratigraphic top of the chert unit. The chert is a member of the Euro Basalt (upper Warrawoona Group) and is underlain by altered metabasalt and overlain by serpentinite and komatiitic basalt.

Description of stromatolites: Small domical and conical stromatolites lie in partly silicified laminated carbonate rock (Fig. 3). The stromatolites are well preserved in cross section, but bedding plane exposures are far less common. The age of the stromatolites is between 3.43 and 3.34 billion years.

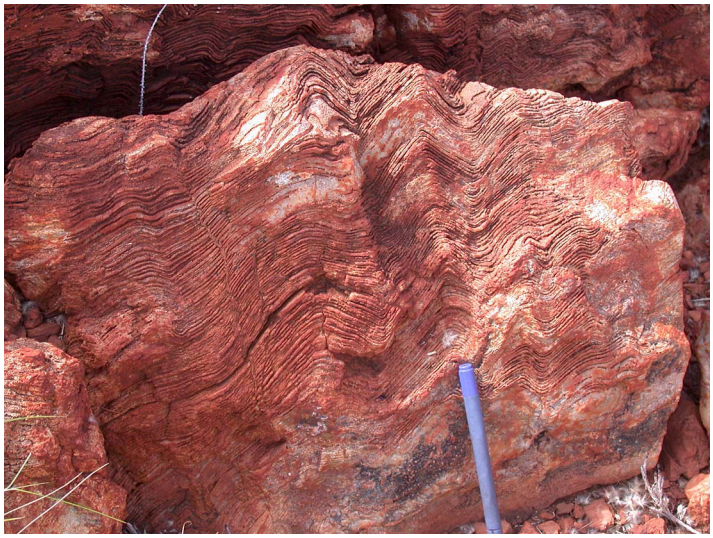
Suitability of site for tourism: The Gallop Well site is suitable as a tourist site because:

- the site is ideally located for access. It is close to a main road, and within one hours drive of Marble Bar and three and a half hours of Port Hedland. At present, there is no formed track to the site, but wheel tracks will soon develop into a well-defined track as the site becomes better known;
- it is well away from the other significant sites, so is particularly suitable for directing interest away from more-sensitive areas that need a high level of conservation;
- the stromatolites at the locality are not as well preserved or as scientifically significant as those at other locations. It is hoped that visitors will respect the site, but if damage occurs, any loss would not be as disastrous as at other sites;
- explanatory signs could be erected to explain salient features of the site, identify specific features of the stromatolites, and stress the need for conservation;
- a check of land access has shown no access issues. The location is close to, but not actually within, a water reserve on Corunna Downs Pastoral Lease and no registered Aboriginal sites are indicated. Consultations with stakeholders are ongoing.

A.



B.



C.

Figure 3. Stromatolites at Gallop Well

A. Typical stromatolitic banding and small domical stromatolites

B. Two adjacent conical stromatolites. It is difficult to explain the formation of cones other than by biological accretion

C. Example of poorly preserved 'egg-carton' stromatolites

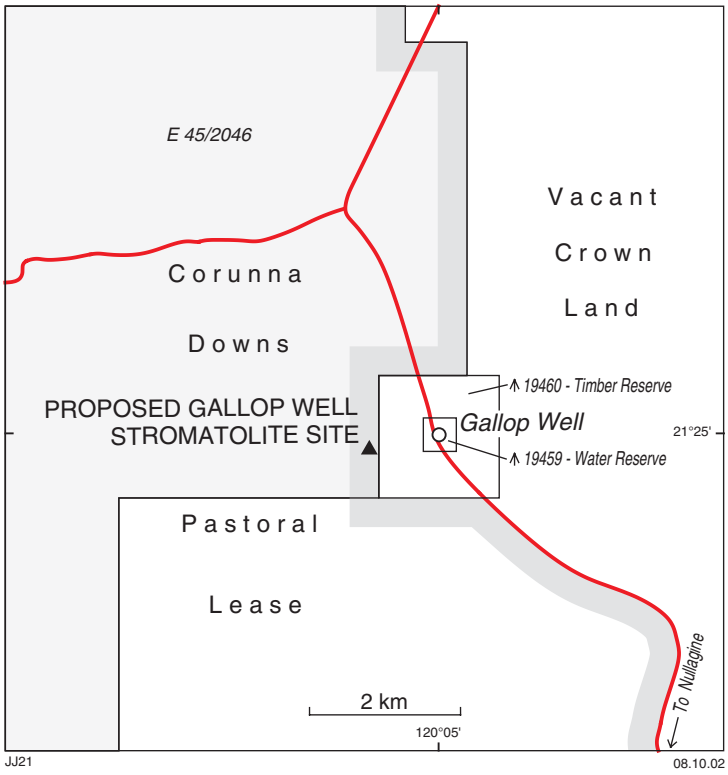


Figure 4. Location of Gallop Well site in relation to Exploration Licence (E45/2046), Corunna Downs Pastoral Lease, and the Water Reserve at Gallop Well

Conclusions

Six sites in the 3.5 billion year-old Warrawoona Group have been identified as being of such scientific significance as to justify designation as reserves to protect them from exploitation. The sites are: North Pole 2*, Trendall, Awramik*, Chinaman Creek, Spinaway Creek, and Strelley West. Of these, Trendall, Chinaman Creek, Spinaway Creek, and Strelley West currently have no protection. Awramik* and North Pole 2* are in reserves vested with the Minister for Planning and Infrastructure (The North Pole 2* reserve also incorporates North Pole 1* and 3*). It is proposed that the four unprotected sites be designated as reserves vested with the Minister for State Development (the Department of Mineral and Petroleum Resources is within his portfolio), and that the North Pole* and Awramik* Reserves be transferred to the same authority to simplify management.

The Gallop Well site is ideally located to meet requirements for a public viewing area for 3.5 billion year-old stromatolites because it is located near a main road and close to Marble Bar. The site does not contain unique material, or well-preserved fossils of specific scientific interest, so the site is not one of outstanding value that requires heritage protection. Making this site publicly available would channel attention away from more significant sites. Limitations imposed by unspectacular preservation could be overcome by explanatory signs. The number of requests received by the Geological Survey of Western Australia for information about how to visit the stromatolite sites, as well as preliminary enquiries to other stakeholders, indicate that there would be widespread support for making the Gallop Well location available as a public viewing site.

Further reading

AWRAMIK, S. M., SCHOPF, J. W., and WALTER, M. R., 1983, Filamentous fossil bacteria from the Archaean of Western Australia: Precambrian Research, v. 20, p. 357–374.

AWRAMIK, S. M., SCHOPF, J. W., and WALTER, M. R., 1988, Carbonaceous filaments from North Pole, Western Australia, are they fossil bacteria in Archaean stromatolites? A discussion: Precambrian Research, v. 39, p. 303–309.

BUICK, R., 1984, Carbonaceous filaments from North Pole, Western Australia, are they fossil bacteria in Archaean stromatolites?: Precambrian Research, v. 24, p. 157–172.

BUICK, R., 1988, Carbonaceous filaments from North Pole, Western Australia, are they fossil bacteria in Archaean stromatolites? A reply: Precambrian Research, v. 39, p. 311–317.

BUICK, R., DUNLOP, J. S. R., and GROVES, D. I., 1981, Stromatolite recognition in ancient rocks: an appraisal of irregularly laminated structures in an Early Archaean chert–barite unit from North Pole, Western Australia: Alcheringa, v. 5, p. 161–181.

BUICK, R., GROVES, D. I., and DUNLOP, J. S. R., 1995, Abiological origin of described stromatolites older than 3.2 Ga: comment and reply — comment: Geology, v. 23, p. 191.

CARTER, J. D., 1987, Important geological localities beyond the Perth region, their significance and value, protection and preservation: Geological Society of Australia (W.A. Division), 281p.

HICKMAN, A. H., 1980, Excursion guide, Archaean geology of the Pilbara Block: Second International Archaean Symposium, Perth, 1980: Geological Society of Australia (W.A. Division) Excursion Guide, 55p.

HOFMANN, H. J., 1999, Archean stromatolites as microbial archives, *in* Microbial Sediments *edited by* R. RIDING and S. M. AWRAMIK: Springer-Verlag.

HOFMANN, H. J., GREY, K., HICKMAN, A. H., and THORPE, R. I., 1999, Origin of 3.45 Ga-old stromatolites in Warrawoona Group, Western Australia: Geological Society of America, Bulletin 111, p. 1256–1262.

LOWE, D. R., 1980, Stromatolites 3,400-Myr old from the Archaean of Western Australia: Nature, v. 284, no. 5755, p. 441–443.

LOWE, D. R., 1983, Restricted shallow-water sedimentation of early Archaean stromatolitic and evaporitic strata of the Strelley Pool Chert, Pilbara Block, Western Australia: Precambrian Research, v. 19, p. 239–283.

LOWE, D. R., 1992, Probable non-biological origin of pre-3.2 Ga-old 'stromatolites' in the Barberton and Pilbara greenstone belts: Geological Society of America, Abstracts with Programs, v. 24, no. 7, p. A137.

LOWE, D. R., 1994, Abiological origin of described stromatolites older than 3.2 Ga: Geology, v. 22, p. 387–390.

LOWE, D. R., 1995, Abiological origin of described stromatolites older than 3.2 Ga: comment and reply — reply: Geology, v. 23, p. 191–192.

McNAMARA, K. J., 1988, Stromatolites — the ultimate living fossils: Australian Natural History, v. 22, no. 10, p. 476–480.

McNAMARA, K. J., 1997, Stromatolites: Perth, Western Australian Museum, 28p.

SCHOPF, J. W., (editor), 1983, Earth's earliest biosphere, its origin and evolution: Princeton, New Jersey, Princeton University Press, 543p.

SCHOPF, J. W., 1993, Microfossils of the Early Archean Apex Chert: new evidence of the antiquity of life: Science, v. 260, p. 640–646.

SCHOPF, J. W., 1999, Cradle of Life: the discovery of earth's earliest fossils: Princeton, New Jersey, Princeton University Press, 367p.

SCHOPF, J. W., and KLEIN, C., (editors), 1992, Evolution of the Proterozoic biosphere, a multidisciplinary study: New York, Cambridge University Press, 1348p.

SCHOPF, J. W., and PACKER, B. M., 1987, Early Archaean (3.3 to 3.5 Ga-old) fossil microorganisms from the Warrawoona Group, Western Australia: Science, no. 237, p. 70–73.

SCHOPF, J. W., and WALTER, M. R., 1992, Archaean microfossils: new evidence of ancient microbes, *in* Evolution of the Proterozoic biosphere, a multidisciplinary study *edited by* J. W. SCHOPF and C. KLEIN: New York, Cambridge University Press, p. 214–239.

WALTER, M. R., (editor), 1976, Stromatolites: Amsterdam, Elsevier, Developments in Sedimentology, 20, 790p.

WALTER, M. R., 1977, Interpreting stromatolites: American Scientist, v. 65, no. 5, p. 563–571.

WALTER, M. R., BUICK, R., and DUNLOP, J. S. R., 1980, Stromatolites 3,400–3,500 Myr old from the North Pole area, Western Australia: Nature, v. 248, p. 443–445.