RECORD 2023/16

PALAEO DOWN UNDER 3
POST-CONFERENCE EXCURSION GUIDE

NORTHERN PERTH BASIN

17–20 JULY 2023

Compiled by
AJ Mory and H Ryan

Department of Energy, Mines, Industry Regulation and Safety
GOVERNMENT OF WESTERN AUSTRALIA

Geological Survey of Western Australia

Department of **Energy, Mines, Industry Regulation and Safety**

GOVERNMENT OF WESTERN AUSTRALIA

RECORD 2023/16

PALAEO DOWN UNDER 3 POST-CONFERENCE EXCURSION GUIDE

NORTHERN PERTH BASIN

17–20 JULY 2023

Compiled by

AJ Mory and H Ryan*

* Western Australian Museum, Perth Cultural Centre, Perth WA 6000

Perth 2024

Geological Survey of Western Australia

MINISTER FOR MINES AND PETROLEUM
Hon David Michael MLA

DIRECTOR GENERAL, DEPARTMENT OF ENERGY, MINES, INDUSTRY REGULATION AND SAFETY
Richard Sellers

EXECUTIVE DIRECTOR, GEOLOGICAL SURVEY AND RESOURCE STRATEGY
Michele Spencer

REFERENCE
The recommended reference for this publication is:
Mory, AJ and Ryan, H (compilers) 2024, Palaeo Down Under 3 post-conference excursion guide, northern Perth Basin, 17–20 July 2023: Geological Survey of Western Australia, Record 2023/16, 49p.

ISBN 978-1-74168-026-3
ISSN 2204-4345

About this publication
The guide was prepared for a field trip associated with the 'Palaeo Down Under 3' conference held in Perth 10–14 July 2023 by Australasian Palaeontologists, a specialist group within the Geological Society of Australia.
This Record has been prepared for ease of printing in A5 format.

Acknowledgement of Country
We respectfully acknowledge Aboriginal peoples as the Traditional Custodians of this land on which we deliver our services to the communities throughout Western Australia. We acknowledge their enduring connection to the lands, waterways and communities and pay our respects to Elders past and present.

Published 2024 by the Geological Survey of Western Australia
This Record is published in digital format (PDF) and is available online at <www.dmirs.wa.gov.au/GSWApublications>.

Further details of geoscience products are available from:
First Floor Counter
Department of Energy, Mines, Industry Regulation and Safety
100 Plain Street, EAST PERTH WESTERN AUSTRALIA 6004
Telephone: +61 8 9222 3459 Email: publications@dmirs.wa.gov.au
www.dmirs.wa.gov.au/GSWApublications

Cover image: Ripples in Irwin River Coal Measures

Contents

Figures

Tables

Itinerary

Monday 17 July 2023

8:30	Depart WA Museum Boola Bardip
10:00–10:45	Locality 1: Molecap Quarry, Gingin
12:45–14:00	Lunch at Green Head
15:00–16:00	Locality 2: Leander Point, Port Denison
16:45	Arrive Abrolhos Reef Lodge

Tuesday 18 July 2023

8:30	Depart Abrolhos Reef Lodge
10:00–1200	Locality 3: Fossil Cliff, Irwin River
12:00–12:45	Lunch at Coalseam Conservation Reserve
2:00–15:45	Locality 4: quarry in Kockatea Shale
16:15	Arrive Abrolhos Reef Lodge

Wednesday 19 July 2023

6:30	Depart Abrolhos Reef Lodge
8:30–9:30	Locality 5: Z-bend, Murchison River
10:00–11:30	Locality 6: The Loop, Murchison River
12:00–13:00	Lunch at the Skywalk, Kalbarri National Park
13:30–14:30	Locality 7: Meanarra Hill, Kalbarri National Park
16:00–17:30	Locality 8: Blue Hills
18:30	Arrive Abrolhos Reef Lodge

Thursday 20 July 2023

8:30	Depart Abrolhos Reef Lodge
11:00–12:00	Locality 9: Lake Thetis, Cervantes, Nambung National Park
12:00–13:30	Lunch at Cervantes
14:00–16:00	Locality 10: The Pinnacles, Nambung National Park
18:30	Arrive WA Museum Boola Bardip

Palaeo Down Under 3 post-conference excursion guide: northern Perth Basin, 17–20 July 2023

compiled by AJ Mory and H Ryan*

General safety precautions

1. Keep within sight of other excursion participants at field sites. Do not wander off on your own.
2. Protect yourself from the sun with a broad-brimmed hat and full-length, loose-fitting clothes, and apply sun protection lotion (preferably 30+) regularly.
3. Use insect repellent if mosquitoes, bees, ticks or sand flies are a problem.
4. Do not approach snakes — they are usually frightened by moderate noise.
5. Drink sufficient water to avoid dehydration.
6. Wear protective footwear when wading in water.
7. If you smoke, do not discard cigarette butts in the bush. Note that some farms ban smoking in their paddocks.

Notes

This guide is derived mostly from Mory et al. (2005) and subsequent guides such as Mory and Haig (2011), with updates from new research.

Collecting specimens is permitted only at sites 1–4 and 8, whereas vertebrate fossils may not be collected at any site.

* Western Australian Museum, Perth Cultural Centre, Perth WA 6000

Perth Basin overview

The Perth Basin, on the western margin of the Precambrian Yilgarn Craton, contains a thick uppermost Carboniferous – Cenozoic succession and extends over 1000 km between the Southern Carnarvon Basin and the southern coast of the state. Separating the two basins are two transitional areas — the onshore Coolcalalaya Sub-basin (Mory et al., 1998) and the offshore Houtman–Abrolhos Sub-basins (inner and outer Abrolhos Sub-basin of Crostella, 2001) — both traditionally regarded as part of the Perth Basin (Fig. 1). The Northampton Inlier, which lies between these two sub-basins, is part of the Mesoproterozoic to Neoproterozoic Pinjarra Orogen that underlies most of the Perth Basin.

The northern part of the basin comprises an eastern faulted terrace between the Perth and Urella Faults (Irwin Terrace) and an onshore deep half-graben (Dandaragan Trough) in which the stratigraphic succession gradually shallows westwards towards a coastal basement high (Dongara Terrace – Beagle Ridge; Fig. 2), and then deepens into offshore, dominantly Mesozoic, sub-basins. The east–west Allanooka Fault marks the boundary with structurally shallow basement at the northern end of the Dandaragan Trough (Mory and Iasky, 1996). South of 31° S, the Dandaragan Trough grades into another set of deep troughs also dominated by a thick Mesozoic succession (Crostella and Backhouse, 2000; Thomas, 2014).

Numerous deep wells, outcrop and extensive geophysical coverage show that in the northern Perth Basin the main onshore sedimentary succession is of Permo-Carboniferous to earliest Cretaceous age and up to 12 000 m thick. Apart from young Cenozoic deposits, the onshore succession post-dating the Valanginian separation of Western Australia and Greater India has been removed by erosion. Farther south, post-breakup Cretaceous deposits are typically thin onshore but thicken dramatically offshore. Older strata in the northern Perth Basin are restricted to a few small outcrops of the Ordovician–Silurian Tumblagooda Sandstone adjacent to the Northampton Complex and in the Coolcalalaya Sub-basin — the best exposures of this unit are in the Southern Carnarvon Basin along coastal cliffs and the Murchison River gorge near Kalbarri (Hocking, 1991). The only fossil evidence for other Paleozoic rocks older than Permo-Carboniferous glacial facies in the Perth Basin is from the Coolcalalaya Sub-basin. There, rare, poorly preserved Devonian fish plates are present in petroleum well core (Allen and Trinajstic, 2017) and Devonian – Early Carboniferous palynomorphs have been extracted from shallow bores (Mory et al., 1998). Reworked Devonian spores in the uppermost Jurassic on the eastern edge of the Dandaragan Trough (Ingram, 1967; Backhouse, 1993) presumably were derived from that sub-basin.

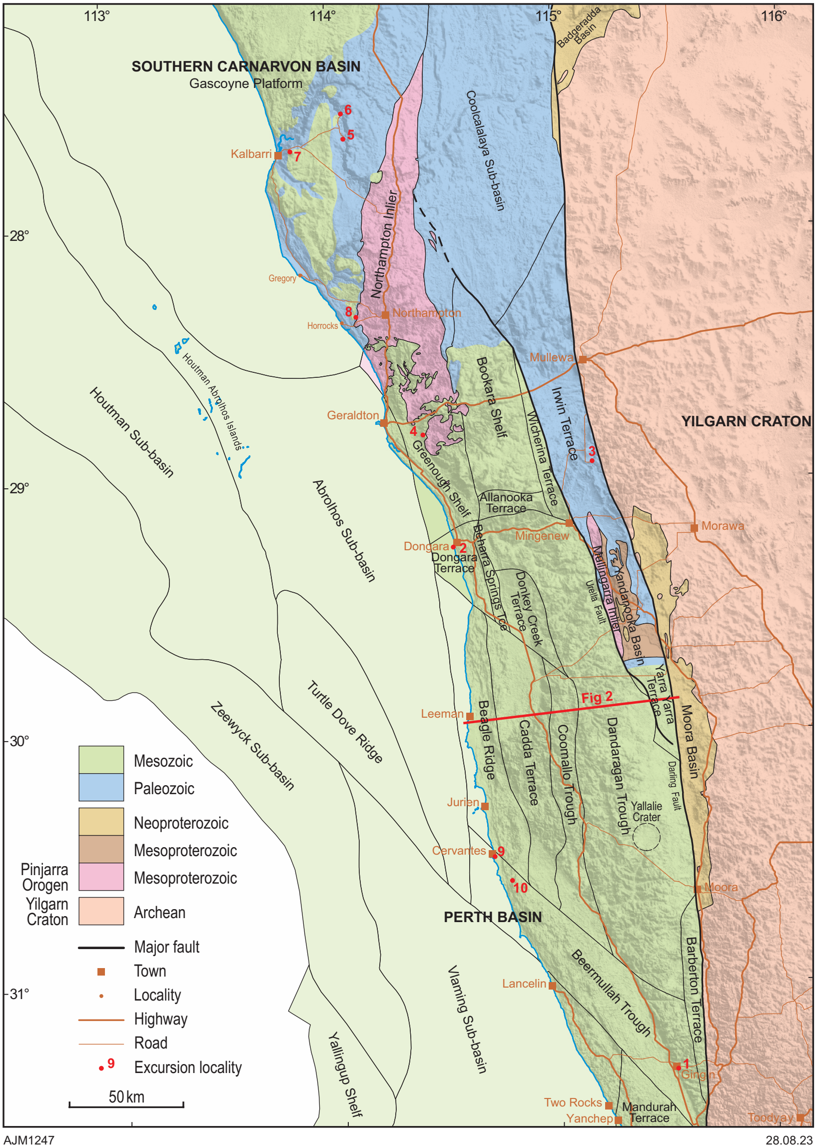

Figure 1. Tectonic subdivisions of the northern Perth Basin showing numbered localities visited and location of Figure 2 (from GeoVIEW.WA, superimposed on digital elevation)

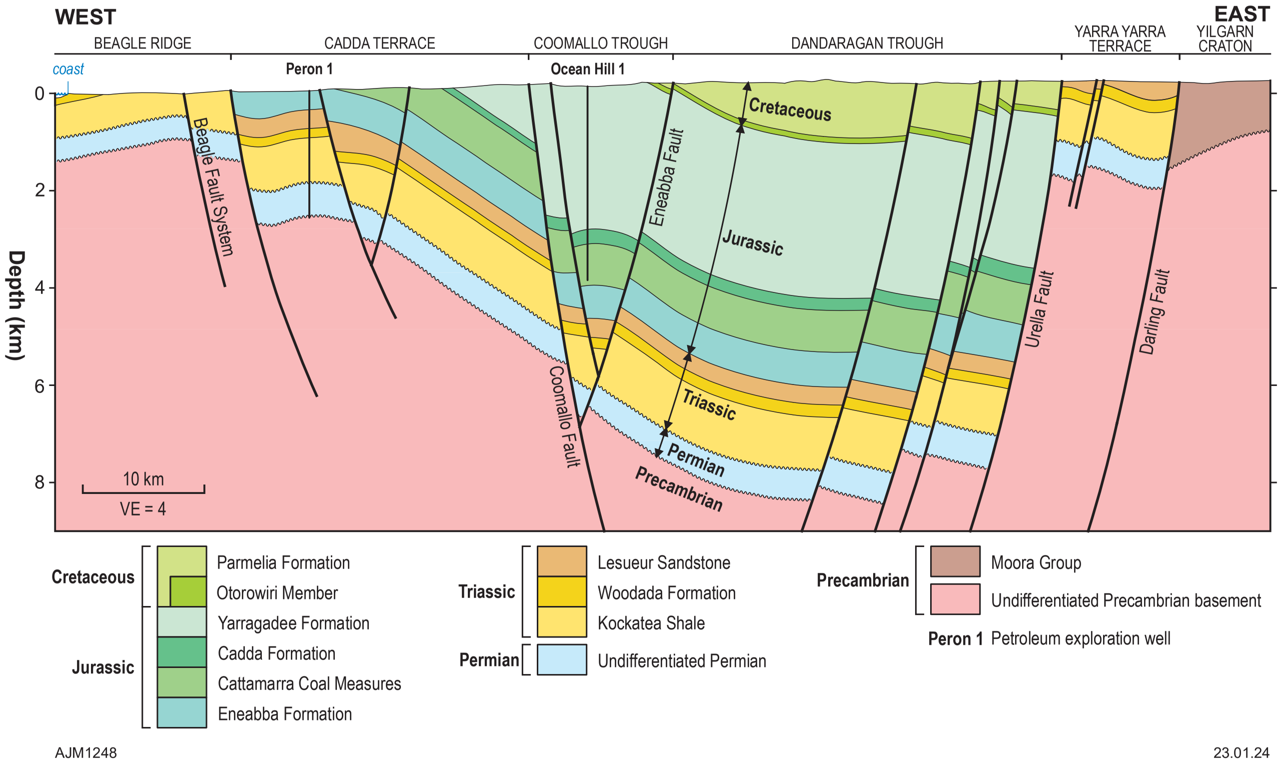

Figure 2. Representative east–west cross-section of the northern Perth Basin (location shown in Fig. 1; from Mory and Iasky, 1996, plate 11, section E–E)

The onshore northern Perth Basin succession (Fig. 3) contains:

- **Ordovician–Silurian** coastal to fluvial siliciclastic facies of the Tumblagooda Sandstone
- **upper Pennsylvanian to lower Permian** predominantly argillaceous, fluvio-glacial, deltaic and marine facies
- **upper Permian** non-marine and shoreline siliciclastics to shallow-water carbonates
- **Triassic to lowermost Cretaceous** non-marine siliciclastics with shallow-marine facies restricted to the lowermost Triassic and Middle Jurassic
- **Cretaceous** post-breakup, dominantly marine facies, south of Moora–Cataby
- **Cenozoic** surficial deposits, mostly restricted to the Swan Coastal Plain.

Overall, the Triassic and Jurassic thicken to the south along the onshore axis of the basin whereas the Permian appears to thin southwards. In the north, the Northampton Complex was a positive feature during the Middle Triassic to Early Jurassic. Substantial thickening of the Middle Jurassic to Lower Cretaceous succession southwards into the Dandaragan Trough suggests rifting began in the Bajocian. Analysis of structural trends indicates that pre-existing basement fabric largely determined the pattern of faulting during Phanerozoic tectonic phases. The following lists the broad onshore tectonostratigraphic succession of stacked depocentres (in ascending stratigraphic order):

- **Ordovician to Early Carboniferous broad interior sag** with alternating sand-dominated and carbonate-dominated formations. This succession is mostly missing in the Perth Basin but is preserved in the adjacent Southern Carnarvon Basin where the eastern boundary onlaps Precambrian metamorphic basement. The western part of that basin was truncated during Early Cretaceous continental breakup.
- **Late Carboniferous – Permian interior rift** deposited a 5 km-thick sedimentary succession in the Merlinleigh Sub-basin (Southern Carnarvon Basin) compared to about half that thickness along the Irwin Terrace (northern Perth Basin). The Permian depocentres are superimposed on broader earlier Paleozoic basins or lie on Precambrian basement. Isopach maps of Permian formations in the northern Perth Basin show distinct changes from an Asselian–Sakmarian half-graben controlled by the Darling–Urella Fault, followed by an Artinskian sag-phase centred on the northern Dandaragan Trough (Eyles et al., 2006, fig. 4) and a return to a half-graben in the late Permian (Mory and Iasky, 1996, fig. 13). Whereas Permian deposition may have extended farther east, strata of that age on the eastern Precambrian

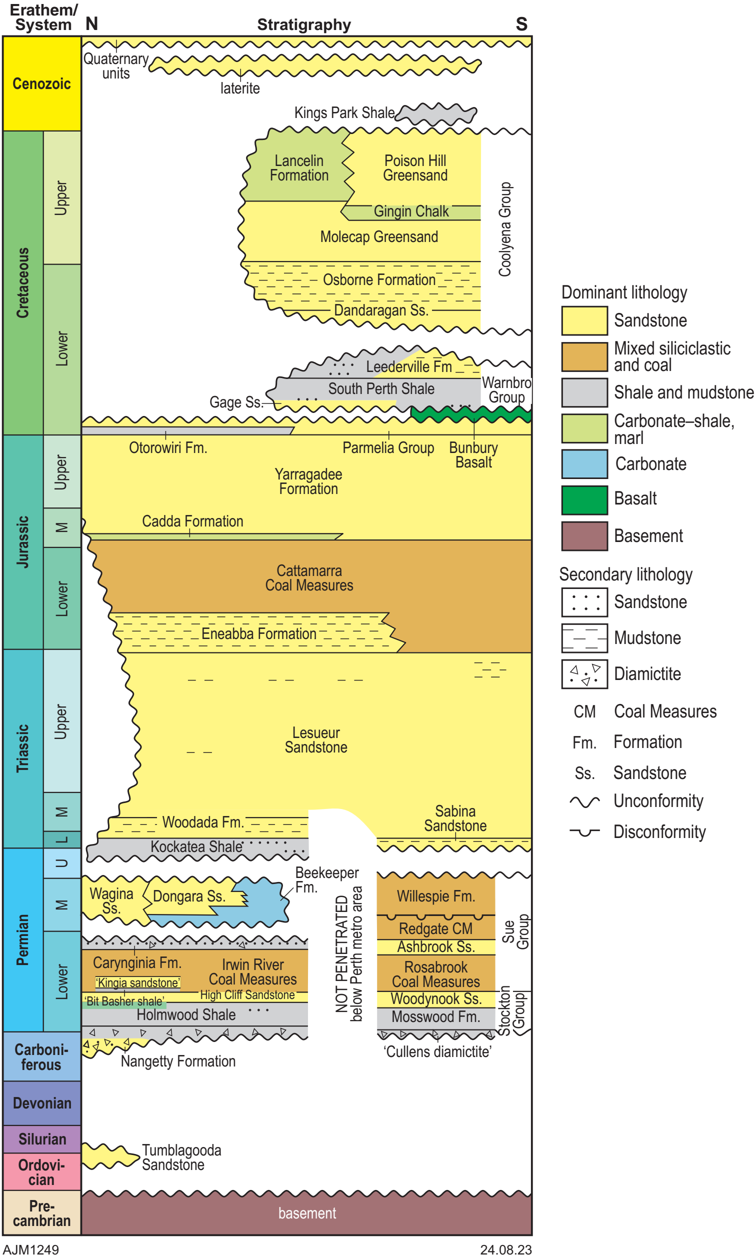

Figure 3. Stratigraphic summary for the Perth Basin

terranes are rare, with the best example at Collie, 200 km south of Perth (see Veevers et al., 2005, for speculation on the extent of Permian cover on the Archean Yilgarn Craton, and Mory et al., 2023, for a discussion of the age of the glacial succession).

- **Triassic–Jurassic pre-rift and syn-rift** in the northern Perth Basin included a rapid regression to fluvial conditions following the Early Triassic, with a minor, but extensive, marine transgression in the Middle Jurassic marking the change from pre-rift to syn-rift facies. Near Geraldton, the Middle Triassic to Lower Jurassic is absent whereas, to the south, deposition of several kilometres of mostly siliciclastic facies was apparently continuous. The low maturity of the Lower Triassic near Geraldton suggests non-deposition rather than significant erosion in that area.
- **Cretaceous (Hauterivian and younger) to Cenozoic passive-margin** deposits in the northern Perth Basin are thin onshore, where they are mostly preserved south of 31° S. Arguably, the Cenozoic should not be included within the basin as such deposits formed dominantly in response to relative sea-level changes rather than overtly tectonic influences.

Because of the administration associated with resource exploration licensing, the sedimentary basins of Western Australia are classified utilizing geography and the present structural configuration rather than stacked basins. Thus, Phanerozoic basins in the state are portrayed as extending from the present surface down to Precambrian, usually metamorphic or granitic, basement, totally ignoring changes in depositional style and major breaks (Mory, 2023, p. 3–13).

References

Allen, HJ and Trinajstic, K 2017, An Early Devonian fish fauna from an unnamed sandstone in Wendy 1 drillhole, northern Perth Basin: Geological Survey of Western Australia, Paleontology Report 2017/1, 4p.

Backhouse, J 1993, Palynology and correlation of Permian sediments in the Perth, Collie, and Officer Basins, Western Australia, *in* Professional Papers: Geological Survey of Western Australia, Report 34, p. 111–128.

Crostella, A 2001, Geology and petroleum potential of the Abrolhos Sub-basin, Western Australia: Geological Survey of Western Australia, Report 75, 57p.

Crostella, A and Backhouse, J 2000, Geology and petroleum exploration of the central and southern Perth Basin, Western Australia: Geological Survey of Western Australia, Report 57, 85p.

Eyles, N, Mory, AJ and Eyles, CH 2006, 50-million-year-long record of glacial to post-glacial environments preserved in a Carboniferous – lower Permian graben, Northern Perth Basin, Western Australia: Journal of Sedimentary Research, v. 76, no. 3, p. 618–632, doi: 10.2110/jsr.2006.047.

Hocking, RM 1991, The Silurian Tumblagooda Sandstone, Western Australia: Geological Survey of Western Australia, Report 27, 124p.

Ingram, BS 1967, Palynology of the Otorowiri Siltstone Member, Yarragadee Formation, *in* Annual report for the year 1966: Geological Survey of Western Australia, Perth, Western Australia, p. 79–83.

Mory, AJ (compiler) 2023, Mesozoic transformation of Western Australia: rifting and breakup of Gondwana: Geological Survey of Western Australia, Unearthed Series, 73p.

Mory, AJ, Crowley, J, Backhouse, J, Nicoll, RS and Gorter, JD 2023, Early Permian zircon ages from the *P. confluens* and *P. pseudoreticulata* spore-pollen zones in the southern Bonaparte and Canning basins, northwestern Australia: Australian Journal of Earth Sciences, v. 70, no. 4, p. 494–509, doi:10.1080/08120099.2023.2185676.

Mory, AJ and Haig, DW 2011, Permian–Carboniferous geology of the northern Perth and Southern Carnarvon Basins, Western Australia — a field guide: Geological Survey of Western Australia, Record 2011/14, 65p.

Mory, AJ, Haig, DW, McLoughlin, S and Hocking, RM 2005, Geology of the northern Perth Basin, Western Australia — a field guide: Geological Survey of Western Australia, Record 2005/9, 71p.

Mory, AJ and Iasky, RP 1996, Stratigraphy and structure of the onshore northern Perth Basin, Western Australia: Geological Survey of Western Australia, Report 46, 101p.

Mory, AJ, Iasky, RP and Shevchenko, SI 1998, The Coolcalalaya Sub-basin: a forgotten frontier 'between' the Perth and Carnarvon Basins, WA, *in* The sedimentary basins of Western Australia 2: Proceedings of the West Australian Basins Symposium *edited by* PG Purcell and RR Purcell: West Australian Basins Symposium, Perth, Western Australia, 30 August – 2 September 1998: Petroleum Exploration Society of Australia, p. 613–622.

Thomas, CM 2014, The tectonic framework of the Perth Basin: Current understanding: Geological Survey of Western Australia, Record 2014/14, 36p.

Veevers, JJ, Saeed, A, Belousova, EA and Griffin, WL 2005, U–Pb ages and source composition by Hf-isotope and trace element analysis of detrital zircons in Permian sandstone and modern sand from southwestern Australia and a review of the paleogeographical and denudational history of the Yilgarn Craton: Earth Science Reviews, v. 68, no. 3–4, p. 245–279, doi:10.1016/j.earscirev.2004.05.005.

Locality 1: Molecap Quarry, Gingin

Background

Cretaceous sedimentary deposits in the northern Perth Basin mostly belong to the Albian–Maastrichtian Coolyena Group (Table 1) and outcrop along the Gingin Scarp and Dandaragan Plateau. Dips are near-horizontal and exposures are poor, even near Gingin where this succession was first mapped (Fig. 4). The better outcrops are mostly confined to gullies cut into the scarp. Only the Gingin Chalk contains fossils that allow a direct correlation to the standard chronostratigraphic scale. McNamara et al. (1993) provides a comprehensive set of illustrations of Gingin Chalk macrofossils. The Osborne Formation, Molecap Greensand and Poison Hill Greensand contain dinocyst and spore-pollen assemblages in the subsurface that allow correlation via a widely used palynomorph zonation outlined by Helby et al. (1987).

Table 1. Cretaceous stratigraphy (Coolyena Group), Gingin area

Age	*Formation*	*Thickness*	*Main features*	*Environment*
mid-Santonian–Maastrictian	Lancelin Formation	up to 120 m	chalk laterally equivalent to the Poison Hill Greensand plus Gingin Chalk; known only from the subsurface west of Gingin	mid- to inner neritic
mid-Campanian–Maastrictian	Poison Hill Greensand	up to 54 m	massive, bioturbated and cross-bedded quartz and glauconitic sandstone	shallow marine
upper Santonian – lower Campanian	Gingin Chalk	21 m	fossiliferous, bioturbated chalk, locally glauconitic	mid-neritic
Cenomanian – lower Santonian	Molecap Greensand	10–12 m	massive quartz and glauconitic sandstone; unconformable on Warnbro Group in outcrop	shallow marine
Albian–Cenomanian	Osborne Formation	60–180 m	glauconitic sandstone, siltstone and claystone; unconformable on Warnbro Group; present in subsurface east of main outcrops near Gingin	shallow marine

Description

The quarry is the type section of the Molecap Greensand in which flat-lying greensand and glauconitic sandstone with phosphate (apatite, dufrenite

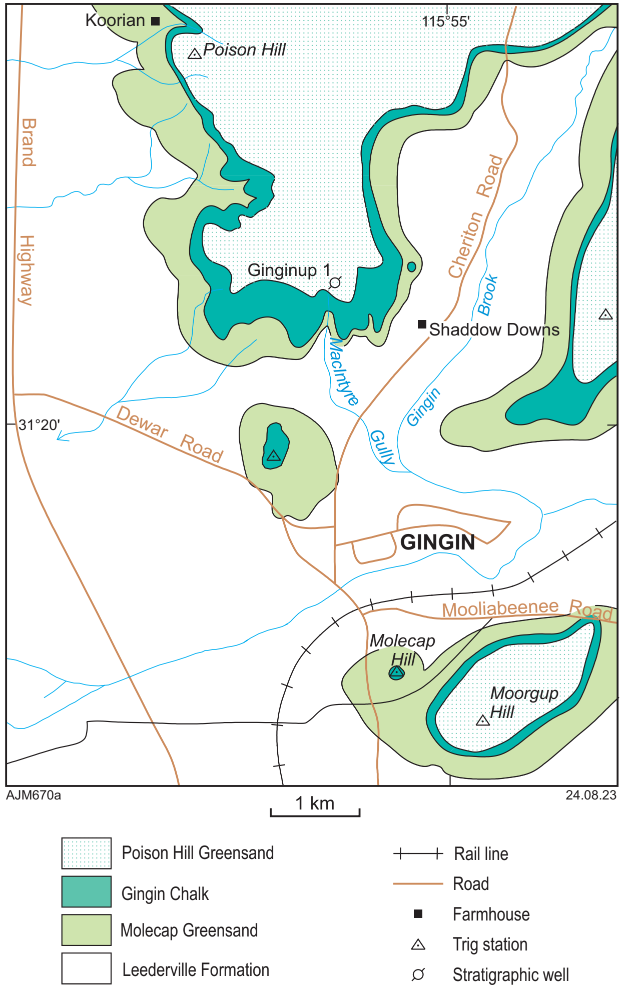

Figure 4. Pre-Cenozoic geology of the Gingin area (after Feldtmann, 1963)

and vivianite) nodules near the top (Marston, 1975) are exposed. Excavation spanned 1932–1962, when 32 000 tons [32 513.5 tonnes] of greensand was extracted to produce 6467 tons [6571 tonnes] of glauconite concentrate for use as a water-softening agent (Low, 1971).

The greensand consists of an unusual admixture of coarse quartz and medium to coarse glauconite grains. Carroll (1941) suggested the heavy mineral assemblage came from the Chittering Valley, a tributary of Gingin Brook. About 18 m of fossiliferous, friable, slightly glauconitic Gingin Chalk disconformably overlies the Molecap Greensand near this locality, but only about one metre is exposed on the southern edge of the quarry (Fig. 5a,b). The only macrofossils known from the greensand are from two 60 cm-thick, phosphate-rich nodule beds near the top and floor of the quarry, and include a theropod dinosaur pedal phalanx (Long, 1995), pterosaur jaw fragments (Kear et al., 2010) and rare shark teeth and bones. The lower nodule bed at the base of the quarry is no longer exposed.

Kear et al. (2005, p. 308) indicate that:

> Macrofossils are sporadic throughout the Molecap Greensand but include fragmentary remains of mosasaurs, plesiosaurs, selachians, chimaeroids, teleost fish and dinosaurs. Isolated, probably reworked ichthyosaur material is also known from the basal part of the sequence. Invertebrates are uncommon (an artefact of poor preservation), and only a handful of benthic molluscan taxa have been identified.

However, their statement encompasses several other exposures apart from Molecap Hill. In contrast, Feldtmann (1963, p. 102), referring to the quarry, specified that:

> … the top of the greensand, a band, from about 3 to 30 inches [~8–76 cm] thick, of dark reddish brown ferruginous material, with phosphatic nodules up to about 8 inches [20 cm] in diameter as well as rare bone fragments and other fossils, separates it from the overlying chalk.

Mikael Siversson (Western Australian Museum, June 2023) confirms that this level near the top has bone fragments, although the phosphatic nodules he has seen are black and relatively small. However, locating this bed may be difficult because the upper part of the exposure has deteriorated.

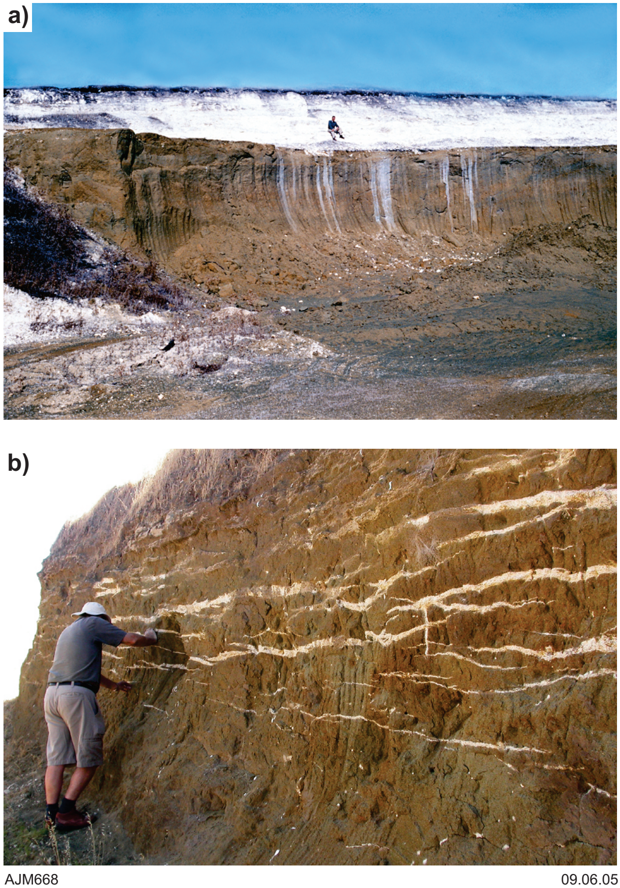

Figure 5. Molecap Greensand, Molecap Hill quarry, Gingin: a) southern face showing contact with Gingin Chalk (photograph from the Australian Heritage Photographic Library, taken by TE Perrigo in 1987); b) eastern face showing veins parallel to topography and minor vertical rootlets filled with chalk.

Nearby drilling indicates the Molecap Greensand is about 11 m thick (Low, 1965). The sparse palynomorphs recovered from that material indicated only a general Cretaceous age (Edgell, 1964c). By comparison, the assemblage of dinocysts that Deflandre and Cookson (1955) described from 'Gingin, Molecap Hill, Lower Greensand' includes '*Paleohystrichophora multispina*' (now *Diconodinium multispinum*) and '*Hystrichosphaeridium striatoconus*' (now *Conosphaeridium striatoconum*). *D. multispinum* is the index for the eponymous Cenomanian zone but the species also ranges into the Turonian, whereas *C. striatoconum* is the index for, and is confined to, the Coniacian zone of that name (Helby et al., 1987), thereby indicating mixing of at least Cenomanian through Coniacian in Deflandre and Cookson's (1955) material, as well as terrestrial plant and marine plankton. Marshall (1984) similarly recovered Cenomanian to Coniacian palynomorphs from this unit in Ginginup 1. This mixed fauna, as well as the mixture of terrestrial and marine vertebrates, and quartz and glauconite grains, has been attributed to slumping induced by the Yallalie impact 110 km to the north (Mory et al., 2005, p. 55); however, it is uncertain if the impact structure is the same age as the greensand (Mory, 2023, p. 60).

Foraminiferal correlations indicate that the base of the Gingin Chalk at Molecap Quarry is younger than the base of the formation at the type section in MacIntyre Gully. It correlates to a level about 10 m above the formation base in that section, indicating almost all of the Santonian part of the chalk is missing at Molecap Hill. Although only a small part of the chalk is exposed at this locality, Feldtmann (1963, p.106) found that it:

> … has proved rich in all the commoner fossils and single specimens of species not found elsewhere have been found here. These include a single valve of *Crania* sp., a small rhynchonellid unlike those of McIntyre Gully, and a small conical coral.

References

Carroll, D 1941, Heavy residues from some Upper Cretaceous sediments at Gingin, Western Australia: Journal of Sedimentary Petrology, v. 11, p. 85–91, doi:10.2110/JSR.11.85.

Deflandre, G and Cookson, IC 1955, Fossil microplankton from Australian late Mesozoic and Tertiary sediments: Australian Journal of Marine and Freshwater Research, v. 6, p. 242–313, doi:10.1071/MF9550242.

Edgell, HS 1964, Palynological examination of samples from CSIRO Gingin Glauconite Holes No. 3, No. 4, & No. 5: Western Australia Geological Survey Palaeontological Report 1964/19, 5p. (unpublished).

Feldtmann, FR 1963, Some pelcypods from the Cretaceous Gingin Chalk, Western Australia, together with descriptions of the principal chalk exposures: Journal of the Royal Society of Western Australia, v. 46, no. 4, p. 101–125, article no. 15, <https://www.biodiversitylibrary.org/part/172269>.

Helby, R, Morgan, R and Partridge, AD 1987, A palynological zonation of the Australian Mesozoic: Association of Australasian Palaeontologists, Memoir 4, p. 1–94.

Kear, BP, Long, JA and Martin, JE 2005, A review of Australian mosasaur occurrences: Netherlands Journal of Geosciences — Geologie en Mijnbouw, v. 84, no. 3, p. 307–313, doi:10.1017/S0016774600021089.

Kear, BP, Deacon, GL and Siverson, M 2010, Remains of a Late Cretaceous pterosaur from the Molecap Greensand of Western Australia: Alcheringa, v. 34, no. 3, p. 273–279, doi: 10.1080/03115511003661651.

Long, JA 1995, A theropod dinosaur bone from the Late Cretaceous Molecap Greensand, Western Australia: Records of the Western Australian Museum, v. 17, p. 143–146.

Low, GH 1965, Drilling of Upper Cretaceous glauconite deposits at Dandaragan, Gingin, and Bullsbrook: Western Australia Geological Survey, Record 1965/6, 17p.

Low, GH 1971, Explanatory notes on the Phanerozoic rocks of the Perth 1:250 000 geological sheet, Western Australia: Western Australia Geological Survey, Record 1971/24, 33p.

Marshall, NG 1984, Late Cretaceous dinoflagellates from the Perth Basin, Western Australia: The University of Western Australia, Perth, Western Australia, PhD thesis (unpublished), 428p.

Marston, RJ 1975, Field excursion to the Swan Coastal Plain, Dandaragan and Darling Plateau north of the Swan River: Geological Society of Australia, Western Australian Division, 4p.

McNamara, KJ, Friend, D and Long, JA 1993, A guide to the fossils of the Gingin Chalk (2nd edition): Western Australian Museum, Perth, 16p.

Mory, AJ 2023, Mesozoic transformation of Western Australia: rifting and breakup of Gondwana: Geological Survey of Western Australia, Perth, Western Australia, Unearthed Series, 73p.

Mory, AJ, Haig, DW, McLoughlin, S and Hocking, RM 2005, Geology of the northern Perth Basin, Western Australia — a field guide: Western Australia Geological Survey, Record 2005/9, 71p.

Locality 2: Leander Point, Port Denison

Background

The Dongara area contains a moderately complete lower Permian to Upper Jurassic succession in the subsurface (Mory and Iasky, 1996), which hosts several gasfields and oilfields. Outcrop near Dongara is limited to Cenozoic units and the Middle–Upper Jurassic Yarragadee Formation east of the Gingin Scarp. Cenozoic units, which cover much of the area along the coast, are mostly of Holocene age, and the Pleistocene Tamala Limestone, which extends inland up to 20 km, and ferruginous duricrust of probable Miocene age east of the Gingin Scarp.

Some of the southernmost coral–algal reefs on the Western Australian continental shelf, with well-developed *Acropora*-dominated platform reefs, are in the Houtman Abrolhos islands at 28–29° S, offshore from Geraldton (Collins et al., 1993). During the last interglacial period, these reefs extended south (to at least Rottnest Island at 32° S; Playford, 1988), implying the south-flowing Leeuwin Current brought warmer waters farther south at that time. Hatcher (1991) examined the influence of the Leeuwin Current on the distribution of coral reefs along the coast, but questioned whether sea temperature was the dominant influence on reef growth in the region:

> … the Leeuwin Current's role in maintaining apparently low rates of nutrient delivery to the benthos, in combination with its elevation of sea temperature and advection of planktonic spores and larvae, serves to inhibit the development of marine macrophyte communities, which compete effectively with coral reef-building communities.

Hatcher (1991) indicates a minimum mean monthly sea-surface temperature at the Houtman Abrolhos of 19.8 °C (with an absolute minimum of 17.6 °C); at Dongara, the minimum mean monthly sea-surface temperature is 18.5°C.

Description

On the south side of the point, a low coastal cliff exposes coral reef and aeolian facies of the Pleistocene Tamala Limestone. First noted by Hartmeyer (1907) and briefly described by Teichert (1946, p 183) and mentioned by Fairbridge (1950, p. 338, 351), the Pleistocene reef forms a low cliff up to 2.5 m above sea level (Fig. 6). The reef incorporates boundstones of branching Acropora in a shelly calcarenite–calcirudite matrix (Fig. 7a), and large palmate Acropora bound by coralline algae and shelly calcarenite–calcirudite (Fig. 7b).

AJM662 11.05.05

Figure 6. Sea cliff in Pleistocene coral reef, Leander Point

According to Fairbridge (1950), the outcrop contains:

> … reef-building corals (*Acropora*, *Platgyra*, *Favites*, etc.), and encrusting *Lithothamnion* layers. In parts of the reef, the lithothamnoids make up 80% of the volume, but, in general, they form the upper part of the reef, corresponding to the former shallowest-water zone.

The shelly calcarenite–calcirudite in the upper part of the exposure represents a drowning of the reef facies. The platform reef is similar to the present-day reef at the Houtman Abrolhos about 100 km to the west-northwest of Leander Point near the edge of the continental shelf. The exposure is disrupted by solution pipes that appear to have a thin, microbially cemented lining that extends onto the upper surface of the shelly facies.

Stirling et al. (1995) dated a faviid coral from this outcrop at about 122–127 ka using the U-series method, matching their analysis of similar facies on Rottnest Island. Their age is close to those from corals in a similar *Acropora*-dominated reef facies at Cape Burney, about 40 km north of Leander Point, for which Johnson et al. (1995) obtained dates of 120–132 ka using electron spin resonance whereas Stirling et al. (1998) obtained ^{230}Th ages spanning 121.7 to 123.5 ± 0.5 ka. The Leander Point, Cape Burney and Rottnest Island Pleistocene reefs are at about the same height above the present sea level, indicating a relatively uniform change in sea level since then.

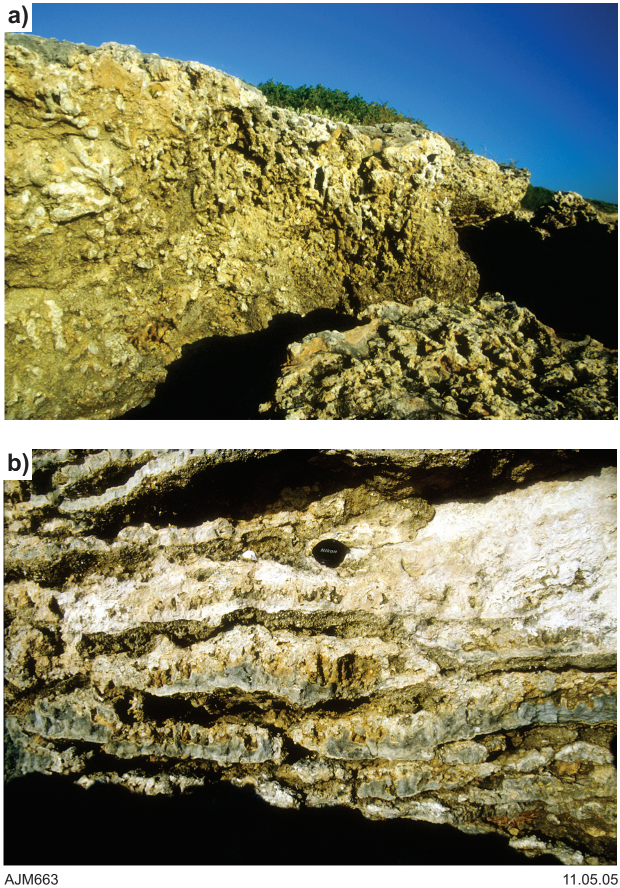

Figure 7. Pleistocene coral facies, Leander Point: a) bafflestone formed of branching *Acropora*; b) bindstone formed of palmate *Acropora*

References

Collins, L, Zhu, Z, Wyrwoll, K-H, Hatcher, B, Playford, P, Chen, J, Eisenhauer, A and Wasserburg, G 1993, Late Quaternary evolution of coral reefs on a cool-water carbonate margin: the Abrolhos Carbonate Platforms, southwest Australia: Marine Geology, v. 110, no. 3–4, p. 203–212, doi:10.1016/0025-3227(93)90085-A.

Fairbridge, RW 1950, Recent and Pleistocene coral reefs of Australia: Journal of Geology, v. 58, no. 4, p. 330–401, doi:10.1086/625751.

Hartmeyer, R 1907, Reisebericht 2. Teil, *in* Die Fauna südwest-Australiens: Ergebnisse der Hamburger südwest-australienische Forschungsreise 1905, Band 1, Lieferung 1 *compiled by* W Michaelson and R Hartmeyer: Verlag von Gustav Fischer, Jena, p. 59–108.

Hatcher, BG 1991, Coral reefs in the Leeuwin Current – an ecological perspective, *in* The Leeuwin Current: an influence on the coastal climate and marine life of Western Australia *edited by* AF Pearce and DI Walker: Journal of the Royal Society of Western Australia v. 74, p. 115–127, <https://www.biodiversitylibrary.org/part/299049>.

Johnson, ME, Baarli, BG and Scott, JH 1995, Colonisation and reef growth on a Late Pleistocene rocky shore and abrasion platform in Western Australia: Lethaia, v. 28, no. 1, p. 85–98, doi:10.1111/j.1502-3931.1995.tb01596.x.

Mory, AJ and Iasky, RP 1996, Stratigraphy and structure of the onshore northern Perth Basin, Western Australia: Western Australia Geological Survey, Report 46, 101p.

Playford, PE 1988, Guidebook to the Geology of Rottnest Island: Geological Society of Australia (WA Division) and the Geological Survey of Western Australia, 67p.

Stirling, CH, Esat, TM, Lambeck, K and McCullock, MT 1998, Timing and duration of the Last Interglacial: evidence for a restricted interval of widespread coral reef growth: Earth and Planetary Science Letters, v. 160, no. 3–4, p. 745–762, doi:10.1016/S0012-821X(98)00125-3.

Stirling, CH, Esat, TM, McCullock, MT and Lambeck, K 1995, High-precision U-series dating of corals from Western Australia and implications for the timing and duration of the last interglacial: Earth and Planetary Science Letters, v. 135, no. 1–4, p. 115–130, doi:10.1016/0012-821X(95)00152-3.

Teichert, C, 1946, Contributions to the geology of Houtman's Abrolhos, Western Australia: Proceedings of the Linnean Society, New South Wales, v. 71, p. 145–196.

Locality 3: Fossil Cliff, Irwin River

Background

Permian sedimentary rocks form well-known exposures in the northern part of the Perth Basin adjacent to the Yilgarn Craton between the Darling and Urella Faults, and are widespread in the subsurface west of the latter fault. The succession comprises mixed marine and continental deposits that locally probably exceed 2600 m in thickness (Playford et al., 1976), and typically rest unconformably on Precambrian metamorphic or plutonic rocks, and Ordovician and ?Devonian strata farther north.

The lower Permian succession consists of glacigene facies of the Nangetty Formation overlain by the Holmwood Shale containing local, cool-water, richly fossiliferous shallow-marine carbonate facies (including the Fossil Cliff Member), followed by siliciclastic shoreface to marginal-marine deposits (High Cliff Sandstone), fluvial–deltaic facies (Irwin River Coal Measures) and restricted-marine facies (Carynginia Formation). The exact age of, and relationship with, the overlying Permian fluvial facies (the Wagina Sandstone) is poorly constrained.

The Holmwood Shale contains thick grey–green shale and thin limestone beds in the lower part, passing transitionally into grey–black micaceous, jarositic and gypsiferous shale and siltstone with minor discontinuous beds of cross-laminated fine sandstone and uppermost coquinite of the Fossil Cliff Member. The shale and siltstone facies are poorly fossiliferous, with cryptostomate bryozoans commonly the only macrofauna. Palynological and invertebrate faunal assemblages are assigned a Sakmarian age (Segroves, 1970; Playford et al., 1976; Archbold, 1998). Lithologies, sedimentary structures, and fossils representative of this formation reflect chiefly cool-water, low-energy marine depositional environments. Fossiliferous limestone lenses probably represent localized methane seeps (Haig et al., 2022) or well-aerated shallow-marine banks.

Description

Fossil Cliff, the type section of the eponymous member, consists of interbedded dark micaceous and gypsiferous siltstone, sandy siltstone, shale and bioclastic calcarenite forming a series of coarsening-upwards parasequences (Figs 8, 9). The carbonate beds are lenticular and the member outcrops sporadically between Fossil Cliff and a point 16 km to the south. The skeletal component of the limestone beds is diverse though fragmentary, whereas the siltstones host less-diverse macrofaunas preserved mostly as moulds. Ferdinando (2002) attributed changes in lithology and fossil content to sea-level fluctuations and high to low variations in terrigenous input.


AJM1250 10.08.23

Figure 8. General view of Fossil Cliff looking west

The age of the Fossil Cliff Member is Sakmarian (either late Tastubian or Sterlitamakian), with the most compelling evidence within the unit being a single specimen of the ammonoid *Metalegoceras kayi* from this section (Glenister et al., 1973). Southeastwardly steepening dips in Fossil Cliff may be the result of rotation along a normal fault (possibly controlling the river course) because there is a minor normal fault dipping steeply to the northwest on the opposite side of the river. At High Cliff on the south side of the river, the Fossil Cliff Member is absent with a locally sharp contact between grey siltstone of the Holmwood Shale and white and red, feldspathic, cross-bedded and bioturbated sandstone of the High Cliff Sandstone.

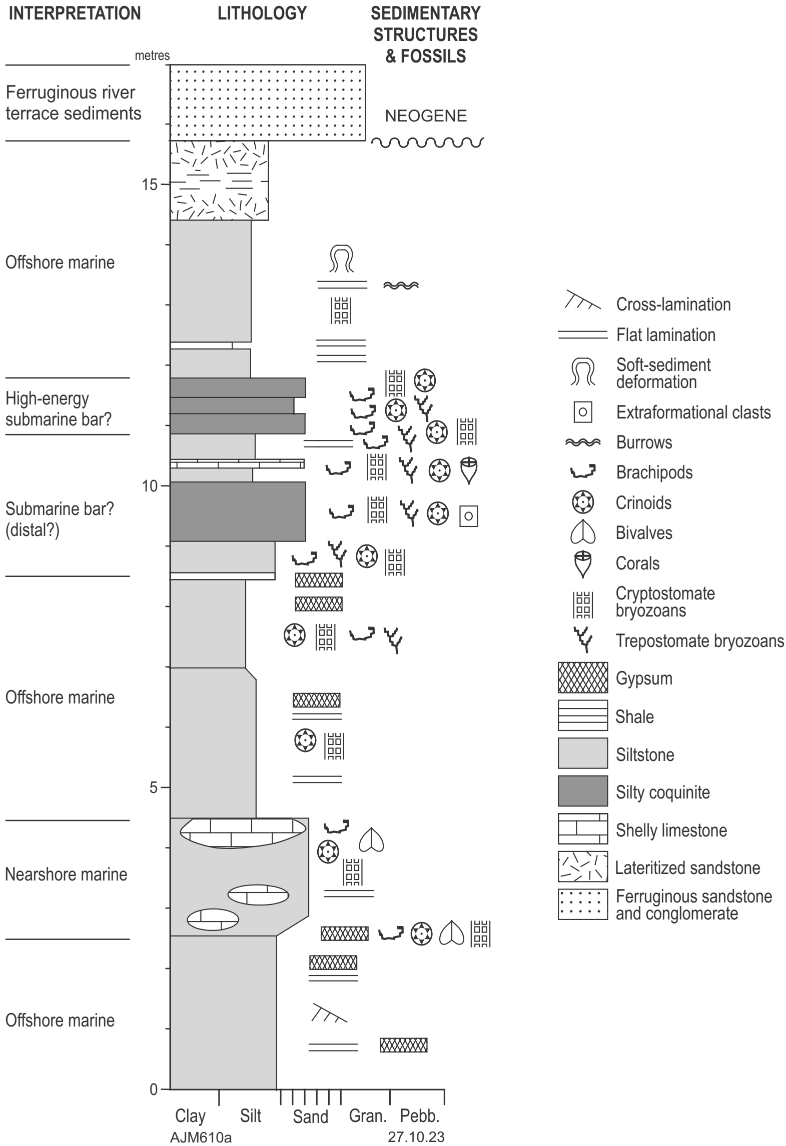

Figure 9. Measured section, Fossil Cliff, Irwin River (after McLoughlin in Haig et al., 1991)

References

Archbold, NW 1998, Marine biostratigraphy and correlation of the West Australian Permian basins, *in* The sedimentary basins of Western Australia 2: Proceedings of the West Australian Basins Symposium *edited by* PG Purcell and RR Purcell: West Australian Basins Symposium, Perth, Western Australia, 30 August – 2 September 1998: Petroleum Exploration Society of Australia, p. 141–151.

Ferdinando, DD 2002, Foraminiferal assemblages in the Fossil Cliff Member of the Holmwood Shale, northern Perth Basin, *in* Geological Survey of Western Australia Annual Review 2000–01: Geological Survey of Western Australia, p. 53–57.

Glenister, BF, Windle, DL Jr and Furnish, WM 1973, Australasian Metalegoceratidae (Lower Permian ammonoids): Journal of Palaeontology, v. 47, no. 6, p. 1031–1043, <https://www.jstor.org/stable/1303164>.

Haig, DW, Dillinger, A, Playford, G, Riera, R, Sadekov, A, Skrzypek, G, Håkansson, E, Mory, AJ, Peyrot, D and Thomas, C 2022: Methane seeps following Early Permian (Sakmarian) deglaciation, interior East Gondwana, Western Australia: multiphase carbonate cements, distinct carbon-isotope signatures, extraordinary biota: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 591, doi:10.1016/j.palaeo.2022.110862.

Haig, DW, Ferdinando, DD, Jones, PJ, Logan, BW, Lynch, D, McLoughlin, S, Malz, H, Oertli, HJ and Neal, JW 1991, Guide to pre-symposium excursion A3: Northern Perth Basin and Southern Carnarvon Basin: Eleventh International Symposium on Ostracoda, Warrnambool, Victoria, Australia (unpublished).

Playford, PE, Cockbain, AE and Low, GH 1976, Geology of the Perth Basin, Western Australia: Western Australia Geological Survey, Bulletin 124, 311p.

Segroves, KL 1970, The sequence of palynological assemblages in the Permian of the Perth Basin, Western Australia, *in* Proceedings and papers *edited by* SH Haughton: Second Gondwana Symposium, University of Cape Town and University of the Witwatersrand, Johannesburg, July–August 1970: Council for Scientific and Industrial Research, Pretoria, South Africa, p. 511–529.

Locality 4: Shale quarry, Glengarry Station

Background

Flat-lying Triassic and Jurassic sedimentary deposits unconformably overlie paragneiss of the Northampton Complex east and north of Geraldton, although Triassic outcrops are rare. Northeast of the quarry, the Lower Triassic Kockatea Shale has a 25 cm-thick basal conglomerate and pebbly sandstone (not exposed in the quarry) unconformably overlying gneiss of the Northampton Complex. Of the 15–20 m of mudstone overlying the basal conglomerate, only the upper ~11 m is exposed in the quarry (Fig. 10).

AJM1251 17.08.23

Figure 10. Overview of Glengarry Quarry

Description

The base of the quarry exposes the only unweathered Lower Triassic Kockatea Shale known in outcrop and the quarry walls expose part of the formation beneath unconformably overlying Jurassic units. The shale contains a mixed shallow-marine and terrestrial fossil assemblage (Haig et al., 2015). Nearby exposures of granite indicate the Lower Triassic directly overlies Precambrian basement. Correlation of outcrop gamma, measured along the walls of the quarry, to the nearest petroleum wells suggests significant onlap onto basement such that the lowermost part of the Triassic is missing.

In the quarry, a progradational trend is evident up-section with increasing sand content (including an increase in grain size and bed thickness). The sandstone beds display cross-lamination, although this is difficult to see with increasing weathering towards the top of the section. The unweathered dark grey and laminated shale at the base of the quarry section is carbonaceous and pyritic (Fig. 11). Some of the shale totally disaggregates in contact with water.

Figure 11. Carbonaceous facies of the Kockatea Shale near base of Glengarry Quarry

On weathered surfaces of the shale, a dull grey mottling is due to gypsum growth as the shale dries with present-day exposure. Very weathered ferruginized coarse sandstone, attributed to the Lower Jurassic Greenough Sandstone of the Chapman Group, unconformably overlies the Kockatea Shale in the quarry with an irregular contact (Fig. 10).

The fossil assemblage from the shale in the quarry described by Haig et al. (2015) includes fern-like leaves, probable scales from seed-cones, rare insects (including a cockroach wing), vertebrate bone and a jaw (possibly from an amphibian) and spinicaudatans, as well as marine foraminifera, lingulid brachiopods, pecten-like bivalves, gastropods (marine snails), ammonoids, crustaceans (including prawn-like specimens) and fish scales. A very well preserved palynomorph assemblage extracted from the basal bed is dominated by spiny acritarchs, with less common spores and pollen belonging to the Early Triassic *K. saeptatus* Zone. The ammonoids are similar to those known elsewhere in the Kockatea Shale from the Smithian substage of the Olenekian (approximately 250.9–251.3 Ma).

Reference

Haig, DW, Martin, SK, Mory, AJ, McLoughlin, S, Backhouse, J, Berrell, RW, Kear, BP, Hall, R, Foster, CB, Shi, GR and Bevan, JC 2015, Early Triassic (early Olenekian) life in the interior of East Gondwana: mixed marine–terrestrial biota from the Kockatea Shale, Western Australia: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 417, p. 511–533, doi:10.1016/j.palaeo.2014.10.015.

Localities 5 and 6: Z-bend and The Loop, Murchison River

Background

The Tumblagooda Sandstone consists of a redbed succession up to 3500 m thick that was deposited in braided fluvial, tidal sand flat and coastal settings extending north at least 700 km from outcrops in the northern Perth Basin east of Geraldton to Onslow in the subsurface. During the Ordovician, the basin was a northwards-opening, interior fracture, which developed in equatorial to low tropical latitudes. The location and nature of the western margin of this basin is unknown.

The age of the Tumblagooda Sandstone is uncertain due to the lack of clear internal evidence. Suggestions include Cambrian to Ordovician (Öpik, 1959; Retallack, 2009), Ordovician (Schmidt and Hamilton, 1990; Schmidt and Embleton, 1990), Ordovician to Silurian (Shillito and Davies, 2020), Silurian (Hocking, 1991; Trewin, 1993a,b; McNamara and Trewin, 1993) and Cretaceous (Clarke and Teichert, 1948). The presence of the Telychian (late Llandovery) conodont *Ozarkodina broenlundi* Aldridge in the Dirk Hartog Group, 70 m above the Tumblagooda Sandstone, in Coburn 1 (Nicoll *in* Yasin and Mory, 1999) provides at least a minimum age for the formation even though the well lies 80 km north of the outcrop. A Late Ordovician – earliest Silurian age for the Tumblagooda Sandstone seems most likely, although Shillito and Davies (2020) suggest it is a lateral equivalent of the Dirk Hartog Group.

Along the Murchison River gorge and adjoining coastal cliffs of Kalbarri National Park, about 1300 m of the Tumblagooda Sandstone is exposed in a section within which dips rarely exceed five degrees (Hocking, 1991). The predominantly sandy facies of the Tumblagooda Sandstone imply high sediment influx, probably a function of periodic faulting along the basin margin. Terrigenous influx to the basin lessened near the end of the Ordovician, and a prolonged period of tectonic quiescence began, allowing predominantly dolomitic deposits to accumulate in nearshore-marine to marine-shelf settings in the Silurian (Dirk Hartog Group, present only in the subsurface to the north of Kalbarri; Iasky and Mory, 1999).

Hocking (1991) recognized four facies associations (FA1 to FA4, in stratigraphic order from oldest to youngest) that delineate two fining-upwards, sharp-based megacycles of fluvially dominated facies overlain by tidal sand flat or interdistributary bay facies (FA1–2 and FA3–4). Fluvial paleocurrents flowed to the northwest, with remarkably little scatter. Facies at the Z-bend and The Loop are primarily tidal sand flat (FA2), with a laterally persistent fluvial sheet near the base, towards the top of the lower couplet.

Facies association 1 consists of trough-cross-bedded, medium to coarse sandstone with unimodal, northwestward paleocurrents. It was deposited as large, sheet-braided fluvial lobes and grades upwards into FA2.

Facies association 2 contains fine to medium, mostly thin-bedded sandstone, deposited in a largely tidal environment when sediment influx to the basin lessened. Laterally extensive, comparatively thin sheets of FA1 in the lower part of FA2 gradually diminish in abundance upwards. Trewin (1993a,b) considered there was a strong aeolian component in FA2 — an interpretation not accepted by Hocking (2000). Adhesion surfaces and indicators of emergence are common, whereas examples of aeolian cross-bedding are not obvious.

Facies association 3 sharply overlies FA2 and is similar to FA1, although it shows fining-upwards cyclicity on a scale of 10–15 m. Like FA1, it was deposited in a sheet-braided fluvial environment by lobes that prograded to the northwest, although depositional energy levels were higher overall than for FA1.

Facies association 4 is a cyclic, interdistributary bay sequence that formed adjacent to, and above, the braided fluvial deposits of FA3. Most of the association consists of fining-upwards cycles, 0.5 to 2 m thick, from medium sandstone to red, commonly bioturbated siltstone. There is a subaqueous channel complex near the top of the association, which is well exposed in the face of Red Bluff.

Bradley et al. (2018) interpret the abundant ichnotaxa and bi-directional flow structures in facies associations 2 and 4 as tidally influenced, probably within a macrotidal estuary with interbedded tidal channels and repeated fluvial incursions. The apparent lack of sediment binding by vascular plants allowed high-energy conditions but some sedimentary features, such as wind adhesion marks, were possibly preserved by microbial films, an interpretation also suggested by Shillito and Davies (2020).

Description

The Z-bend exposes tidal deposits of the Tumblagooda Sandstone consisting of thin-bedded, bioturbated and rippled facies with arcing sets of eurypterid tracks superimposed on wave ripples. These facies are interbedded with trough-cross-bedded sandstones which typically are laterally continuous, which indicates sheet braiding. This continuity is attributed to the lack of higher plant taxa during deposition. The preserved eurypterid tracks are considered to mark some of the earliest excursions of animals into non- and marginal-marine environments (but there is some controversy about how 'marine' or otherwise these facies are; participants can judge this based on their own observations). The Loop, 12 km downstream from the Z-bend, provides further illustration of facies within the Tumblagooda Sandstone with many examples of trackways (McNamara, 2014; Trewin and McNamara, 1995).

The main tourist lookout at the Z-bend is immediately south of a prominent joint fissure, and consists of a bluff of mostly thin-bedded, tidal deposits of the Tumblagooda Sandstone. Bioturbated and rippled tidal deposits are also exposed on the walk down from the car park. From the lookout, joint control of the Murchison River course is clearly visible (Fig. 12). A thicker bedded sheet of trough-cross-bedded fluvial sandstone cuts into thin-bedded tidal deposits between 10 and 20 m above the base of the gorge. About 100 m downstream from the lookout is one of the few channels in the gorge, which shows a northwest-trending incision at the base of the fluvial lobe markedly cutting into thinly bedded tidal facies on the southern bank.

AJM1253 17.08.23

Figure 12. Tumblagooda Sandstone at the Z-bend, Murchison River. The asterisk marks a large sandstone channel

The Loop exposes similar facies of the Tumblagooda Sandstone to those at the Z-bend. Although exposures next to the skywalk car park are highly weathered and ferruginized, an ammonite recovered during its excavation can be assigned tentatively to the Aptian. This indicates an older stratigraphic level than exposed at Meanarra Hill.

References

Bradley, G-M, Redfern, J, Hodgetts, D, George, AD and Wach, GD 2018, The applicability of modern tidal analogues to pre-vegetation paralic depositional models: Sedimentology, v. 65, no. 6, p. 2171–2201, doi:10.1111/sed.12461.

Clarke, EdC and Teichert, C 1948, Cretaceous stratigraphy of the lower Murchison River area, Western Australia: Royal Society of Western Australia, Journal and Proceedings, v. 32, p. 19–46, <https://www.biodiversitylibrary.org/part/238128>.

Hocking, RM 1991, The Silurian Tumblagooda Sandstone, Western Australia: Geological Survey of Western Australia, Report 27, 124p.

Hocking, RM 2000, Geology of the Southern Carnarvon Basin — a field guide: Geological Survey of Western Australia, Record 2000/10, 102p.

Iasky, RP and Mory, AJ 1999, Geology and petroleum potential of the Gascoyne Platform, Southern Carnarvon Basin, Western Australia: Geological Survey of Western Australia, Report 69, 46p.

McNamara, KJ 2014, Early Paleozoic colonisation of the land: evidence from the Tumblagooda Sandstone, Southern Carnarvon Basin, Western Australia: Journal of the Royal Society of Western Australia, v. 97, p. 111–132, <https://www.biodiversitylibrary.org/part/298976>.

McNamara, KJ and Trewin, NH 1993, A euthycarcinoid arthropod from the Silurian of Western Australia: Palaeontology, v. 36, p. 319–335, <https://www.biodiversitylibrary.org/part/174127>.

Öpik, AA, 1959, Tumblagooda Sandstone trails and their age: Department of National Development, Bureau of Mineral Resources, Geology and Geophysics, Canberra, Report 38, p. 3–20.

Retallack, GJ 2009, Cambrian, Ordovician and Silurian pedostratigraphy and global events in Australia: Australian Journal of Earth Sciences, v. 56, p. 571–586, doi:10.1080/08120090902806321.

Schmidt, PW and Embleton, BJJ 1990, The palaeomagnetism of the Tumblagooda Sandstone, Western Australia: Gondwana palaeozoic apparent polar wandering: Physics of the Earth and Planetary Interiors, v. 64, p. 303–313, doi:10.1016/0031-9201(90)90045-Y.

Schmidt, PW and Hamilton, RL 1990, Palaeomagnetism and the age of the Tumblagooda Sandstone, Western Australia: Australian Journal of Earth Sciences, v. 37, p. 381–385, doi:10.1080/08120099008727938.

Shillito, AP and Davies, NS 2020, The Tumblagooda Sandstone revisited: exceptionally abundant trace fossils and geological outcrop provide a window onto Palaeozoic littoral habitats before invertebrate terrestrialization: Geological Magazine, v. 157 (12), p. 1939–1970, doi:10.1017/S0016756820000199.

Trewin, NH 1993a, Controls on fluvial deposition in mixed fluvial and aeolian facies within the Tumblagooda Sandstone (Late Silurian) of Western Australia: Sedimentary Geology, v. 85, p. 387–400, doi:10.1016/0037-0738(93)90094-L.

Trewin, NH 1993b, Mixed aeolian sandsheet and fluvial deposits in the Tumblagooda Sandstone, Western Australia, *in* Characterization of fluvial and aeolian reservoirs *edited by* CP North and DJ Prosser: The Geological Society of London, Special Publication, no. 73, p. 219–230, doi:10.1144/GSL.SP.1993.073.01.

Trewin, NH and McNamara, KJ 1995, Arthropods invade the land: trace fossils and palaeoenvironments of the Tumblagooda Sandstone (?late Silurian) of Kalbarri, Western Australia: Transactions of the Royal Society of Edinburgh: Earth Sciences, v. 85, p. 177–210, doi:10.1017/S026359330000359X.

Yasin, AR and Mory, AJ 1999, Coburn 1 well completion report, Gascoyne Platform, Southern Carnarvon Basin, Western Australia: Geological Survey of Western Australia, Record 1999/5, 99p.

Locality 7: Meanarra Hill, Kalbarri

Background

The Santonian to Campanian Toolonga Calcilutite contains chalk in the lower part (Johnstone et al. 1958), with phosphatic nodules near its base and chert nodules in the upper half (Clarke and Teichert 1948). It overlies the Albian to Turonian Alinga Formation of the Winning Group and is in turn overlain by the Campanian to lower Maastrichtian Korojon Calcarenite. Fossils within the unit at Meanarra Hill include echinoid spines, crinoids, serpulid worms, belemnites, bivalves (of which *Inoceramus* is particularly abundant), brachiopods and foraminifera, but only brachiopods have been formally described from this locality (Craig, 1999). The age of the unit is largely derived from foraminifera, but Hocking et al. (1987, p. 158) indicate that it also 'contains ostracods (Bate, 1972), bryozoans, pelagic crinoids, serpulids and sponges (Rigby, 1983)', and that 'Bivalves, including small oyster-like forms, and brachiopods are common in shallower water facies. Abundant Inoceramus fragments commonly 'mask' other fossils.'

The following description is also from Hocking et al. (1987, p.158):

> The Toolonga Calcilutite is a calcareous pelagic deposit [in which] the proportion of planktonic species in the foraminiferal assemblages is in excess of 90% indicating an outer shelf to slope environment from the Rankin Platform to Brigadier 1 and Delambre 1 (Apthorpe, 1979). Limited data quoted by Clark (1979) suggest that the planktonic percentage of the Toolonga Calcilutite ranges between 15% and 75% in the onshore Carnarvon Basin. This lower abundance suggests that the offshore areas around the Rankin Platform are significantly deeper than the onshore Carnarvon Basin. Elsewhere in the Carnarvon Basin, inner to middle shelf conditions prevailed. Energy levels were low except for isolated areas such as the Giralia Anticline, which was structurally and topographically high. Near the basin margin there was some dilution of the carbonate by terrigenous detritus.
>
> The generally low volume of terrigenous material in the formation was attributed by Apthorpe (1979) to a dry climate and low continental runoff. The calcareous bloom [was] probably a result of globally changed oceanic circulation patterns, after the breakup of Gondwana, which introduced warmer waters to the northwest of Australia.

Description

Little fresh outcrop remains at Meanarra Hill, as much of the gully has been stabilized with rock-filled cages to mitigate erosion. By comparison, most of the hillsides consist of talus or derived material, but they still contain some fossils, especially towards the top of the section facing the walkway and viewing platforms.

References

Apthorpe, MC 1979, Depositional history of the upper Cretaceous of the Northwest Shelf, based on Foraminifera: APEA Journal, v. 19 (1), p. 74–89, <https://www.publish.csiro.au/aj/pdf/AJ78009>.

Bate, RH 1972, Upper Cretaceous Ostracoda from the Carnarvon Basin, Western Australia: The Palaeontological Association, London, Special Papers in Palaeontology No. 10, 145p., doi:10.1017/S0016756800039893.

Clark, FE 1979, Upper Cretaceous foraminifera and biostratigraphy of C-Y Creek, Western Australia: Carleton University, Ottawa, Canada, M.Sc. thesis (unpublished), <https://repository.library.carleton.ca/concern/parent/h702q6382/file_sets/02870v92t>.

Clarke, EdC and Teichert, C 1948, Cretaceous stratigraphy of the lower Murchison River area, Western Australia: Royal Society of Western Australia, Journal and Proceedings, v. 32, p. 19–46, <https://www.biodiversitylibrary.org/part/238128>.

Craig, RS 1999, Late Cretaceous brachiopods of the Perth and Carnarvon Basins, Western Australia: Records of the Western Australian Museum, v. 19, p. 413–442.

Hocking, RM, Moors, HT and van de Graaf, WJE 1987, Geology of the Carnarvon Basin, Western Australia: Geological Survey of Western Australia, Bulletin 133, 289p.

Johnstone, D, Condon, MA and Playford, PE 1958, Stratigraphy of the lower Murchison River area and Yaringa North Station, Western Australia: Journal of the Royal Society of Western Australia, v. 41, no. 1, p. 13–16, <https://biostor.org/reference/256802>.

Rigby, JK 1983, A First Report of Cretaceous Sponges from the Carnarvon Basin in Western Australia: Journal of Paleontology, v. 57, no. 4, p. 766–772, <https://www.jstor.org/stable/1304633>.

Locality 8: Blue Hills

Background

Ordovician–Silurian, Lower Triassic, Lower Jurassic and Lower Cretaceous formations exposed west of the gneiss and granulite of the Northampton Complex are essentially flat lying. The large depositional breaks deduced between these units rely on regional stratigraphic correlations with limited paleontological evidence as most contacts are disconformable. The Ordovician–Silurian Tumblagooda Sandstone onlaps onto the Northampton Inlier and in turn the Mesozoic of the Perth Basin has been deposited across both of those units. Exposures of the Lower Triassic Kockatea Shale are typically poor, apart from where sandy facies are common. Sandstone of the Lower Jurassic Chapman Group capping the higher hills in the area disconformably overlies the Kockatea Shale. Within the Kockatea Shale, Playford et al. (1976) list relatively few species of brachiopods, bivalves, nautiloids, ammonoids, annelids, ostracods, conodonts, vertebrates and palynomorphs, but, apart from the ammonites at Mount Minchin 10 km to the north, these are mostly from boreholes south of this locality.

Description

In the gully south of the road, a bed with stromatolites below the Lower Triassic Kockatea Shale overlies pebbly cross-bedded sandstone of the Tumblagooda Sandstone. The bed is strongly ferruginized and contains several stromatolite horizons encrusted either onto sandstone surfaces or pebbles in the pebbly sandstone above the Tumblagooda erosion surface. Growth forms in the stromatolites include low, flat encrustations on the underlying rock, broad domal structures up to 50 cm across, pillars several centimetres in width and digitate forms with thin columns (each about 0.5 cm wide; Fig. 13). Small nodules are developed on the surfaces of some of the domes. In places, there is a succession of growth forms from flat encrustations or broad domes to pillars and digitate columns, similar to those at Lake Thetis, Cervantes (Locality 9). Repetitions of this growth cycle, or various parts of it, are also present. Individual stromatolites are typically less than 20 cm thick and the bed may correlate with upper, microbialitic parts of the Hovea Member (Thomas and Barber, 2004; Thomas et al., 2004; Chen et al., 2014; Taniwaki et al., 2022). Olden (2020) and Olden et al. (2019, 2022), however, favour an age possibly as old as early Permian.

The pebbly sandstone beds including the stromatolitic horizons appear to be fluvial in origin, with imbricated clasts and elongated stromatolites indicating north-northeast-directed paleocurrents (Olden et al., 2022). The uppermost stromatolitic bed is overlain by laminated mudstone with thin, fine sandstone interbeds containing small burrows that are difficult to see in friable leached mudstone. Ichnofauna and microbial sedimentary structures are present nearby (Chen et al., 2012; Luo et al., 2019), preserved in thin mud layers cemented to sandstone surfaces by reddish iron oxides. Higher in the succession and 20 km to the north of Blue Hills, laminated sandstone beds in the Kockatea Shale are more abundant and preserve ammonoid moulds (Edgell, 1964; Skwarko and Kummel, 1974), to which a Griesbachian–Smithian (now Induan–Olenekian) age is attributed. The precise age of the stromatolite bed is uncertain.

Laminae within all stromatolitic forms are defined by elongate, near-circular vermiform microstructures up to 110 μm long, with internal diameters of 10–14 μm, resembling silicified sheaths of filamentous cyanobacteria. Secondary ferruginous alteration had little effect on the exceptional preservation, which Olden et al. (2023) attributes to early biogenic–diagenetic mechanisms.

Figure 13. Examples of stromatolites from Blue Hills

References

Chen, Z-Q, Fraiser, ML and Bolton, C 2012, Early Triassic trace fossils from Gondwana Interior Sea: Implication for ecosystem recovery following the end-Permian mass extinction in south high-latitude region: Gondwana Research, v. 22 (1), p. 238–255, doi:10.1016/j.gr.2011.08.015.

Chen, Z-Q, Wang, Y, Kershaw, S, Luo, M, Yang, H, Zhao, L, Feng, Y, Chen, J, Yang, L and Zhang, L 2014, Early Triassic stromatolites in a siliciclastic nearshore setting in northern Perth Basin, Western Australia: Geobiologic features and implications for post-extinction microbial proliferation: Global and Planetary Change, v. 121, p. 89–100, doi:10.1016/j.gloplacha.2014.07.004.

Edgell, HS 1964, Triassic ammonite impressions from the type section of the Minchin Siltstone, Perth Basin, *in* Annual report for the year 1963: Geological Survey of Western Australia, p. 55–57.

Luo, M, Chen, Z-Q, Shi, GR, Feng, X, Yang, H, Fang, Y and Li, Y 2019, Microbially induced sedimentary structures (MISS) from the Lower Triassic Kockatea Formation, northern Perth Basin, Western Australia: Palaeoenvironmental implications: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 519, p. 236–247, doi:10.1016/j.palaeo.2018.06.040.

Olden, LJ 2020, Mid Phanerozoic stromatolites in the Northern Perth Basin: Understanding their evolution and occurrence: School of Earth and Planetary Sciences, Curtin University, PhD thesis (unpublished), 92p.

Olden, LJ, Barham, M, Cunneen, J, Olierook, HKH, Suosaari, E and Smith, GC 2022, Mid-Phanerozoic microbialite forms and associated facies in the northern Perth Basin, Western Australia, and their relationship to the end-Permian mass extinction: Australian Journal of Earth Sciences, v. 69 (4), p. 473–496, doi:10.1080/08120099.2022.1995044.

Olden, LJ, Barham, M, Olierook, H, Fougerouse, D, Godel, B, Cunneen, J and Forman, J 2023, Preserved cellular microstructures in Mid-Phanerozoic stromatolites from Western Australia, *in* AESC Abstracts: Australian Earth Sciences Convention, Perth, Western Australia, 27–30 June 2023: Geological Society of Australia, 1p.

Olden, LJ, Cunneen, J, Barham, M, Olierook, HK, Smith, G and Suosaari, E 2019, Are stromatolites in the northern Perth Basin following the End Permian mass extinction?: ASEG Extended Abstracts, v. 2019, no. 1, p. 1–4, doi:10.1080/22020586.2019.12073172.

Playford, PE, Cockbain, AE and Low, GH 1976, Geology of the Perth Basin, Western Australia: Western Australia Geological Survey, Bulletin 124, 311p.

Skwarko, SK and Kummel, B 1974, Marine Triassic molluscs of Australia and Papua New Guinea, *in* Palaeontological Papers 1972 *edited by* DJ Belford, D Burger, SK Skwarko and B Kummel: Bureau of Mineral Resources, Geology and Geophysics, Bulletin 150, p. 111–139.

Taniwaki, T, Elders, C, Böttcher, ME, Holman, AI and Grice, K 2022, Photic zone redox oscillations and microbialite development recorded by Early Triassic sediments of the Perth Basin: A geochemical approach: Geochimica et Cosmochimica Acta, v. 336, p. 188–207, doi:10.1016/j.gca.2022.09.011.

Thomas, BM and Barber, CJ 2004, A re-evaluation of the hydrocarbon habitat of the northern Perth Basin: The APPEA Journal, v. 44, no. 1, p. 59–92, doi:10.1071/AJ03002.

Thomas, BM, Willink, RJ, Grice, K, Twitchett, RJ, Purcell, RR. Archbold, NW, George, AD, Tye, S, Alexander, R, Foster, CB and Barber, CJ 2004, Unique marine Permian-Triassic boundary section from Western Australia: Australian Journal of Earth Sciences, v. 51, p. 423–430, doi:10.1111/j.1400-0952.2004.01066.x.

Cervantes–Jurien area

Of the surficial Cenozoic deposits along the coastal plain, which generally are no more than 50 m thick, most attention has been given to the stromatolites and thrombolites in Lake Thetis, next to Cervantes, and The Pinnacles in Nambung National Park. The region also has a lower Permian to Upper Jurassic succession, of which only the Upper Triassic – Jurassic is exposed east of the Gingin Scarp in a faulted broad anticline (Mory, 1994, 1995a; Mory and Iasky, 1996) directly east of Jurien. However, the best Mesozoic exposures in this region are in the thickly vegetated central part of Mount Lesueur National Park, into which vehicular access is restricted. The scarp is a prominent geographical feature, with a series of mid-Neogene strandline and dune deposits containing heavy mineral sands along its foot. These deposits span 30–170 m above present sea level and are mined at Cataby, Eneabba and Gingin for ilmenite, rutile and zircon with minor monazite and leucoxene.

Locality 9: Lake Thetis

Background

Modern stromatolites from Western Australia are most famously known from Shark Bay, but they and thrombolites are also found in lakes near the coast, including Lake Thetis north of Perth; Government House and Serpentine Lakes on Rottnest Island; Lakes Clifton, Preston, Richmond and Walyungup south of Perth; and Pink Lake near Esperance.

Description

Lake Thetis lies about 1.5 km inland from the ocean and formed in an interdunal depression in the Holocene Quindalup Dune System (Grey and Planavsky, 2009; Grey et al., 1990) or possibly over a doline in the Pleistocene Tamala Limestone. The small lake contains permanent water and is up to 2.25 m deep, although the level shows seasonal variations. There is no substantial surface drainage into the lake, which is fed by direct rainfall and continental ground water (Grey et al., 1990), although a subterranean connection to the sea cannot be completely discounted. Stromatolites and thrombolites are forming in this metahaline lake through microcrystalline carbonate precipitation mainly within cyanobacterial *Entophysalis* biofilms. The stromatolitic structures are crudely laminated and some exhibit digitate columnar branching in which filamentous cyanobacteria are preserved in the uppermost few millimetres (Wacey et al., 2018).

Grey and Planavsky (2009) placed the age of the interdunal depression encompassing Lake Thetis at about 3–4.5 ka, based on C^{14} dates from the lake and its margins in Grey et al. (1990). This is consistent with a 5600 ± 260 years C^{14} date from bivalves in a disused coquina quarry adjacent to the northern edge of the lake (Mory, 1995a) and C^{14} dates of ~4000 ± 60 years BP obtained by Annette George (University of Western Australia, June 2023) from shallow core near the centre of the lake. Similar middle Holocene coquinas extend along the coast north of Jurien almost to Dongara (Mory, 1995b) and are present on Rottnest Island (Playford, 1988).

Physical and chemical factors affect the lake (Table 2). Grey et al. (1990) found different microbial mat types form concentric zones across the lake's floor and foreshore (Fig. 14). Five types have been recognized (Table 3) and three of these may be visible from the shore. In seasonally flooded high foreshore areas, the crenulate mat forms reticulate ridges and blisters a few centimetres in diameter due to desiccation. During February, at the height of summer, the mat is extremely friable; it is best seen in the splash zones around the edges of stromatolite domes along the southwestern shoreline (when the water level is low; Fig. 14b), where it forms aggregations of nodules (0.5 – 10 cm in diameter) on the lower sides of the stromatolites. Diatomaceous mat forms an orange-brown gelatinous band in the shallows, associated with nodular mats. The diatom mat appears tightly constrained by light penetration because it is nearly always about 25 cm below the surface and it migrates as lake levels change to maintain this position. The lithified surfaces of many of the stromatolites contain abundant diatom frustules.

Table 2. Physical and chemical factors at Lake Thetis (after Grey et al., 1990, and the Bureau of Meteorology)

Mean rainfall	382 mm (May–Sept) 126 mm (Oct–April)
Annual evaporation	1700 mm
Mean annual minimum temperature	20°C
Mean maximum temperature (February)	>30°C
Maximum temperature variation	<10°C to >37°C
Salinity	39–53 gL^{-1}
Alkalinity (carbonate plus bicarbonate)	0.5% meq L^{-1}
pH	8.28 – 8.6
Maximum water depth	2.5 m

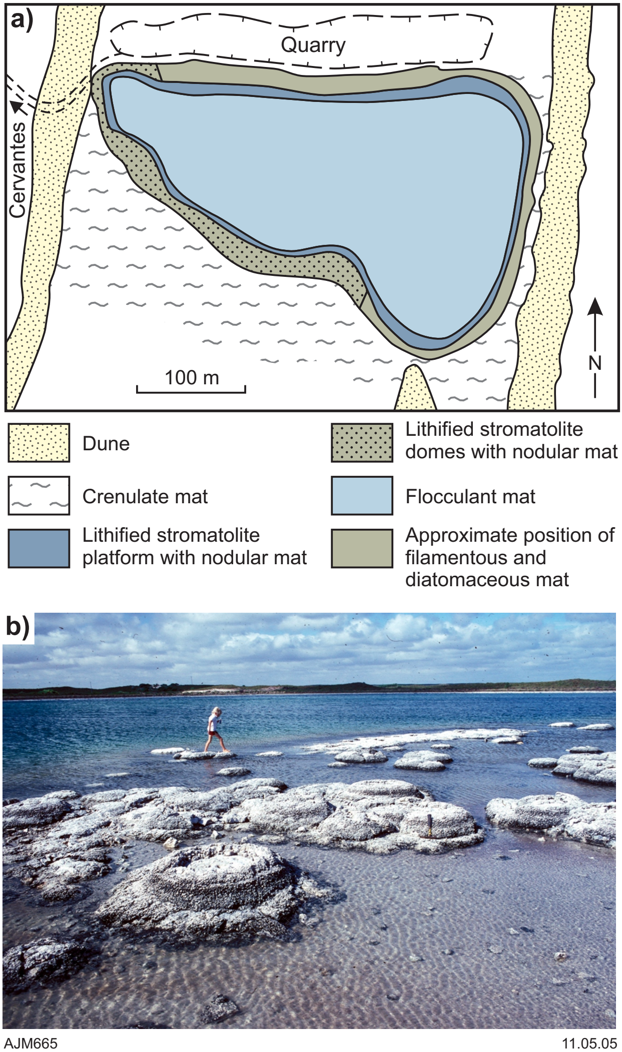

Figure 14. Lake Thetis: a) sketch map from Grey et al. (1990); b) stromatolites exposed on the southern shore during a low water level in summer. Note that it is no longer permitted to walk on the stromatolites or microbial mats

Table 3. Mat types at Lake Thetis (after Grey et al., 1990)

Mat type	*Location and substrate*	*Gross morphology and colour*	*Microbial community*
Crenulate	mat above high water level on coarse, calcareous sand; position varies seasonally	reticulate ridges and blisters on surface producing alternating layers of organic-rich sand and mud; black to olive green	predominantly filamentous but with some coccoid cyanobacteria; genera include *Calothrix*, *Scytonema*, *Gloeocapsa*
Nodular	littoral to mid-foreshore zone on lithified stromatolite domes and reef; changes with position of water line	on SW shore mat forms nodules in clusters with an irregular surface and abundant mucilage; on N shore mat is patchier with less surface relief; produces indistinct laminations; black to grey	coccoid cyanobacteria, including *Gloeocapsa*
Filamentous	low marginal shelf that is permanently submerged; on lithified plates and angular fragments in cracks on underside of plates and as a fragile benthic mat over flocculent mat with little seasonal change	film and/or fragile coating; produces no laminations; bright green	filamentous cyanobacteria, including *Oscillatoria*
Diatomaceous	marginal shelf, at water depths of 25–30 cm, on lithified stromatolites and plates; changes position with change in water depth in lake	mucilaginous coating; produces no laminations; beige–brown	diatoms
Flocculent	permanently submerged in centre of lake; surface approximates oxic/anoxic interface; sometimes is dispersed throughout water column and concentrated at water's edge	gently undulating mat up to about 50 cm thick, with distinct sediment–water interface where surface undisturbed; produces no laminations; purple–pink with blue-green patches	filamentous and coccoid cyanobacteria, diatoms, purple sulfur bacteria; genera include *Oscillatoria*, cf. *Synechocystis*, cf. *Thiocystis*/*Thiocapsa*

The floor of the lake beneath the flocculent mat is composed of fine carbonate mud, with shell fragments, aragonite and red-purple organic material composed mainly of purple sulfur bacteria (Grey et al., 1990). Silica is also being deposited inorganically as light brown organic particles containing traces of calcium, sulfur and chlorine (MW Pryce, cited by Grey et al., 1990). The purple mud of the lake floor includes irregular sandy laminae and fine, sand-sized irregular carbonate micronodules (Grey et al., 1990).

Lithified carbonates on the margins of the lake form terraces composed of coalesced, planed and domal stromatolites (Grey et al., 1990). Fractured and weathered domes reveal that the centres of many of the stromatolites show a pattern of crude, concentric, upwardly convex laminae, and most include internal morphological variation. In some, there is a thrombolitic core (without layers) with an outer layer (up to 15 cm thick) of digitate branching columns. Grey et al. (1990) noted that branching seems confined to areas of low wave activity. Fenestrae (about 1 mm high and 10 mm or more in length) and larger elongate cavities may develop between the laminae.

Grey et al. (1990) noted that the lithified carbonate platform extends up to 10 m into the lake where there is an abrupt slope to the unconsolidated floor of the central part of the lake (at 2 – 2.5 m depth). The surface of the platform consists of a crust (1–5 cm thick), including a massive white papillate to botryoidal surface layer (0.1 – 1.0 cm) and a cream fenestral lower layer (0.5 – 4.0 cm), with the basal section commonly coloured green due to associated micro-organisms.

Reitner et al. (1996) and Arp et al. (2001) discussed the method of calcification of the Lake Thetis stromatolites. According to the former:

> The recent growth results mainly from calcifying *Entophysalis* films which are forming a more or less laminated crust. Within the deeper parts of the *Entophysalis*-biofilm the outer basophilic polysaccharide envelopes contain abundant heterotrophic bacteria. Calcification events exactly start at these points. The older, subfossil portions of the microbialites are characterized by plumosely arranged *Scytonema*-filaments, which are enclosed by fibrous aragonite. Within small cryptic primary and secondary cavities clearly laminated organomicrites are lining cavity walls. The formation of this type of 'microstromatolites' is related to organic films, which contain no active microbes. These organic films are composed of degraded organic material (polysaccharides, proteins etc.) acting as matrices and templates for nucleation and growth of organomicrites and fibrous aragonite crystals.

References

Arp, G, Reimer, A and Reitner, J 2001, Photosynthesis-induced biofilm calcium concentrations in Phanerozoic oceans: Science, v. 292, no. 5522, p. 1701–1704, doi:10.1126/science.1057204.

Grey, K, Moore, LS, Burne, RV, Pierson, BK and Bauld, J 1990, Lake Thetis, Western Australia: an example of saline sedimentation dominated by benthic microbial processes: Australian Journal of Marine and Freshwater Research, v. 41, no. 2, p. 275–300, doi:10.1071/MF9900275.

Grey, K and Planavsky, NJ 2009, Microbialites of Lake Thetis, Cervantes, Western Australia — a field guide: Geological Survey of Western Australia, Record 2009/11, 21p.

Mory, AJ 1994, Geology of the Hill River - Green Head 1:100 000 sheet: Geological Survey of Western Australia, 1:100 000 Geological Series Explanatory Notes, 29p

Mory, AJ 1995a, Geology of the Wedge Island 1:100 000 sheet: Western Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes, 19p.

Mory, AJ 1995b, Geology of the Mingenew–Dongara 1:100 000 sheet: Western Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes, 39p.

Mory, AJ and Iasky, RP 1996, Stratigraphy and structure of the onshore northern Perth Basin, Western Australia: Western Australia Geological Survey, Report 46, 101p.

Playford, PE 1988, Guidebook to the Geology of Rottnest Island: Geological Society of Australia (WA Division) and the Geological Survey of Western Australia, 67p.

Reitner, J, Paul, J, Arp, G and Hause-Reitner, D 1996, Lake Thetis domal microbialites: A complex framework of cacified biofilms and organomicrites (Cervantes, Western Australia), *in* Globale und regionale Steuerungsfaktoren biogener Sedimentation: Teil 1: Riff-Evolution *edited by* J Reitner, F Neuweiler and F Gunkel: Geologisches Institut der Georg-August-Universität Göttingen, Göttingen, Germany, p. 85–89, doi:10.23689/fidgeo-1817.

Wacey, D, Urosevic, L, Saunders, M and George, AD 2018, Mineralisation of filamentous cyanobacteria in Lake Thetis stromatolites, Western Australia: Geobiology, v. 16 (2), p. 203–215, doi:10.1111/gbi.12272.

Locality 10: The Pinnacles, Nambung National Park

Background

Pinnacle development in the Pleistocene Tamala Limestone is known from many locations along its 1000 km distribution between Esperance and Shark Bay. The formation is composed mostly of aeolian calcarenite, possibly up to 150 m thick south of Cervantes, and extends up to 20 km inland from the present coast.

Description

The Pinnacles developed from deep differential weathering on the surface of the Tamala Limestone (McNamara, 1986). Weathering apparently took place preferentially along fissures in the limestone and residual columns of rock became covered by a residue of unconsolidated quartz sand. In the Pinnacles Desert, much of the residual sand has been blown clear of the limestone columns by persistent winds (Fig. 15a), commonly exposing abundant calcified fossil rhizoliths (Fig. 15b). Residual sands with a fossil soil horizon separating quartz from carbonate sand are present (Fig. 15b). The following model for the development of pinnacles is summarized from McNamara (1986):

1. Large taproots that penetrated aeolian dune deposits stabilized by vegetation were preferentially lithified by many iterations of dissolution and precipitation of calcium carbonate during wet winters and dry summers, respectively.
2. A subsoil calcrete developed at the base of the thin humic layer across the dunes.
3. Cracking of the subsoil calcrete allowed preferential leaching of the underlying friable limestone by surface waters. Following prolonged weathering, only limestone pinnacles (originally lithified around taproots) remained, surrounded by residual quartz sand from the dune deposit.

Such an explanation, however, does not entirely explain pinnacles made up of aeolian cross-beds and paleosols, as interpreted by Lipar (2009), Lipar and Webb (2014, 2015a) and Lipar et al. (2017). They emphasise microbial activity as forming laminae on generally vertical karstified surfaces to produce column-like morphologies, but seem to have ignored the lithified rhizoliths in many of the pinnacles. In addition, they erected a series of members for beds that can be correlated between individual pinnacles (Fig. 16), for which the regional significance is uncertain. The isotopic dates for their members are from six U–Th analyses and two optically stimulated luminescence analyses that range between ~75 and 500 ka and are probably best considered as maximum ages — additional analyses are needed to confirm the veracity of their correlations. Whereas they deduce a likely Marine Isotope Stage 5 age, i.e. ~75–125 ka, for the formation of the pinnacles, the timing is likely to be towards the younger end of this range given the ~125 ka age of the raised coral reef at Point Leander.

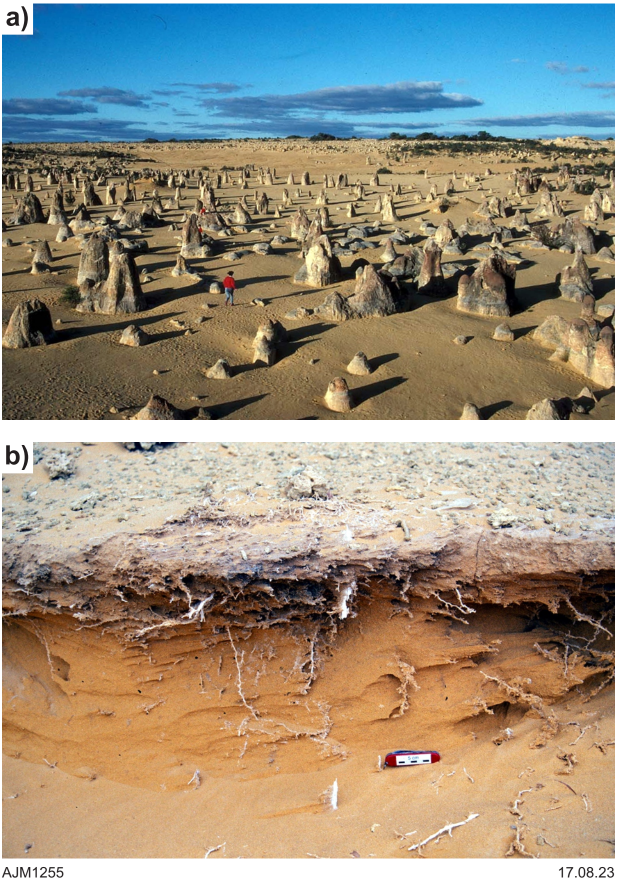

Figure 15. Pinnacles Desert: a) general view of pinnacles in the Pleistocene Tamala Limestone; b) weakly calcified rhizoliths at the contact between Holocene calcareous cross-bedded sand and underlying silica sand (Burragenup Member and Cooloongup Sand of Lipar and Webb, 2015a, respectively)

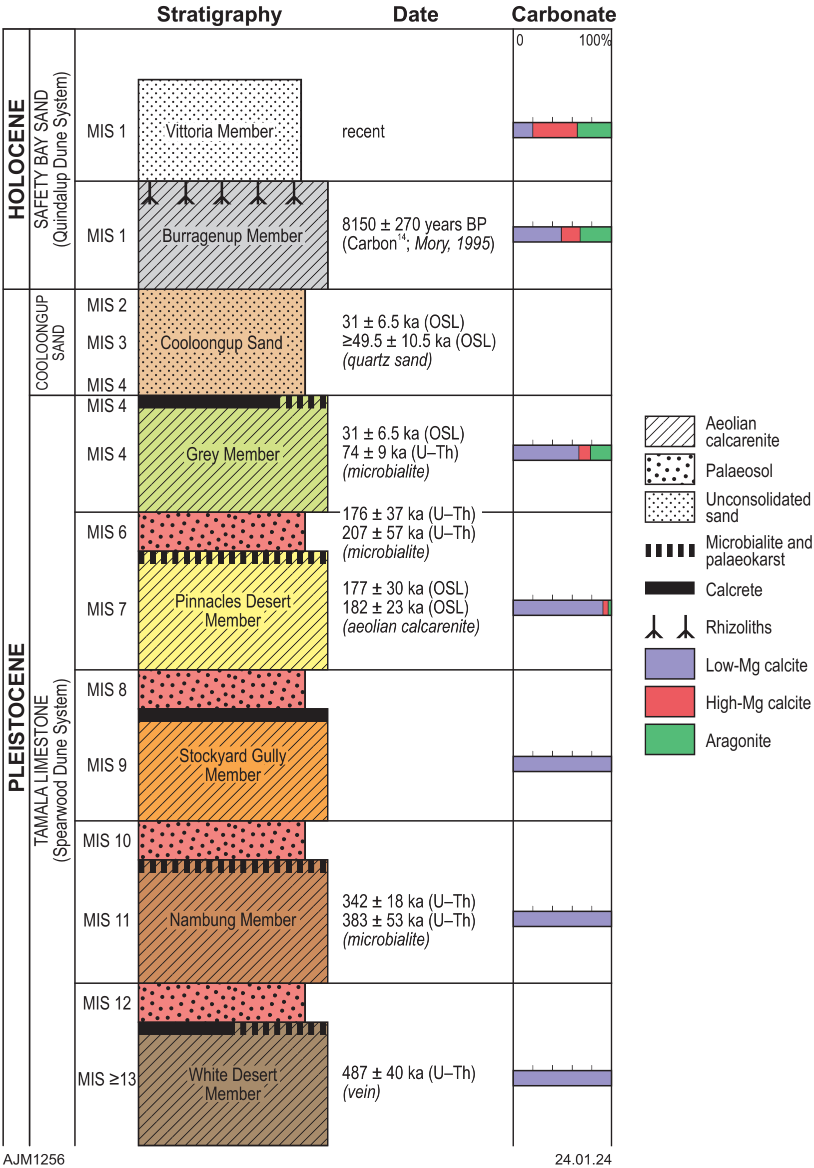

Figure 16. Pleistocene–Holocene stratigraphy, Pinnacles Desert (from Lipar and Webb, 2015a)

As with The Pinnacles, it was originally suggested that similar karst features in southwestern Victoria, at Cape Dunuesne, developed from early tree moulds (Boutakoff, 1963). That hypothesis was rejected by Grimes (2004, p. 14) in favour of ‘solution pipes formed by focussed vertical water flow through the porous calcareous sands (aeolianites)’. Lipar and Webb (2015b, p. 81) and Lipar et al. (2015) suggest those pinnacles not only formed in a similar way to those at Nambung, but that the timing of events was much the same:

> … the coeval Tamala Limestone in south-western Western Australia shows simultaneous changes in paleoclimate: high effective precipitation during the transition from MIS 11 to MIS 10, and a relatively dry transition from MIS 9 to MIS 8. Abundant rainfall during MIS 5 caused extensive limestone dissolution … and the resulting quartz sand residue was redeposited during MIS 2–4.

Aboriginal artefacts (including chert flakes) found in blowout depressions around the pinnacles and, in one instance, cemented to a pinnacle, contain Eocene foraminifera. As there are no onshore exposures of this Eocene facies known in the Perth Basin, the flakes probably came from the now-submerged continental shelf (Glover, 1975; Quilty, 1978).

Active coastal dunes of the Quindalup Dune System border the beach along the road into The Pinnacles. In 1992, a 31.7 × 23 cm egg from the large, flightless, now extinct *Aepyornis maximus* (Madagascan elephant bird) was found buried in one of these Holocene dunes, and was dated at about 2000 years BP (Long et al., 1998). The egg feasibly drifted on ocean currents from Madagascar, rather than reaching Australia entirely by human intervention. In their discussion of alien vegetation, Rippey and Rowland (1995) mention a South African study in which it took about 18 months for drift cards to cross the Indian Ocean from South Africa to Western Australia.

References

Boutakoff, N 1963, The geology and geomorphology of the Portland area: Geological Survey of Victoria, Memoir 22, 175p.

Glover, JE 1975, The petrology and probable stratigraphic significance of Aboriginal artefacts from part of south-western Australia: Journal of the Royal Society of Western Australia, v. 58, p. 75–85, <https://www.biodiversitylibrary.org/part/238203>.

Grimes, KJ 2004, Solution Pipes or Petrified Forests? Drifting sands and drifting opinions!: The Victorian Naturalist, v. 121, no. 1, p. 14–22.

Lipar, M 2009, Pinnacle syngenetic karst in Nambung National Park, Western Australia: Acta Carsologica, v. 38 (1), p. 41–50, doi:10.3986/ac.v38i1.134.

Lipar, M and Webb, JA 2014, Middle–late Pleistocene and Holocene chronostratigraphy and depositional history of the Tamala Limestone, Cooloongup and Safety Bay sands, Nambung National Park, southwestern Western Australia: Australian Journal of Earth Science, v. 61, no. 8, p. 1023–1039, doi:10.1080/08120099.2014.966322.

Lipar, M and Webb, JA 2015a, The formation of the pinnacle karst in Pleistocene aeolian calcarenites (Tamala Limestone) in southwestern Australia: Earth Science Reviews, v. 140, p. 182–202, doi:10.1016/j.earscirev.2014.11.007.

Lipar, M and Webb, JA 2015b, The Middle–Late Pleistocene Bridgewater Formation on Cape Bridgewater, south-western Victoria: chronostratigraphy and palaeoclimatic significance: Proceedings of the Royal Society of Victoria, v. 127, no. 2, p. 81, doi:10.1071/RS15020.

Lipar, M, Webb, JA, Cupper, ML and Wang, N 2017, Aeolianite, calcrete/microbialite and karst in southwestern Australia as indicators of Middle to Late Quaternary palaeoclimates: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 470, p. 11–29, doi:10.1016/j.palaeo.2016.12.019.

Lipar, M, Webb, JA, White, SQ and Grimes, KG 2015, The genesis of solution pipes: Evidence from the Middle–Late Pleistocene Bridgewater Formation calcarenite, southeastern Australia: Geomorphology, v. 246, p. 90–103, doi:10.1016/j.geomorph.2015.06.013.

Long, JA, Vickers-Rich, P, Hirsch, K, Bray, E and Tuniz, C 1998, The Cervantes egg: an early Malagasy tourist to Australia: Records of the Western Australian Museum, v. 19, p. 39–46.

McNamara, KJ 1986, The Pinnacles Desert, a geological masterpiece: Australian Natural History, v. 22, no. 1, p. 12–16.

Quilty, PG 1978, The source of chert for aboriginal artefacts in southwestern Australia: Nature, v. 275, no. 5680, p. 539–541, doi:10.1038/275539a0.

Rippey, E and Rowland, B 1995, Plants of the Perth Coast and Islands: The University of Western Australia Press, Nedlands 292p.

Appendix: Fossilworks extracts*

Class	*Order*	*Family*	*Genera and species*
Molecap Hill			
Rhynchonellata			
	Rhynchonellida	Basiliolidae	*Eohemithyris wildei*
		Notosariidae	*Protegulorhynchia bevanorum*
			Protegulorhynchia meridionalis
			Tegulorhynchia hrodelberti
	Terebratulida	Bouchardiidae	*'Magasella cretacea' = Bouchardiella cretacea*
		Chlidonophoridae	*Gisilina ovata*
		Inopinatarculidae	*Inopinatarcula acanthodes*
		Kingenidae	*Kingena mesembrina*
		Terebratulidae	*Liothyrella archboldi*
			Terebratulidae indet.
		Zenobiathyridae	Zenobiathyris mutabilis
			Zenobiathyris plicatilis

Source:

Craig, RS 1999, Late Cretaceous brachiopods of the Perth and Carnarvon Basins, Western Australia: Records of the Western Australian Museum, v. 19, p. 413–442.

Class	*Order*	*Family*	*Genera and species*
Leander Point			
Anthozoa			
	Scleractinia		*Acropora muricata*
		Acroporidae	*'Acropora palifera' = Isopora palifera*
			Acropora ex gr. *humilis*
			Acropora ex gr. *divaricata*
			Acropora ex gr. *hyacinthus*
			Montipora sp.
		Merulinidae	*'Favia stelligera' = Goniastrea stelligera*
			Favites sp.
		Faviidae	*Favia* sp.

Source:

Greenstein, BJ and Pandolfi, JM 2008, Escaping the heat: range shifts of reef coral taxa in coastal Western Australia: Global Change Biology, v. 14, no. 3, p. 513–528, doi:10.1111/j.1365-2486.2007.01506.x.

*** <www.fossilworks.org>**

Class	*Order*	*Family*	*Genera and species*
Fossil Cliff			
Rhynchonellata			
	Spiriferida	Elythidae	*Phricodothyris occidentalis*
		Ingelarellidae	*Tomiopsis woodwardi*
		Trigonotretidae	*'Trigonotreta neoaustralis' = Koenigoria neoaustralis*
			'Neospirifer hardmani' = Quadrospira hardmani
		Spiriferellidae	*'Elivina hoskingae' = Spiriferella hoskingae*
Strophomenata			
	Productida	Productidae	*Callytharrella callytharrensis*
		Rugosochonetidae	*'Neochonetes* (*Sommeria*) *pratti' = Neochonetes* (*Sommeriella*) *pratti*
		Strophalosiidae	*Strophalosia irwinensis' = Coronalosia irwinensis*
			Heteralosia etheridgei' = Etherilosia etheridgei

Sources:

Archbold, NW 1981, Studies on Western Australian Permian brachiopods: 2. The Family Rugosochonetidae Muir-Wood 1962 : Proceedings of the Royal Society of Victoria, v. 93, no. 2, p. 109–128, <https://www.biodiversitylibrary.org/part/302976>.

Archbold, NW 1985, Studies on Western Australian Permian brachiopods: 5. the Family Dictyoclostidae Stehli 1954: Proceedings of the Royal Society of Victoria, v. 97, no. 1, p. 19–30, <https://www.biodiversitylibrary.org/part/303046>.

Archbold, NW 1986, Studies on Western Australian Permian brachiopods: 6. The genera Strophalosia King, 1844, Heteralosia King, 1938 and Echinalosia Waterhouse, 1967: Proceedings of the Royal Society of Victoria, v. 98, no. 3, p. 97–119, <https://www.biodiversitylibrary.org/part/303076>.

Archbold, NW and Thomas, GA 1984, Permian Elythidae (Brachiopoda) from Western Australia: Alcheringa, v. 8, no. 4, p. 311–326, doi:10.1080/03115518408618953.

Archbold, NW and Thomas, GA 1986, Neospirifer and Trigonotreta (Spiriferida, Brachiopoda) from the Permian of Western Australia: Alcheringa, v. 10, no. 2, p. 125–161, doi:10.1080/03115518608619165.

Bivalva			
	Arcida	Parallelodontidae	*Parallelodon bimodoliratus*
	Cardiidia	Kalenteridae	*Stutchburia hoskingae*
			Stutchburia variabilis
		Sanguinolitidae	*Myofossa* (*Ragozinia*) *amatopensis*
			Praeundulomya subelongata
	Cyrtodontida	Cyrtodontidae	*'Cypricardinia elegantula' = Dickinsartella elegantula*

Class	*Order*	*Family*	*Genera and species*
	Mytilida	Myalinidae	*Modiolus koneckii*
			Pseudomyalina sp.
	Pectinida	Heteropectinidae	*'Aviculopecten tenuicollis' = Etheripecten tenuicollis*
			Deltopecten sp.
			Girtypecten ovalis n. sp.
		Deltopectinidae	*Deltopecten* sp.
		Limipectinidae	?*Acanthopecten* sp.
	Pholadida	Vacunellidae	*Myonia* sp.
	Pholadomyida	Megadesmidae	?*Astartila tumida*
Gastropoda			
	Bellerophontida	Bellerophontidae	*Bellerophon* sp. nov.
			Bellerophon cf. *formani*
			Retispira irwinensis
		Euphemitidae	*Stachella crucilirata*
	Cycloneritimorpha	Naticopsidae	?*Naticopsis* sp. nov.
	Eotomarioidea	Gosseletinidae	*Mourlonia obscura*
			'Ptychomphalina talboti' = Mourlonia talboti
			'Mourlonia (*Pseudobaylea*) *freneyensis' = Pseudobaylea freneyensis*
			'Mourlonia (*Woolnoughia*) *angulata' = Woolnoughia angulata*
	Euomphalina	Euomphalidae	*'Straparollus* (*Leptomphalus*) sp. nov.' = *Leptomphalus*
		Platyceratidae	*Platyceras* cf. *abundans*
	Orthogastropoda	Phymatopleuridae	*Baylea perthensis*
	Prosobranchia	Soleniscidae	*Macrochilina winensi*
Cephalopoda			
	Ammonoidea	Metalegoceratidae	*Metalegoceras kayi*
Anthozoa			
	Stauriida	Amplexidae	*'Amplexus'* sp.
Trilobita			
	Proetida	Phillipsiidae	*Ditomopyge* sp.

Class	*Order*	*Family*	*Genera and species*

Sources:

Archbold, NW 1986, Studies on Western Australian Permian brachiopods: 6. The genera Strophalosia King, 1844, Heteralosia King, 1938 and Echinalosia Waterhouse, 1967: Proceedings of the Royal Society of Victoria, v. 98, no. 3, p. 97–119, <https://www.biodiversitylibrary.org/part/303076>.

Dickins, JM 1963, Permian pelecypods and gastropods from Western Australia: Bureau of Mineral Resources, Geology and Geophysics, Canberra, ACT, Australia, Bulletin 63, 205p.

Glenister, BF, Windle, DF and Furnish, WM 1973, Australasian Metalegoceratidae (lower Permian ammonoids): Journal of Paleontology, v. 47, no. 6, p. 1031–1043, <https://www.jstor.org/stable/1303165>.

Hill, D 1942, Further Permian corals from Western Australia: Journal of the Royal Society of Western Australia, v. 27, p. 57–75, <https://www.biodiversitylibrary.org/part/237992>.

Morris, NJ, Dickins, JM and Astafieva-Urbaitis, K 1991, Upper Palaeozoic Anomalodesmatan Bivalvia: Bulletin of the British Museum of Natural History (Geology), p. 51–100, < https://www.biodiversitylibrary.org/part/83294>.

Meanarra Hill

Rhynchonellata			
	Rhynchonellida	Basiliolidae	*Eohemithyris wildei*
		Notosariidae	*Tegulorhynchia hrodelberti*
	Terebratulida	Bouchardiidae	*Bouchardiella cretacea*
		Chlidonophoridae	*Gisilina ovata*
		Inopinatarculidae	*Inopinatarcula acanthodes*
		Kingenidae	*Kingena mesembrina*
		Zenobiathyridae	*Zenobiathyris mutabilis*

Source:

Craig, RS 1999, Late Cretaceous brachiopods of the Perth and Carnarvon Basins, Western Australia: Records of the Western Australian Museum, v. 19, p. 413–442.

Kockatea Shale (Mount Minchin)

Cephalopoda			
	Ammonoidea	Arctoceratidae	*Arctoceras* sp. A
			Arctoceras sp. B
		Prionitidae	*Anasibirites kingianus*
			Hemiprionites sp.
			Prionites sp.

Source:

Skwarko, SK and Kummel, B 1974, Marine Triassic molluscs of Australia and Papua New Guinea, *in* Palaeontological Papers 1972 *edited by* DJ Belford, D Burger, SK Skwarko and B Kummel: Bureau of Mineral Resources, Geology and Geophysics, Bulletin 150, p. 111–139.

Note: the species listed are only for localities in this guide and exclude trace fossils

RECORD 2023/16

PALAEO DOWN UNDER 3 POST-CONFERENCE EXCURSION GUIDE
NORTHERN PERTH BASIN, 17–20 JULY 2023

Compiled by AJ Mory and H Ryan

Further details of geoscience products are available from:

First Floor Counter
Department of Energy, Mines, Industry Regulation and Safety
100 Plain Street
EAST PERTH WESTERN AUSTRALIA 6004
Phone: +61 8 9222 3459 Email: publications@dmirs.wa.gov.au
www.dmirs.wa.gov.au/GSWApublications