# AUSTRALIAN REGOLITH GEOSCIENTISTS ALLIANCE

May 2023

## ARGA NEWS AND UPDATES

**See you at the Australian Earth Sciences Convention in Perth!**

The ARGA Committee can't believe its May already, where has the year gone? We hope to see as many of you as possible at the upcoming Australian Earth Sciences Convention in Perth, June 26th to 30th. ARGA will be hosting the ARGA Symposium on the Tuesday and Wednesday. The symposium will focus on: Mineral exploration in weathered and covered terrains on day 1, while on day 2 the focus will be on Australasia's changing landscapes. ARGA are very excited to present two fantastic keynote speakers for these special sessions:

- Faster, smarter mineral exploration in regolith terrains by mapping, planning and interpretating in 3D, while thinking in 4D – Simon Bolster (Tues, 3 pm)
- Landscape evolution models of Australia's northern margins since the Cretaceous using coupled climate, surface process, tectonic, and geodynamic models - Sabin Zahirovic (Wed, 10 am)

Of course, the AESC program is jam packed with fantastic research, case studies and innovations and this represents a rare chance for the ARGA Specialist Group to mix and promote regolith geoscience within the GSA. There is still time to register for the conference, so if you are on the fence about attending – maybe the ARGA Symposium fieldtrip will change your mind? Check out full details in the next section! The ARGA Annual AGM will also be held at 5 pm (AWST), Tues 27th June – please check out the special post about the AGM and how to be involved, if not attending the AESC. The program may be downloaded from: [https://aesc2023.com.au/program/](https://aesc2023.com.au/program/)


**Sea to Scarp – ARGA Symposium Fieldtrip, Thurs 29th June 2023**

Are you visiting Perth for AESC or based in WA? Do you want to learn about the geology and landscape of the Perth area? Then you need to book in for ARGA's Specialist Group fieldtrip, Sea to Scarp. This excursion will take you from Perth's historic port at Fremantle, through the Swan Valley and to the reservoir which links the coast with the Yilgarn, piping water to Kalgoorlie. Registrations will open shortly, please register your interest with ARGA by emailing: secretary@regolith.org.au .

**NExUS 2023 Applications now open!**


Did you celebrate #MayTheFourth? NExUS certainly did! Here is a cheeky graphic to promote this excellent early career experience – please share with your colleagues and networks, as NExUS really does offer one of the only pathways to regolith course work. Applications for NExUS 2023 are open now and close on 31/07/2023.

For more information on the programs and how to apply please visit: https://set.adelaide.edu.au/nexus/apply

## REGOLITH SCIENCE ON THE WEB

***ARGA Webinar and Networking Event – Wednesday 31st May***

As we move closer to the AESC in June, ARGA hopes to keep connecting its members so we can make a real impact at AESC in Perth – and for those not able to attend the conference or AGM in Perth, we are able to connect via our Webinar and Networking Events. We look forward welcoming Prof. Anthony Dosetto from University of Wollongong (https://scholars.uow.edu.au/tony-dosseto) , presenting a talk with a focus on regolith and weathering processes based on his isotope studies (e.g. U-series, Li isotopes, etc). Make sure to register now and save the date – ***Wednesday 31st May, 130 pm (AEST).***

**CLICK HERE TO REGISTER!**

## WHAT'S NEW?

**ARGA gets professional – now on LinkedIn**

Have you noticed that the ARGA Specialist Group now has a LinkedIn presence also? That's right, ARGA will be posting updates, research, and opportunities via its LinkedIn page. Feel free to share any post and encourage others to Follow the page also. We welcome contributions and comments, insights, and questions. https://www.linkedin.com/company/australian-regolith-geoscientists-alliance-arga/

## UPCOMING CONFERENCES AND EVENTS

**26 June- 30th June 2023 – Australian Earth Sciences Convention, *Reimagining the Earth Sciences*, Perth**

Includes ARGA Symposium and AGM, register now- https://aesc2023.com.au/

**24th July 2023 – Regolith Geochemistry Workshop & Introduction to Exploration Hydrogeochemistry Workshop @ 6th International Archaean Conference, Perth**

https://6ias.org/workshops/

## KEEPING UP TO DATE WITH ARGA

Australian Regolith Geoscientists Alliance ARGA on the web https://regolith.org.au/

ARGA LinkedIn Page https://www.linkedin.com/company/australian-regolith-geoscientists-alliance-arga/

ARGA Facebook page https://www.facebook.com/groups/10150125426600193/

ARGA is on TWITTER! https://twitter.com/AusRegolith

ARGA is on INSTAGRAM https://www.instagram.com/ausregolith/

**Would you like to contribute? Suggestions and feedback to:**

**Anna Petts secretary@regolith.org.au**

AESC ARGA Symposium
2023
day field trip

# Sea to Scarp

# Itinerary

List of stops

Departure Perth Convention Centre/Elizabeth Key

1. Site 1. Fremantle Round House
2. Site 2. Peppermint Grove
3. Site 3. Kings Park - Swan River Estuary View

   Lunch at Guilford

4. Site 4. All Saints Church
5. Site 5. John Forest National Park
6. Site 6. Mundaring Weir – Pump station 1

   Sundowner at Mundaring Weir Hotel

   Return to Perth Convention Centre/Elizabeth Key

# Introduction

Ancient igneous and metamorphic rocks form the line of hills on the eastern horizon of Perth; younger, softer sediments make up the flat coastal plain. These two geological features define the character of the Perth Region The steep rise in topography from the eastern edge of the coastal plain up to the hills is called the Darling Scarp. This scarp* is the surface expression of the Darling Fault (Fig. 2), which is one of the major fractures in the Earth's crust — it extends for almost 1000 km, from east of Shark Bay, in the State's northwest, to Point D'Entrecasteaux on the south coast. Rapid erosion of the rocks along the scarp prior to the Cretaceous period has caused the scarp to retreat 1–3 km inland of the actual line of the fault The sedimentary rocks of the coastal plain lie in the Perth Basin (Fig. 2), which is part of a rift valley that developed between what is now Australia and a region that was to the north of India, when those continents were part of a supercontinent called Gondwana (Veevers et al., 1975). From time to time the sea flooded onto Gondwana, typically along narrow gulfs like the present-day Red Sea. These gulfs were destined to be the lines along which the supercontinent would fragment. The western and southern coastlines of Western Australia are the sites of such gulfs, and the Perth Basin is at the southern end of the gulf that extended south from the ancient Tethys Ocean.

The area east of the Darling Fault forms part of the Yilgarn Craton (Fig. 2) — a stable craton of Archean rocks that occupies much of the southern half of Western Australia. The oldest rocks in the Yilgarn Craton near Perth are metamorphic, and are found in a distinct belt along the Chittering Valley and near Toodyay (60 km northeast of Midland) and Canning Dam. Most of these rocks were originally muds and sands that were deposited in ancient seas between 3170 and 2830 million years ago (Wilde, 2001). Earth movements about 2800 million years ago altered these ancient sedimentary rocks into the metamorphic rocks we see today. About 2600 million years ago large volumes of granitic magma were forced into the pre-existing metamorphic rocks before cooling and solidifying. Monzogranite is the most common rock type and is intimately mixed with the gneissic metamorphic rocks of the Chittering Valley.

After granite magmatism ended the Yilgarn Craton became stable. About 1400 million years ago a zone of deformation and mobilization developed on its western margin, and the Darling Fault was formed. Sedimentary rocks were deposited at the foot of the Darling Scarp that belong to the Cardup Group (Low, 1972; Playford et al., 1976) and consist of conglomerate, sandstone, siltstone, and shale. These sedimentary rocks are Proterozoic in age, possibly around 1400 million years old (Fitzsimons, 2003), and rest directly on the Archean granites of the Yilgarn Craton. They are unrelated to the sedimentary rocks in the Perth Basin.

Sediments from eroded continental rocks started to accumulate in the Perth Basin about 460 million years ago in the Ordovician period. This predominantly fluvial sedimentation prevailed through to the Late Jurassic and earliest Cretaceous periods, some 140 million years ago. During these times major faulting took place in the basin along the zone of crustal weakness that had developed in this part of Gondwana.

During the Early Cretaceous period, sea-floor spreading was initiated west of the basin, and Gondwana began to break up as Greater India moved slowly away from Australia (Veevers and Cotterill, 1978). Initially, the whole of the Perth Basin was affected by uplift and erosion, but with the onset of sea-floor spreading much of the central and southern Perth Basin subsided, allowing the ocean to advance from the west. Large thicknesses of marine sediments were deposited as the sea over the Perth Basin grew wider and deeper. Uplift and erosion occurred again throughout the basin in Late Cretaceous to Paleogene times. During the Paleogene there was initially some marine carbonate sedimentation followed by continental clastic sedimentation. The Paleogene was also a period when exposed rocks of the Darling and Dandaragan Plateaus were deeply and intensely weathered, resulting in a widespread cover of lateritic materials. Although more pronounced during the Paleogene, this weathering has continued until geologically recent times. These lateritic materials are iron rich and aluminium rich, and form strongly cemented, hard cappings to rocks on ridges (duricrusts), and discontinuous aprons of gravels up to 2 m thick on slopes flanking the ridges. The duricrusts and gravels overlie pale-coloured and mottled clays of intensely weathered granites, dolerites, and Cretaceous sedimentary rocks.

The youngest sedimentary rocks of the Perth Basin were deposited during Neogene and Quaternary times. They are unconsolidated or partly lithified, and formed during erosional and depositional events related to periods of higher and lower sea levels during Pleistocene and Holocene times (Quilty, 1977). These sedimentary rocks consist mainly of sands, limestones, silts, clays, and gravels of marine, estuarine, and eolian origin. Figure 3 comprises a series of geological sections to show the stratigraphic relationships of these younger formations. The diagram on the inside back cover is an expansion of the geological time scale covering the Quaternary period.

This Field guide geological sites and information are from and based on the following publications:

[1] Geology and landforms of the Perth Region, CODE 978 1 74168 072 0 - Department of Mines, Industry Regulation and Safety Bookshop (eruditetechnologies.com.au)

[2] https://dmpbookshop.eruditetechnologies.com.au/product/john-forrest-national-park-railway-reserve-heritage-geotrail-geology-explorer.do

## Geology and landforms of Perth Region

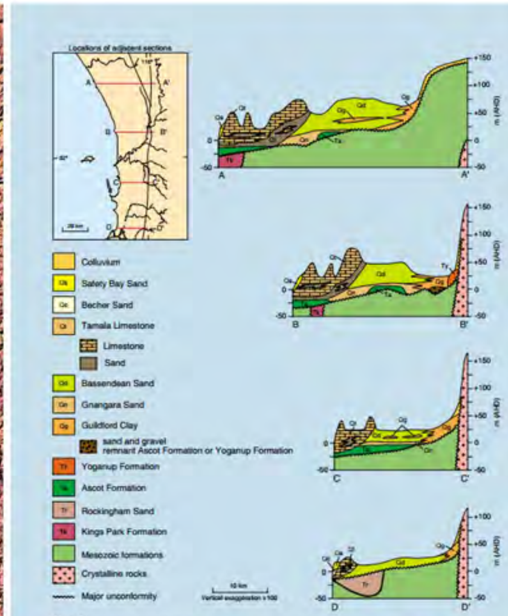




*Figure 3.*
*Geological sections showing the stratigraphic relationships of the superficial formations (after Davidson, 1995)*

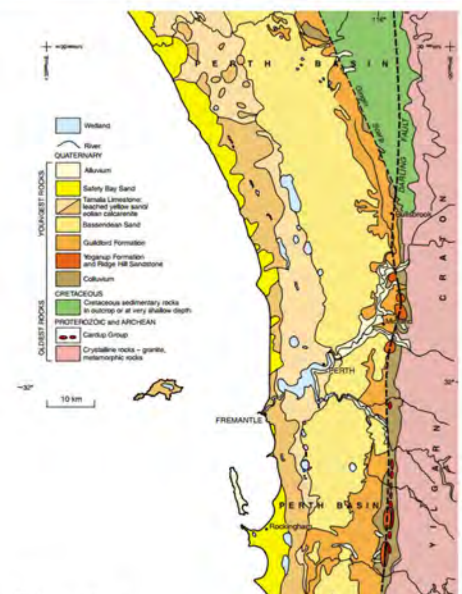
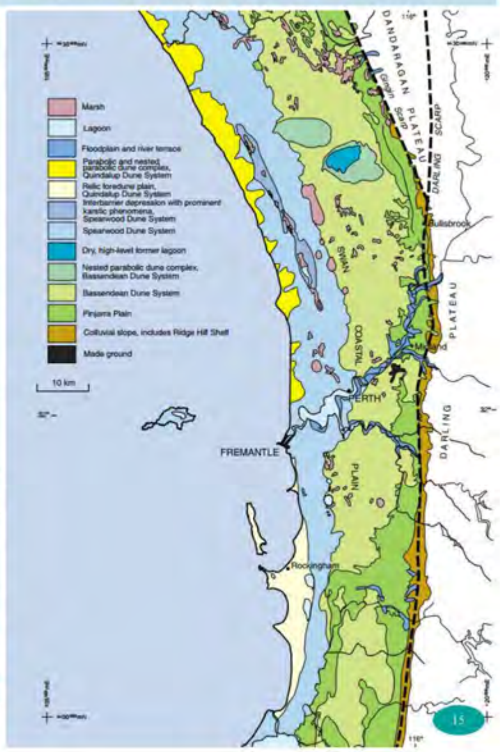



*Figure 2.*
*Simplified geology of the Perth Region (modified from Davidson, 1995)*



# Site 1 Fremantle Round House

- The Swan River Estuary,
- String of Islands including Rottenest Island,
- Traditional owners stories
- The Round House – Tamala Limestone
- The Whalers Tunnel

[1] Marine deposits of Pleistocene age are fairly widespread along the west coast of Western Australia. In the Perth region limestones of this age form discontinuous pockets and lenses of shelly Calcarenite, interbedded with eolian Calcarenite of the Spearwood Dune System. These shallow-marine and beach deposits are known as the Tamala Limestone, and they form a series of cemented coastal sand dunes. The offshore reefs and islands in the region represent drowned lines of these sand dunes that were deposited during periods of lower sea level. At least three chains of offshore reefs and islands can be distinguished south of Fremantle including Rottnest Island, Carnac Island, Garden Island (Google Earth Image). Outcrops of marine units within the Tamala Limestone can be seen along the river and ocean shorelines around the Cottesloe – Mosman Park area, in the cliffs along the shore line, and quarries on Tim's Thicket Road at Dawesville, 16 km southwest of Mandurah. A number of interesting features are developed within exposures of Tamala Limestone across the Perth Region. These include paleosols, rhizoliths, calcreted surfaces (beach rock), karstic features (e.g. sinkholes, caves), raised beaches, and elevated shoreline platforms. South of the Perth Region, between Mandurah and Bunbury, fossiliferous marine and estuarine limestones within the Tamala Limestone formation form the Yoongarillup Plain — a strip of low, undulating ground between the Spearwood and Quindalup Dune Systems (Gozzard, 2007, Semeniuk, 1990).

**The Roundhouse History**

The Roundhouse is the oldest public building in the State of Western Australia. Opened in January 1831, just 18 months after settlement, it was built to hold any person convicted of a crime in the settlement and was used until 1886.

After it ceased being used as a gaol it became a Police Lock-up until the late 1890s and then was used as accommodation for the Water Police, and afterwards as a storage facility for Fremantle Ports. When threatened with demolition in the 1920s it was saved and later control went to the State Government before it was deeded to the City of Fremantle.

Information and Images from https://www.fremantleroundhouse.com.au

**Whalers Tunnel**

Civil engineer Henry Reveley supervised the construction of the Whalers Tunnel (1837-38) which runs underneath the Round House jail, through Arthur Head. It was (as a sign says) the first underground engineering project in the colony and 'convict labour' was used - meaning the labour of convicted men who were imprisoned in the jail, not that of transported convicts, who did not begin to arrive until 1850.

Information from https://fremantlestuff.info/buildings/whalerstunnel.html

**Geology of Rottnest Island**

Digital StoryMap and a geology guide app and pamphlet available from https://www.dmp.wa.gov.au/Geological-Survey/Geology-of-Rottnest-Island-16421.aspx

**Wadjemup, the Noongar name of the island, is often referred to as 'the place across the water where the spirits are'**

For Aboriginal people across Western Australia, Wadjemup / Rottnest Island is a significant place. Once connected to the mainland some 6,500 years ago, Wadjemup was used by the Whadjuk Noongar people for important ceremonies and meetings. After the sea levels rose Wadjemup was no longer accessible by land and there is no physical evidence that Whadjuk Noongar people visited Wadjemup after the completion of islandisation and European settlement.

Following the colonisation of Western Australia in the early 1800s, Wadjemup played an increasingly sorrowful role in Aboriginal history. European settlers established Wadjemup first as a prison, incarcerating thousands of Aboriginal boys and men from across Western Australia, then as a forced labour camp – known as the Rottnest Island Aboriginal Establishment.

Information from https://www.rottnestisland.com/learn/history/aboriginal-history

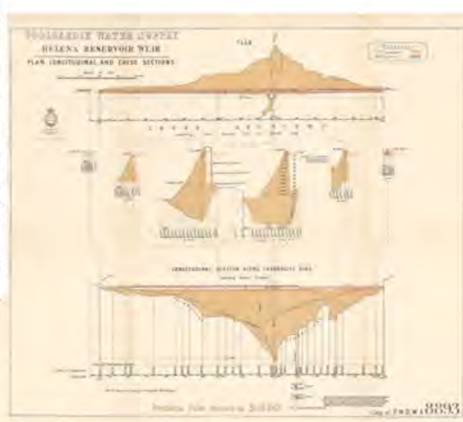
# C. Y. O'Connor

C.Y. O'Connor -State Library of Western Australia

Charles Yelverton O'Connor CMG (11 January 1843 – 10 March 1902) was the first Engineer-in-Chief of Western Australia.
Recruited by Sir John Forrest, the Premier of Western Australia at the time, he was tasked with improving the colony's railways, roads, water supply, and harbours.
His two most notable projects included the development of Fremantle Harbour and the Goldfields Water Supply Scheme.
he Goldfields Water Supply Scheme received a significant amount of unwarranted criticism—particularly from the media.
The unrelenting criticism, delays, and the lack of funding and co-operation took its toll on O'Connor who chose to take his own life on 10 March 1902.
That morning he took his customary early morning horse ride past Fremantle Harbour, then south to Robb Jetty. Once there he rode his horse into the sea and shot himself.
O'Connor unfortunately did not live to see the successful completion of his Goldfields Water Supply Scheme.
In 2009, the American Society of Civil Engineers named the Goldfields pipeline an International Historic Civil Engineering Landmark.
At the time of its opening the project was the largest engineering undertaking of its time. The amount of steel used in construction was greater than any steel structure elsewhere in the world, and never before had water been pumped so far or lifted so high.
The Goldfields pipeline is also listed on the National Heritage List as it continues to generate billions of dollars in economic activity. Despite a decline in the production of gold, the regular supply of water to the Goldfields meant that agriculture was able to prosper.
Today Western Australia's wheat fields are the most productive in Australia, accounting for 42% of the nation's wheat crop. In addition to this six million sheep rely on the water that the pipeline carries.
Information from Culture WA
https://culture.wa.gov.au/feature/c-y-oconnor#block-mainnavigation





# Site 2- Peppermint Grove and Minim Cove

**Eolian and Marine calc arenites units of the Tamala Limestone**


## Peppermint Grove

[1] The foreshore of the Swan River at Peppermint Grove (Fig. 9) is an excellent location to observe the relationship between eolian calcarenites and shelly marine units of the Tamala Limestone. The marine units here constitute the type section of the Peppermint Grove Member and they can be seen to interfinger with the eolian parts of the Tamala Limestone.

The northern end of the outcrop, about 80 m north-northeast of the Scotch College boatshed, is a section that records the continuing retreat of the sea (regression), from a shallow-marine environment to a beach environment (Fig. 10). The base of the section comprises a 1.4 m-thick, medium-scale cross bedded calcarenite unit, indicative of offshore deposition in shallow water. In this environment, water currents cause ripples in the sediment to migrate, and as the lee sides avalanche, dipping foreset laminae are produced. The orientation of the cross-beds therefore indicates the direction of the currents. The cross-bedded calcarenite is overlain by a 0.9 m-thick, ripple-bedded calcarenite unit. Ripple beds form as a result of the oscillating motion of waves, and therefore indicate deposition in a near-shore surf zone. The ripple-bedded unit is overlain by a 1.6 m-thick, planar-bedded calcarenite, which indicates high-energy movement of sediment in a foreshore beach environment.

After further regression, this location became relatively high compared to the retreating shoreline, and the top of the planar-bedded unit became an erosional surface on which calcrete developed during a phase of subaerial soil formation and weathering. Above this calcrete paleosol is a variably thick (up to 0.6 m), slightly shelly calcarenite that is up to 7.3 m above the present sea level. This indicates that there was a later episode of marine deposition, during which the sea level was about 7.5 m higher than it is today (Playford et al., 1976).

A thick (2.5 m) sequence of large-scale cross-bedded calcarenite overlies the complete marine sequence. These large-scale cross-beds represent the avalanching lee sides of migrating dunes through the action of wind, and indicate that a major dune-building episode followed the period of marine and shoreline deposition.

*Figure 10.*
*Shallow-water cross-bedded and ripple-bedded marine calcarenite grading up into planar-bedded beach calcarenite at Peppermint Grove (MGA 384020E 6459370N)*

*Figure 11.*
*Brecciated calcrete (left of photo) draping shelly marine units at Peppermint Grove (MGA $_{3}$84015E $_{64}$59345N)*



*Figure 13.*
*Thick, planar-bedded, shelly marine calcarenite at Peppermint Grove (MGA $_{3}$84005E $_{64}$59330N)*

In the central part of the section, about 55 m north-northeast of the boatshed, near the prominent cave, there is a sequence similar to that farther north. However, in this location a thick development of brecciated calcrete drapes the underlying calcrete and marine units (Fig. 11). This brecciated calcrete is probably cemented beach material (beach rock) that later formed a low fossil cliff. An unusual feature at this locality is the eye-catching brown and black limestone pebbles within the brecciated calcrete (Fig. 12). These pebbles appear to be restricted to a single vertical zone and may represent the remains of a neptunian dyke, which filled a former undersea fissure or hollow.


*Figure 13.*
*Thick, planar-bedded, shelly marine calcarenite at Peppermint Grove (MGA $_{3}$84005E $_{64}$59330N)*

At the southern end of the section, about 40 m north-northeast of the boatshed (Fig. 13), a 1.7 m-thick unit of abundantly shelly calcarenite abuts and overlies the brecciated calcrete. This unit thins to the south and is overlain by a 0.8 m-thick unit of planar-bedded calcarenite, which thickens to the south. These two units represent another phase of beach deposition. The planar-bedded calcarenite is overlain by about 5 m of large-scale, cross-bedded eolian calcarenite. The planar bedded and cross-bedded calcarenites show extensive development of small- to large-scale rhizoliths.

The brecciated calcrete is interpreted as cemented beach rock, and it can be seen to abut an eroded mass of eolian calcarenite (Fig. 15). This rocky mass was undoubtedly a small rocky point or promontory on the beach. On top of this former rocky point is a third discrete shelly calcarenite containing scattered shells similar to those in the basal shelly calcarenite. The similarities between the marine units at The Coombe and those at Peppermint Grove indicate a close correlation between the two sites in terms of their respective geological histories and environments of deposition.

Based on electron spin resonance, Kendrick et al. (1991) concluded that the upper shell unit at The Coombe is the same age as that at Peppermint Grove, deposited in the second-last interglacial period (Oxygen Isotope Stage 7), and conjectured that the lower shell unit was either deposited in the same period or earlier (Oxygen Isotope Stage 9). Thus, the deposits at The Coombe were probably deposited in the same, seaward part of the estuary as the Peppermint Grove rocks.


*Figure 15.*
*Beach rock (left of photo) abutting and overriding a low fossil cliff (right of photo) at The Coombe (MGA $_{3}$84385E $_{64}$57475N)*

## Minim Cove

The marine units exposed in the cliff sections along the foreshore of the Swan River west of Point Roe (MGA* 384200E 6456140N) are different from those at Peppermint Grove. The type section for these units – the Minim Cove Member of the Tamala Limestone (Fig. 16) – is best exposed at Minim Cove, where two richly fossiliferous units lie within a mainly eolian sequence of calcarenites.

At the base of the section is a lower shell unit comprising a basal, 1.1 m-thick, medium-scale, cross-bedded, shelly calcarenite and an overlying, 0.3 m-thick, planar-bedded, richly fossiliferous calcarenite. The shells in both parts of this unit are a diverse assemblage of mainly molluscs with both valves still joined. The orientation of the shells in the lower part suggests deposition in quiet, shallow marine conditions, whereas the orientation of those in the upper part indicates high-energy current deposition, such as in a beach environment.

Overlying this richly fossiliferous calcarenite is 0.9 m of large-scale, cross bedded, eolian calcarenite. Above this, an upper shell unit comprises 0.2 m of planar-bedded, richly fossiliferous calcarenite, followed by 1.1 m of sparsely shelly calcarenite containing some accumulations of shells and shelly debris.

The top of this upper shell unit is about 4.5 m above river level. Overlying the upper shell bed sequence and extending to the top of the section is a thick sequence of large-scale, cross-bedded, eolian calcarenite, which represents a major dune-building episode that followed the period of marine and shoreline deposition. Solution pipes and small- to large-scale rhizoliths are common throughout the section.


*Figure 16. The section at Minim Cove (MGA 383470E 6456425N)*

#### What is the age of these beds?

Peppermint Grove Member of the Tamala Limestone - The molluscan faunas of the upper and lower shell units at Peppermint Grove have been described in detail by Kendrick (1960) and summarized by Playford et al. (1976). Kendrick (1960) considered the marine deposits to be Middle Pleistocene in age, before the last interglacial period, and concluded that they were deposited in a shallow-marine gulf during a period when temperatures were similar to those of today. In contrast, Chalmer et al. (1976) suggested that the marine units were deposited in the seaward part of an estuary with good oceanic exchange. More recently, studies undertaken to determine absolute ages of the marine units using electron spin resonance (Hewgill et al., 1983) and amino acid racemization (Murray-Wallace and Kimber, 1989) indicate that the upper shell unit was deposited in the second-last interglacial period (Oxygen Isotope Stage 7 or penultimate interglacial), between 190 000 and 240 000 years ago. The age of the lower shelly unit is more problematic because of the degree of weathering, and it could have been deposited during the same interglacial period as the upper shell unit (Oxygen Isotope Stage 7) or earlier, in the third-last interglacial period, between 300 000 and 340 000 years ago (Oxygen Isotope Stage 9 or ante-penultimate interglacial; Kendrick et al., 1991). These studies have also shown that the marine units at Peppermint Grove are significantly older than those at nearby Minim Cove, which were dated at about 132 000 years old (Szabo, 1979).

Minim Cove Member of the Tamala Limestone - Hewgill et al. (1983), using electron spin resonance, and by Murray-Wallace and Kimber (1989), using aminostratigraphy, has shown that the Minim Cove Member is last interglacial in age (Oxygen Isotope Substage 5e). Hewgill et al. (1983) also correlated the Minim Cove Member with the Rottnest Limestone (Playford, 1988) — a coral-reef limestone exposed at Fairbridge Bluff on Rottnest Island — which Szabo (1979), using uranium/thorium dating techniques, determined to be 132 000 ± 5000 years old.

# Site 3. Kings Park Swan River

https://www.flickr.com/photos/travelingotter/4475204662

Seismic survey was carried out across the metropolitan reach of the Swan River (Perth, Western Australia) to investigate its Late Quaternary sub-surficial geomorphology. Shallow imaging data, integrated with sediment cores, pre-existing literature (including dating) and LiDAR images, revealed three main units, forming a complex system of buried paleochannels, which developed during the Late Quaternary glacial sea level low stands, and infilled during interglacial high stands

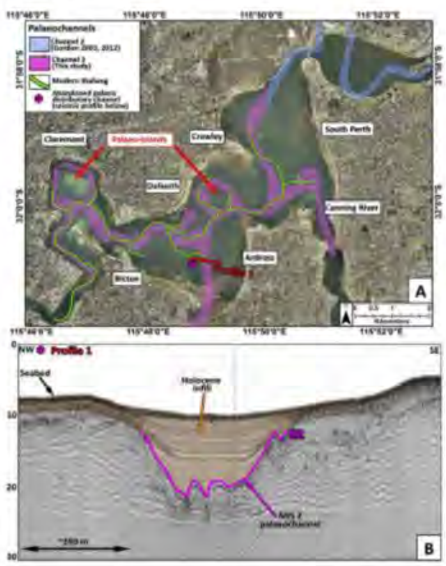



Fig. 6. A: sketch map of the palaeomorphology of Channel 2. The modern thalweg is marked in green. Although the modern and palaeo Swan River have a similar trend, the MIS 2 palaeochannel was likely significative narrower than the contemporary one. Aerial photo provided by Landgate (Western Australia). B: acoustic profile of the abandoned tributary. Depths are in metres, below the sea level.

The deepest unit (U3) is interpreted as the Perth Formation, which consists of ~20 m thick interbedded, fluvial to estuarine sediments that were deposited in a wide large paleo-valley that incised into the underlying basement Tamala Limestone and Kings Park Formation. This period spans ~130- 80 thousand years before present (BP) in the Last Interglacial

Middle -the Swan River Formation

The Perth Formation is overlain by a ~27 m thick unit (U2), composed of heterogenic fluvial to lacustrine sediments, deposited during the Last Glacial lowstand (~80-18 thousand years before present. Similar to U3, U2 also infills channels incised in older deposits and reflects the hydrogeological conditions linked with sea level changes during the Last Glacial lowstand.

Shallowest unit comprises Holocene fluvial and estuarine sediments, up to ten-thousand-year-old. Holocene (last ~10 ky) fluvial and estuarine deposits form the shallowest unit (U1). These sediments are up to 14 m thick and have a highly variable internal structure, ranging from layered to chaotic deposits. The Holocene sediments are also found filling paleochannels and blanketing the pre-existing topography.

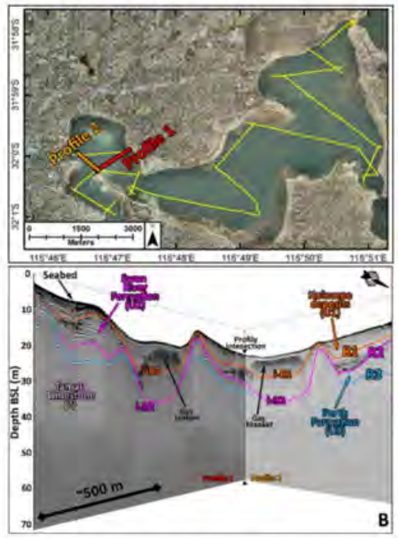



**Figure 1. Top: Locality map showing the study area. Seismic survey track plot is marked, in yellow. Bottom: Intersecting seismic cross section showing the buried geology described in the text. Length of profile 1: ~ 1000 m; length of profile 2: ~650 m.**

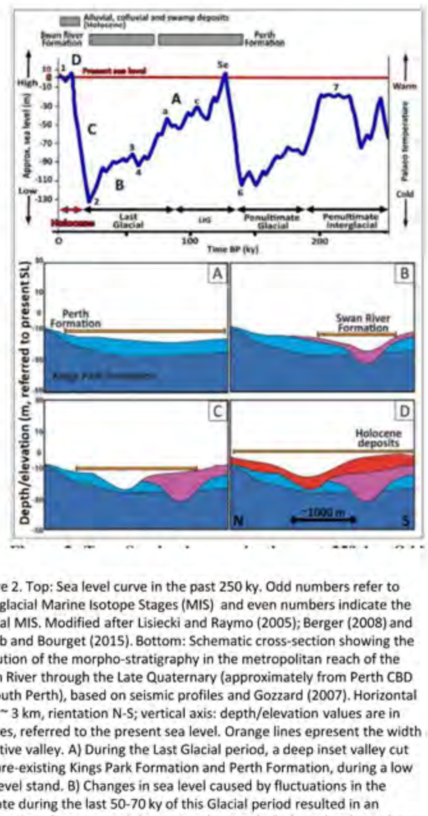



Figure 2. Top: Sea level curve in the past 250 ky. Odd numbers refer to Interglacial Marine Isotope Stages (MIS) and even numbers indicate the Glacial MIS. Modified after Lisiecki and Raymo (2005); Berger (2008) and Saqab and Bourget (2015). Bottom: Schematic cross-section showing the evolution of the morpho-stratigraphy in the metropolitan reach of the Swan River through the Late Quaternary (approximately from Perth CBD to South Perth), based on seismic profiles and Gozzard (2007). Horizontal axis: ~ 3 km, rientation N-S; vertical axis: depth/elevation values are in metres, referred to the present sea level. Orange lines epresent the width of active valley. A) During the Last Glacial period, a deep inset valley cut the pre-existing Kings Park Formation and Perth Formation, during a low sea level stand. B) Changes in sea level caused by fluctuations in the climate during the last 50-70 ky of this Glacial period resulted in an alternation of erosion and deposition during which the paleochannel was filled with the variegate sediments of the Swan River Formation. C) Last Glacial Maximum (MIS 2, ~ 18 ky BP). As the sea level reached its lowest point, the most recent paleochannel was cut and successively (D) infilled with fluvial deposits through the Holocene interglacial conditions

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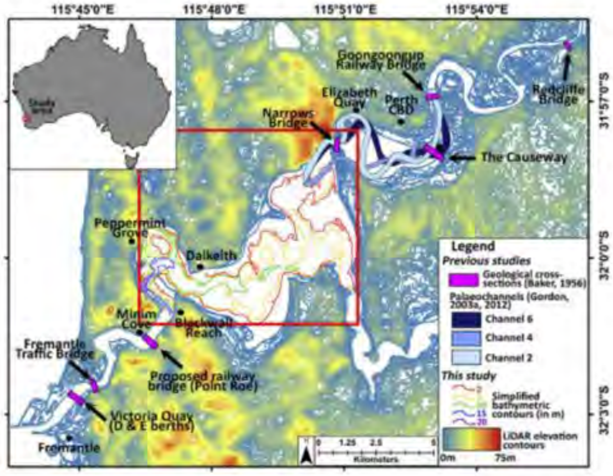


Fig. 1. Locality map showing the study area and locations mentioned in the paper. Simplified palaeochannels proposed by Gordon (2003a, 2012) are represented by 3 shades of blue, representing 3 cutting events. Baker's (1956) cross section locations are highlighted in pink. This study focused on the wide, underfilled middle reach of the Swan estuary, whereas Gordon's studies were restricted to the upper reach of the estuary. Simplified bathymetric contours, limited to the studied area, are also shown.
(Source: Department of Transport).

**Table 1**
Stratigraphic column (modified after Smith et al., 2012) and geological formations of the Swan Coastal Plain present within the survey boundaries (refer to Fig. 2 for the surface geology). Note 1: Tamala Sand is the result of weathering and remobilisation of relict material of the Tamala Limestone which has been blown eastward. Note 2: The Swan River Formation can be found along the middle and lower sections of the Swan and Canning Rivers. The development of this formation can be linked to the fluctuations of sea level. The Swan River Formation subcrops the modern Swan River Holocene estuarine and floodplain clays and sands. Note 3: The Perth Formation reflects the complex palaeoclimate and sea level oscillations that characterised the Last Interglacial period. Three main lithological units (sand, silt and clay) were deposited into a palaeochannel eroded during the earlier lower sea level conditions (Penultimate Glacial period) by the ancestral Swan River, into the Kings Park Formation.

| Stratigraphic column | Formation/Deposit | Lithology | Depositional environment | Age | Notes | References |
|---|---|---|---|---|---|---|
| | Alluvial and swamp deposits | Peat and peaty sand, high clay | Alluvial and Swamp | Holocene | | Commander, 2003 |
| | Fluvial deposits | Silt sand, with clay | Fluvial and estuarine | Holocene | | Commander, 2003 |
| | Safety Bay Sand | Fine-medium sand | Near-shore/eolian | Holocene | | Davidson, 1995 |
| | Tamala Sand | Sand, with clay and silt | Near-shore/eolian | 25 to 15 ky BP | See Note 1 in table caption | Bastian, 1996; Gozzard, 2007a |
| | Swan River Fm | Sand, silt and clay | Heterogenic fluvial and estuarine | 75 to 18 ky BP | See Note 2 in table caption | Gozzard, 2007a |
| | Perth Fm | Interbedded sand, silt and clay | Estuarine to fluvial | 130 to 80 ky BP | See Note 3 in table caption | Gozzard, 2007a |
| | Tamala Limestone | Coarse to medium-grained, mostly cross-bedded calcarenite, with minor lenses of clay and gravel-sized lithoclasts | Eolianites, beachrocks, shallow marine beds, coral reefs and marl | Strongly diachronous; Mid-Late Pleistocene to Holocene | The Tamala Limestone has several members and within the study area, the marine units of Minim Cove Member and Peppermint Grove Member outcrop along the foreshore of the Swan River estuary near Point Roe | Murray-Wallace and Kimber, 1989; Brooke, 2001; Gordon, 2003b |
| | Bassendean Sand | Sand, with lens of clay | Fluvial to estuarine | Middle to Late Pleistocene | Bassandean Sand interfingers to the east with Guildford Fm | Gozzard, 2007b |
| | Gnagara Sand | Very poorly sorted sand | Fluvial to estuarine | Middle Pleistocene | Stratigraphic equivalent of the Guildford Formation | Gozzard, 2007a |
| | Ascot Fm | Shelly calcarenite, silty clay | Marine prograding shoreline | Late Pliocene to Early Pleistocene | Some sections contain fresh-water gastropods (proximity of lake/swamp?) | Kendrick et al, 1991 Gozzard, 2007a |
| | Guildford Fm | Mainly clay and silt, with also lenses of poorly sorted sand and conglomerate | Fluvial, with shallow-marine and estuarine lenses | Early Pleistocene to about 130 ky BP | General fining-upwards sequence, almost without interruption | Davidson, 1995; Gozzard, 2007a; Gozzard, 2007b |
| | Kings Park Fm | Shale, calcareous sandstone and minor limestone | Shallow marine to estuarine deposits | Early Tertiary Palaeocene - Lower Eocene | 600 m thick valley-fill. The marine shale facies may be related to an old submarine canyon that converged in the ancestral Swan River | Quilty, 1974; Collins, 1987; Hudson-Smith and Grinceri, 2007; Mathew, 2010 |



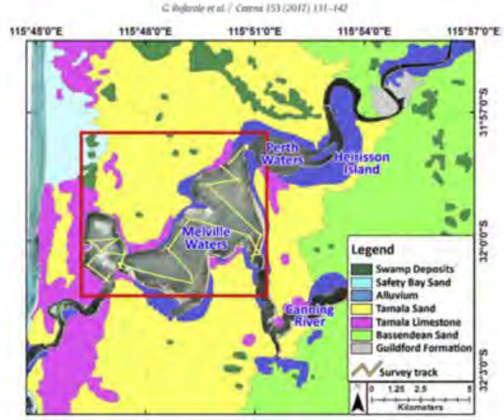


Fig. 2. Simplified surface geology (redrawn after Davidson, 1995 and Gozzard, 2007a), superimposed on Landgate (Western Australia) aerial image. Formation ages are included in Table 1. Geophysical survey track plot and survey boundaries are also marked, in yellow.