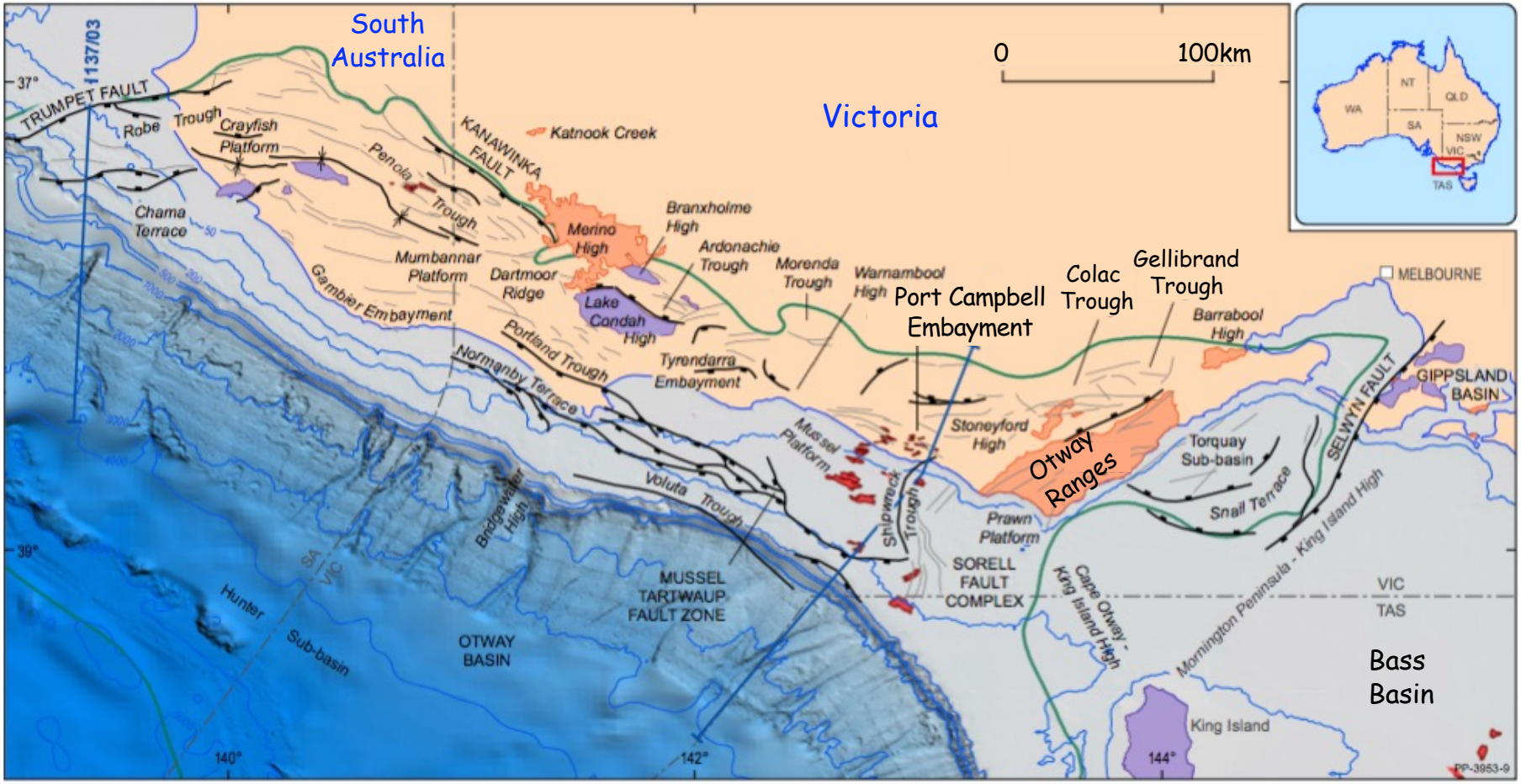
# U3A Geology

## Victorian west coast excursion

# Otway Basin

- Late Jurassic – Cretaceous Otway Basin formed during rifting between Australia and Antarctica
- basin covers an area 60,000km$^2$ across SW Victoria
- basin → broadly NW to SE striking → extending for approximately 500km along onshore and offshore parts of SE Australia
- approximately 80% of the basin is located offshore and 20% onshore
- basin formation → initiated in Mesozoic and was followed by the deposition of a thick sequence of Mesozoic and Cenozoic sediments

# Otway Basin


South Australia
Victoria
0
100km
TRUMPET FAULT
1137/03
Robe Trough
Crayfish Platform
Penola Trough
KANAWINKA FAULT
Katnook Creek
Chama Terrace
Merino High
Branxholme High
Ardonachie Trough
Morenda Trough
Warrambool High
Port Campbell Embayment
Colac Trough
Gellibrand Trough
Barrabool High
MELBOURNE
Mumbannar Platform
Dartmoor Ridge
Lake Condah High
Gambier Embayment
Portland Trough
Normanby Terrace
Tyrendarra Embayment
Mussel Platform
Stonyford High
Otway Ranges
Torquay Sub-basin
SELWYN FAULT
GIPPSLAND BASIN
Voluta Trough
Bridgewater High
Shipwreck Trough
Prawn Platform
Snail Terrace
King Island High
SORELL FAULT COMPLEX
Cape Otway - King Island High
Mornington Peninsula
VIC
TAS
MUSSEL TARTWAUP FAULT ZONE
OTWAY BASIN
Hunter Sub-basin
SA
VIC
Bass Basin
King Island
37°
39°
140°
142°
144°
NT
QLD
WA
SA
NSW
VIC
TAS
PP-3953-9
Field outlines from the GPinfo petroleum database.
Eumeralla Formation
Buried Palaeozoic
Gas field
Basin outline
major fault
minor fault
normal fault
syncline

# Geological history of Otway basin

1. *Early rifting (Late Jurassic-Early Cretaceous)*

   As extension progressed, subsidence occurred. In excess of 5000m of non-marine fluvio-glacial sediments infilled basins

2. *Rift to sag transition (Early-Mid Cretaceous)*

   >4000m of Eumeralla sediments were deposited in a variety of non-marine environments. These sediments are characterised by a large amount of volcanic detritus from volcanic complexes

3. *Compression, uplift and Otway unconformity (Mid-Cretaceous)*

   Rifting ceased in Mid-Cretaceous as Otway Basin was subjected to significant compression → forming Otway unconformity

4. *Renewed rifting (early Late Cretaceous)*

   Renewal phase of extension and rift-related subsidence.

# Geological history of Otway basin

5. *Continental breakup (Late Cretaceous)*

   Moderate uplift resulted in Late Cretaceous unconformity. Rifting continued to control basin development through much of Cretaceous → post-rift succession composed of 3 sequences

6. *Subsidence and marine transgression (Palaeocene-Early Eocene)*

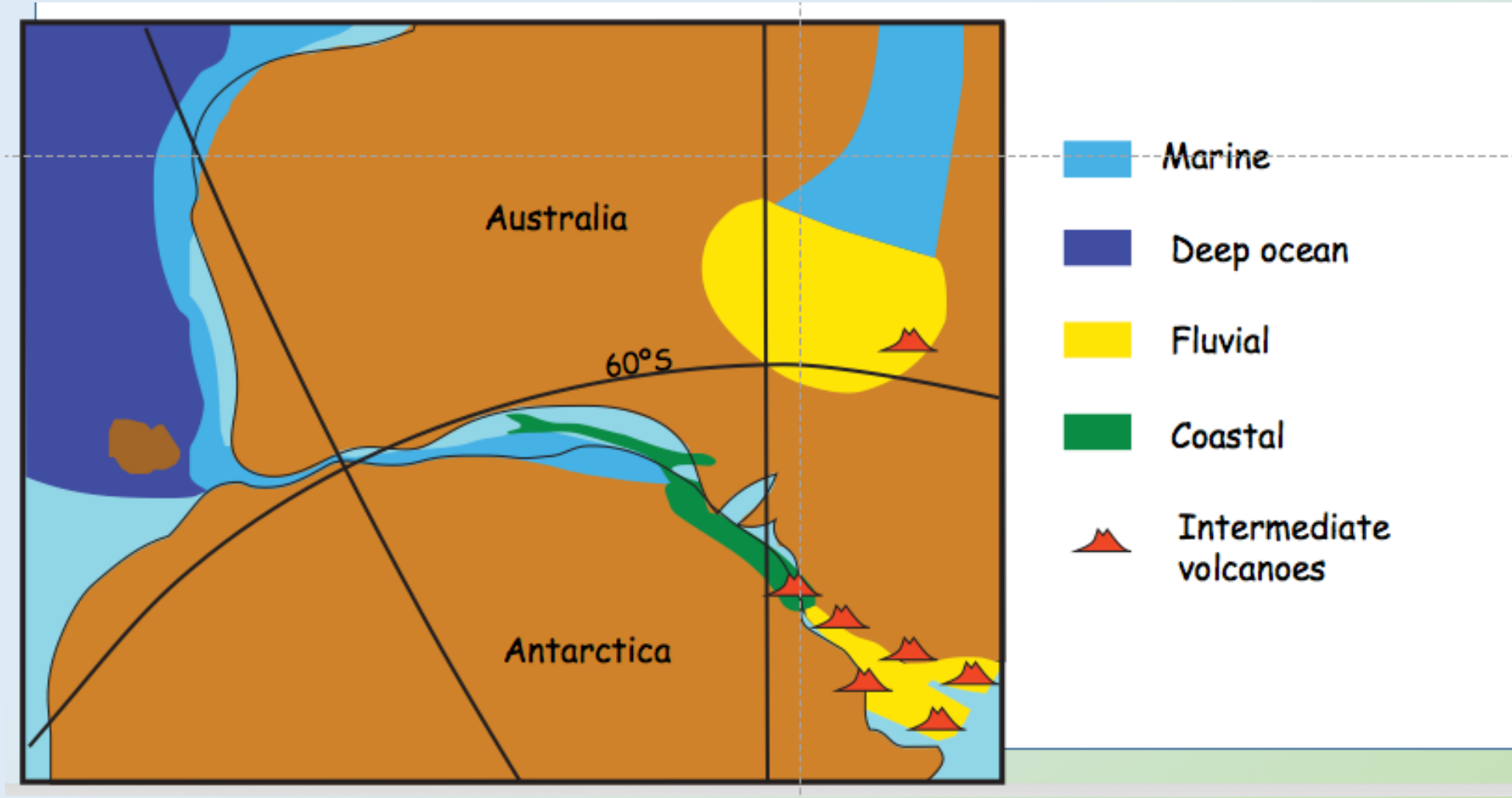
   Peneplain → flooded during marine transgression towards end of Cretaceous. After deposition of distal offshore shale → shallow shelf to coastal depositional environments created

7. *Seafloor spreading Southern Ocean (Mid-Eocene – early Oligocene)*

   Mid-Eocene erosional surface → incised by deep channels infilled and draped by Mid-Eocene to lower Oligocene, Nirranda Group of nearshore to offshore marine sediments

# Gondwana breakup, middle Cretaceous ~100mya

- Early stages of rifting marked by widespread volcanism
- non-marine sediments accumulated alluvial, fluvial, lacustrine envir.
- sediments composed dominantly of quartz-poor volcanic detritus



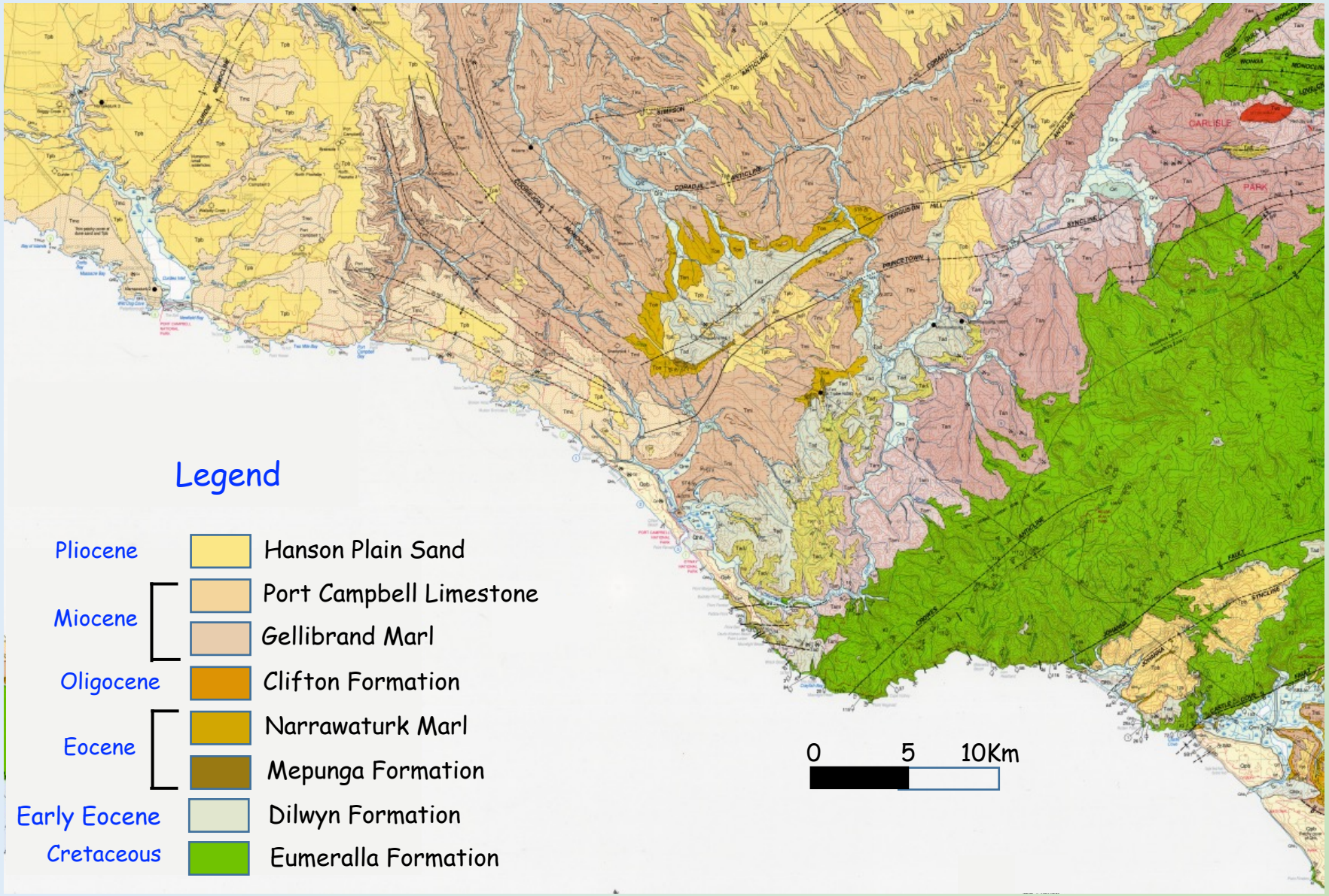
# Port Campbell Embayment

- The Port Campbell Embayment is located in SW Victoria covering the coastal region between Princetown and Peterborough
- erosional features: cliffs, stacks, gorges, caves, headlands and land bridges characterise the area
- two major Tertiary stratigraphic formations (Port Campbell Limestone and Gellibrand Marl) are exposed in beach cliffs along 80km of the Port Campbell coast
- limestone cliffs in the embayment are 30-60metres high and almost vertical
- wave cut platforms occur at several levels

# Port Campbell Embayment

- Sea level fluctuated significantly during the Tertiary Period
- when sea transgressed over coastal plains, several hundreds of metres of Port Campbell limestone was deposited in embayment
- in the Late Miocene (~5myr) the sea retreated from Port Campbell embayment
- produced break in sedimentation → then deposition of Pliocene shallow marine to beach deposits
- uplift in the Pliocene resulted in formation of ranges north of the embayment

# Port Campbell embayment geology



# Structure

- Overall pattern of surface structure → series of NE trending anticlines and synclines that increase in amplitude eastwards
- a number of faults are exposed by cutting Tertiary formations e.g. Point Pebble and Pebble Point
- distance between them is ~1km, they trend E-W and the block between them is down-faulted 10-15m
- both faults are high angle normal faults bounding a graben
- NW of Gibson's Beach, two minor reverse faults cut the Gellibrand Marl and Port Campbell Limestone

# Calcareous sedimentary rock nomenclature

marl – a calcareous mudstone with carbonate and clay in sub-equal amounts

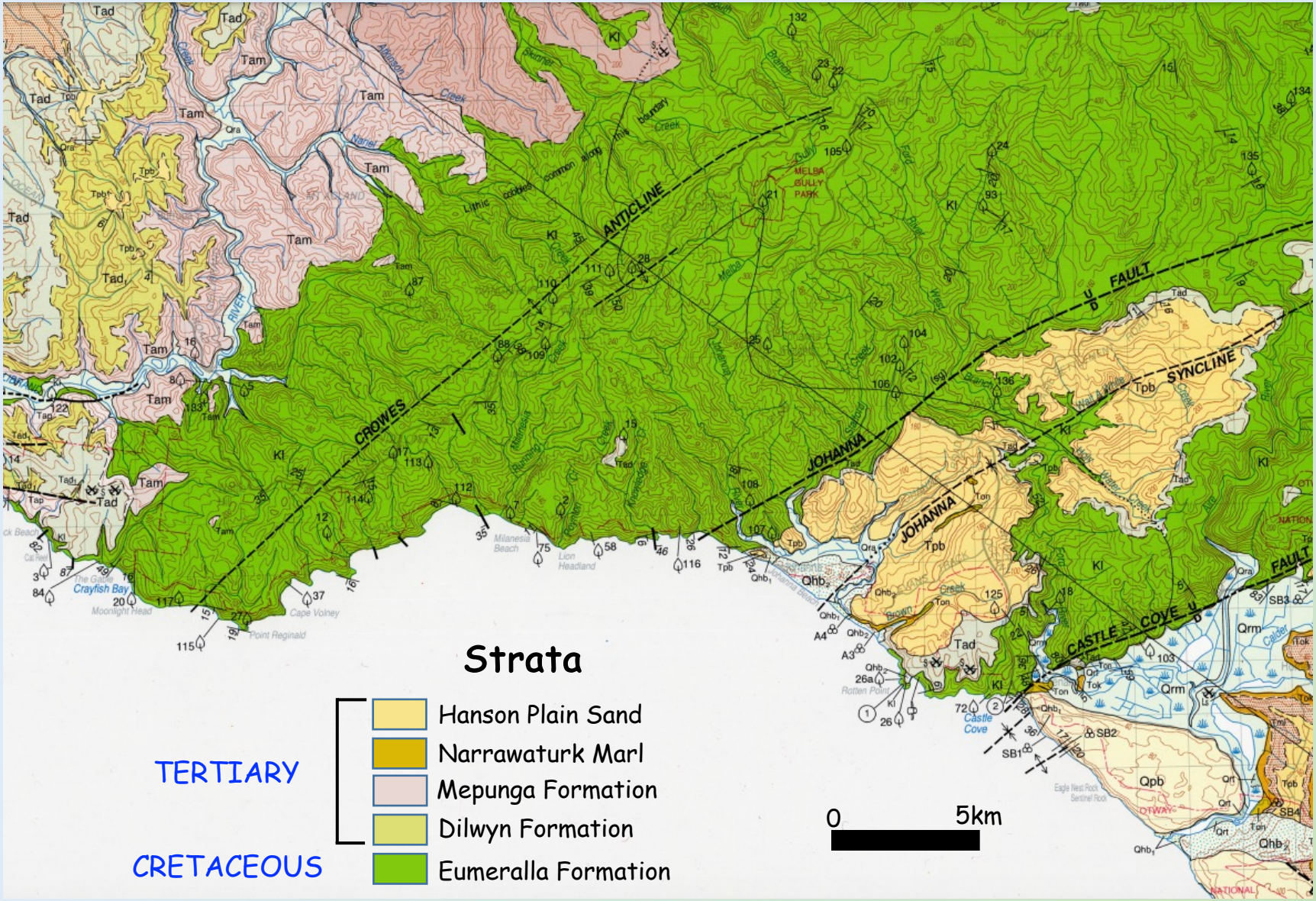
calcarenite – a calcareous sandstone composed of >50% detrital sand-sized, carbonate grains

calcisiltite – calcareous siltstone composed of >50% detrital silt-sized, carbonate grains

# Eumeralla Formation (Early Cretaceous)

- Eumeralla Formation forms the Otway Ranges and crops out over the entire onshore between Crayfish Bay and Castle Cove
- composed of fine to coarse-grained, chlorite cemented volcanogenic sandstones
- formation is 1-3km thick with an estimated 1.5-2.5km removed by erosion
- volcanism produced abundant pyroclastic material that was easily eroded and transported into a depositional basin
- the dominant volcanic suite that gave rise to the sediments was dacitic

# Eastern coastal Otway Basin



# Eumeralla Formation (Early Cretaceous)

- Eumeralla Formation consists primarily of fluvial sedimentary deposits derived from volcanic material
- sediments are folded as a result of NW-SE crustal compression that also activated Cretaceous faults
- the formation was deposited within the Otway Basin at the time that it was a rift valley formed between Australia and Antarctica
- in the Late Cretaceous the climate was cool and wet. Fluvial sediments → deposited by flooding rivers in a subsiding basin
- subsequent uplift of sediments formed the Otway Ranges

# Eumeralla Formation

- Sediments represent a massive anastomosing fluvial system
- sequences characterised by massive, planar and trough cross -bedded sandstone
- beds occur in thick, multistory channel belts of considerable thickness and lateral extent
- beds include palaeosol horizons and thin coal seams
- no marine fossils but, fossils of non-marine fish, insects, dinosaurs and plants are preserved in the rocks

# Eumeralla lithologies

- Sedimentary rocks are of two types, sandstone and mudstone
- sandstones → composed of sand-sized grains of volcanic rock, feldspar, quartz, pyroxene and hornblende
- because of high proportion of feldspar, sandstones are commonly called arkose or greywacke because of being poorly sorted
- mudstones → homogenous appearance, may be laminated
- when fresh, rocks have greenish-grey colour with chlorite from altered volcanic material

# Eumeralla volcanogenic sandstone

Major components in typical Eumeralla sandstone are:

| | |
|---|---|
| volcanic rock fragments | 35-53% |
| calcic plagioclase | 2-5% |
| quartz | 4-17% |
| diagenetic cement | 9-15% |

volcanic pyroxene, amphibole and accessories (apatite, zircon, titanite)

# Origin of Eumeralla Formation sediments

- Exact location of volcanoes subject of debate
- generally considered that they occurred on a landmass to the east called Zealandia before it moved away from Australia
- some geologists argue for their occurrence within the southern rift itself

# Environment of deposition

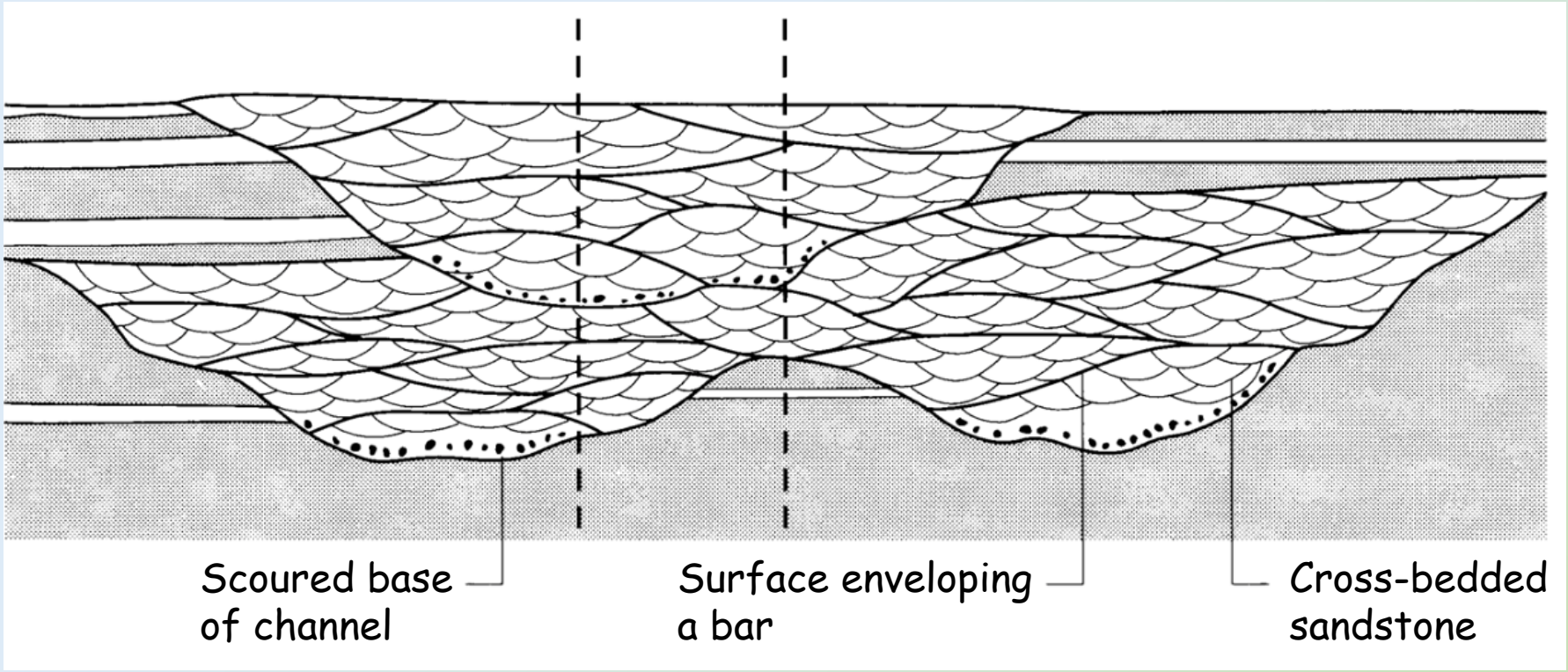
- Nature of sedimentary beds indicate that deposition occurred in complex braided channel systems on flood plains

- there are three main types:
  1. channel deposits
  2. braided bar or levee deposits – generally sandy with cross -bedding
  3. overbank flood deposits – fine sediments, sometimes laminated indicating flooding and submerging other deposits

- all of these occur repeatedly in stacked deposits → abundant supply of sediments as well as subsidence

# Lag and bar deposits

- Coarsest material is sorted out and left behind in deepest part of channel above scour base
- channel lag deposits consist of mudclasts and blocks (from bank erosion), plant debris, boulders and bed-load sand and gravel
- fining upwards of sediment



# Nirranda Group (Middle Eocene to Early Oligocene)

- Nirranda Group includes Middle Eocene to Early Oligocene clastic and carbonate rocks of the Otway Basin

- consists of two formations:

  (1) Mepunga Formation - lower Formation

  (2) Narrawaturk Formation – upper formation

- the top of the Nirranda Group is defined at base of the overlying Clifton Formation that is the basal unit of the Heytesbury Group

- the Group has an average thickness of about 200m but thins into the offshore area.

# Nirranda Group

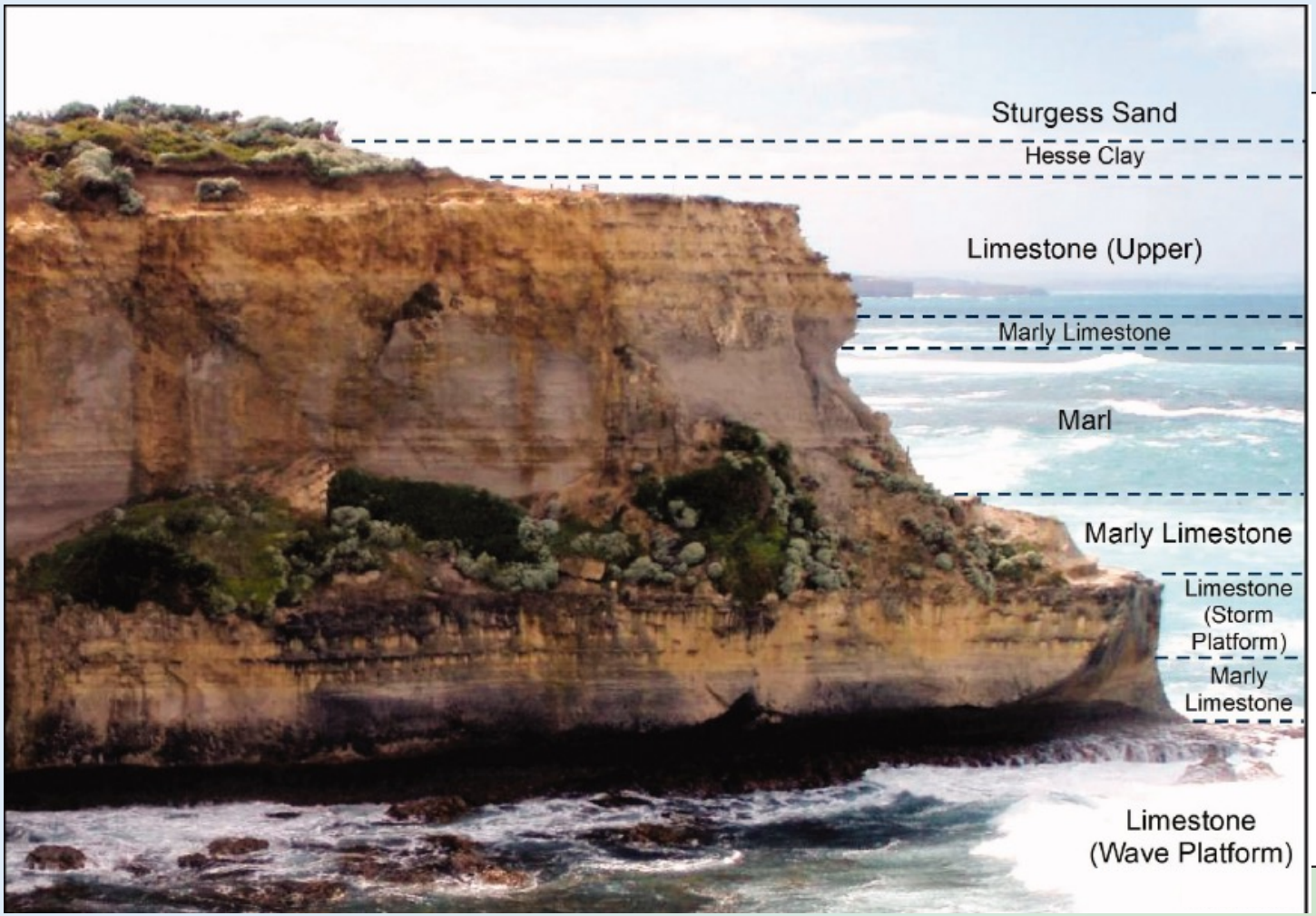
Mepunga Formation – reddish-brown, limonitic quartz sand and limonitic sandy limestone. When cemented, strata are usually dolomitic. Foraminifera, molluscs and especially *turritellid* gastropods are present in the Mepunga Formation.

Narrawaturk Formation – olive grey to greyish-brown marl, silty marl, calcareous mudstone, muddy limestone and beds of calc -arenite. Strata are commonly glauconitic, limonitic and richly fossiliferous. The Narrawaturk Marl is more fossiliferous with foraminifera, bryozoans, brachiopods and molluscs predominant

# Heytesbury Group

- Comprises Late Oligocene to Late Miocene carbonates that occur throughout the Otway Basin
- comprises Clifton Formation, Gellibrand Marl and Port Campbell Limestone
- Clifton Formation → basal, part clastic, part carbonate formation
- Gellibrand Marl and Port Campbell Limestone → carbonate dominated
- outcrops of Clifton Formation and Gellibrand Marl → mainly confined to eastern end of Otway Basin

# Heytesbury Group




Port Campbell Limestone Formation

Newer Volcanics

Hanson Plain Sand

---Unconformity---

Port Campbell Limestone

Gellibrand Marl

Clifton Formation

Heytesbury Group

# Clifton Formation

- The Clifton Formation is 4.5 - 12m thick
- limestones, sandy limestones and sandy marls are dominant facies
- sandy limestone is limonitic and fossiliferous in the upper part
- sandy limestones were deposited in relatively high energy, inner shelf palaeoenvironments
- limestones preserve foraminiferal biofacies

# Gellibrand Marl Formation

- Overlies Clifton Formation
- Predominantly Late Oligocene to Early Miocene in age
- consists mainly of greenish-grey, calcareous silty clay to clayey silt with minor fine to coarse-grained calc-arenite beds. Non-carbonate content is high (qtz silt 12-24%, muscovite 0-22%, kaolinite 3-5%, anatase 0-2%)
- Foraminifera remains are abundant in the marl
- richly fossiliferous with bryozoans, molluscs, echinoids, brachiopods, corals, crab skeletons and shark's teeth also present
- sediments were deposited in a low energy shelf environment

# Port Campbell Limestone Formation
## (Late Oligocene to Early Miocene)

- Conformably overlies the Gellibrand Marl
- dominated by carbonates calcite, dolomite and aragonite
- total carbonate content → 50-97%, clay content low
- most ubiquitous identifiable bioclasts are fragments of molluscs, bryozoans, echinoids and bivalves
- many clasts are indeterminate because of abrasion → most likely bioclasts

# Port Campbell Limestone Formation

- Consists mainly of grey to yellow, weakly cemented calcsiltite to fine-grained, calcarenite with <5% quartz
- minor interbeds of medium to coarse-grained, cross bedded calcarenite
- marl beds (usually <1metre but up to 9metres) occur near the base of the Formation
- bryozoans and molluscs → abundant; echinoids and brachiopods → common
- Port Campbell limestone deposited in moderate energy, continental shelf environment

# Port Campbell Limestone and Gellibrand Marl

## Port Campbell Limestone

→ weakly-cemented, calcareous siltstone to calcareous sandstone composed largely of fragmented calcareous skeletal material.

<5% quartz

## Gellibrand marl

→ calcareous silty clay outcrop of Gellibrand marl. The dark coloured intraclasts are composed of clay

# Marine fossils in the carbonate rocks

There is a wide variety of marine faunal types that are preserved in limestone and marl beds. The most common are:

Foraminifera

Bryozoa

Scaphopods

Gastropods

Echinoids

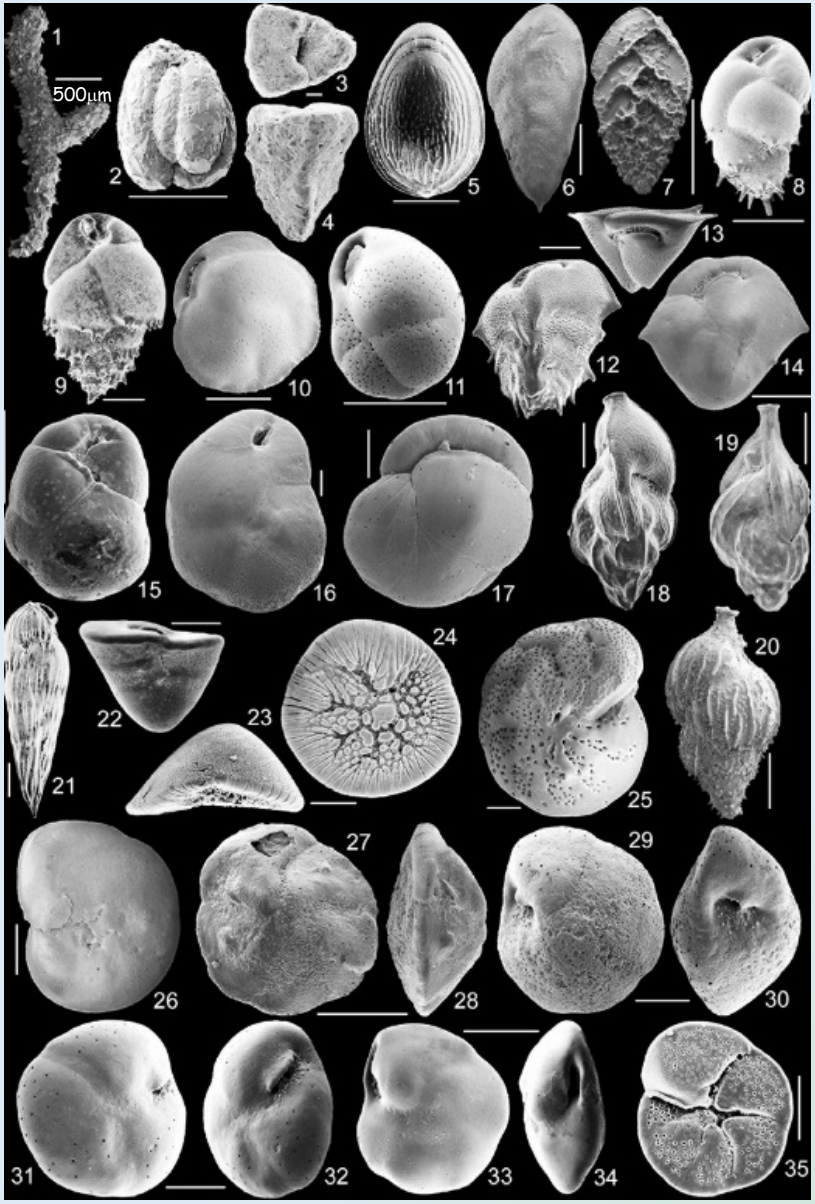
Ostracods

Bivalves

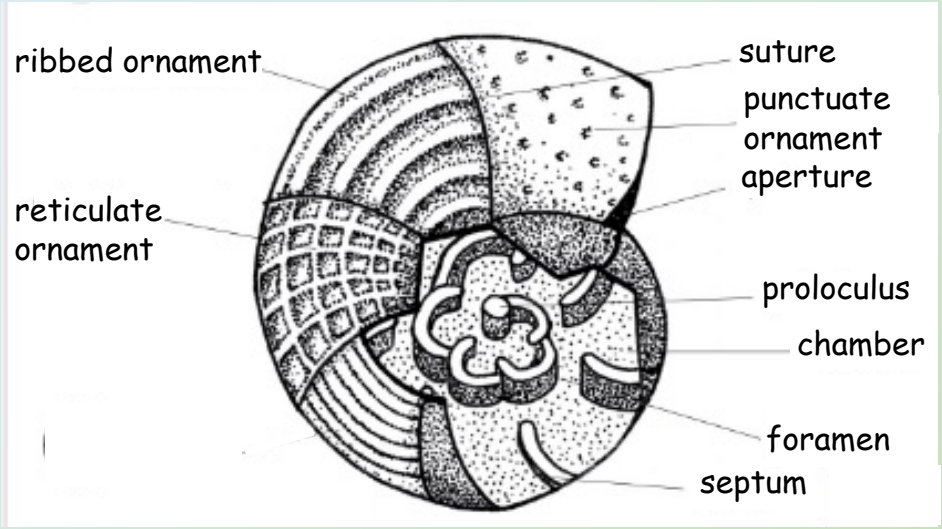
# Foraminifera

- Foraminifera (forams) are tiny shelled marine protozoans
- they comprise a major component of the Cenozoic marine invertebrate community
- forams are the most abundant of microfossils with some 50,000 species (40,000 of which are now extinct)
- most forams have a shell comprising chambers interconnected through holes (foramina)
- forams have adopted two main modes benthic (attach or cling to substrate, crawl on sea bed) and planktonic

# Foraminifera

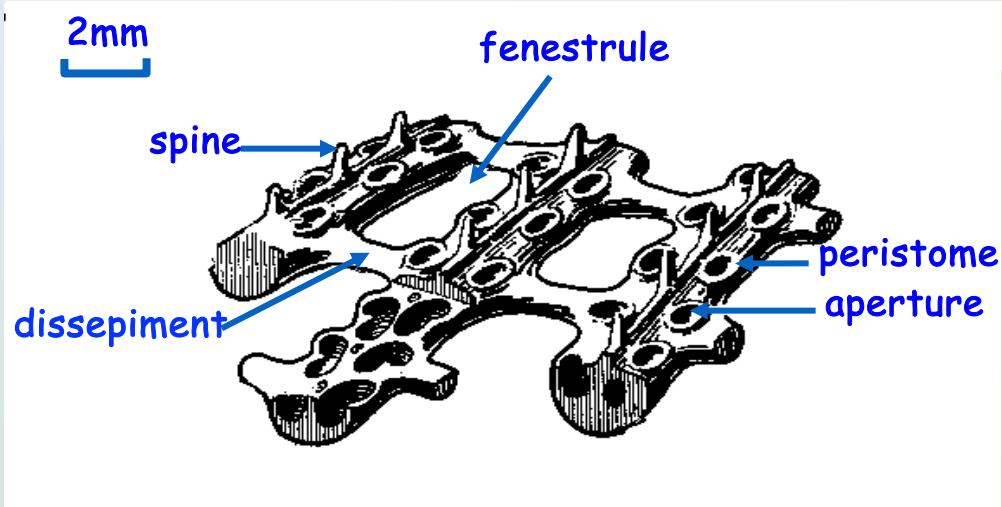






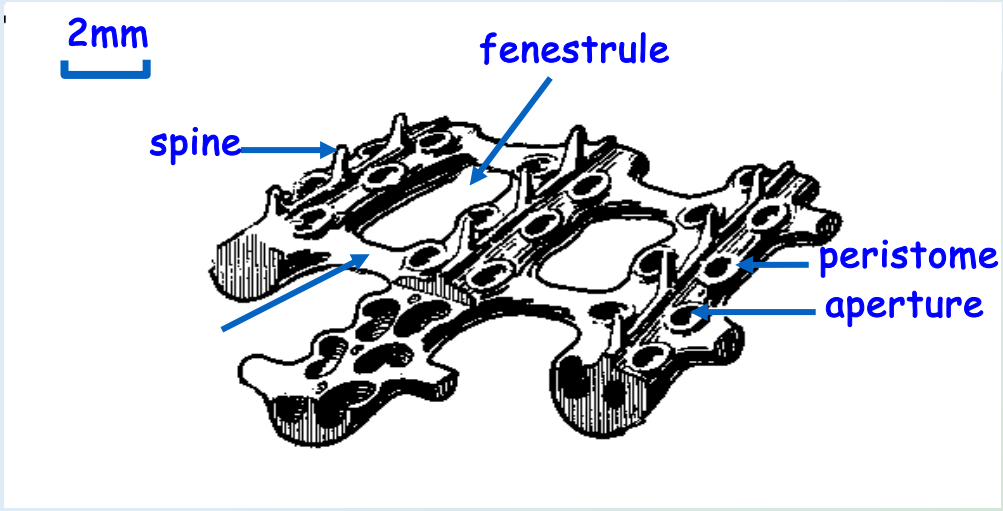
# Bryozoa

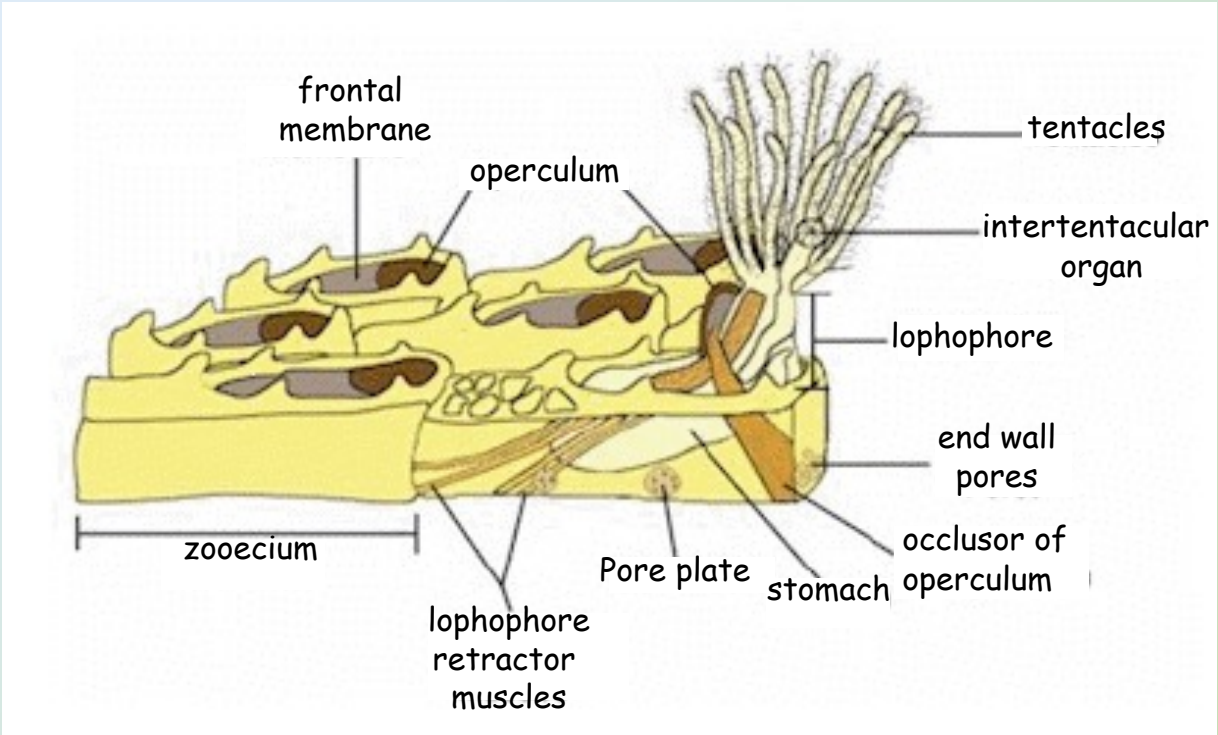
- Bryozoans → only phylum in which all species are colonial
- there are about 6,000 living and 16,000 fossil species
- they are minute colonial organisms with individuals (zooids) less than 1mm in diameter
- zooids are enclosed by a gelatinous, leathery or calcareous exoskeleton usually in form of slender tubes or box-like chambers called zooecia



# Bryozoa

Bryozoan colony in limestone

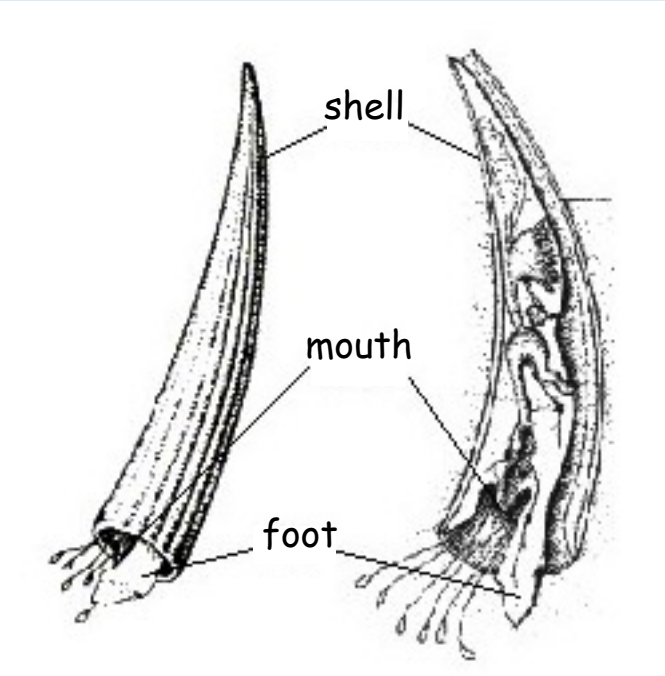


# Scaphopods ("tusk shells")

- Scaphopods (elphant-tusk shells) are marine molluscs generally rare as fossils
- they have a single curved shell open at both ends
- they lack gills and eyes but have a mouth equipped with a single radula and surrounded by tentacles
- also possess a foot for burrowing into soft sediment
- Scaphopods mainly carnivorous living on small organisms e.g. forams

# Scaphopods




# Gastropods e.g. *Turritellidae*

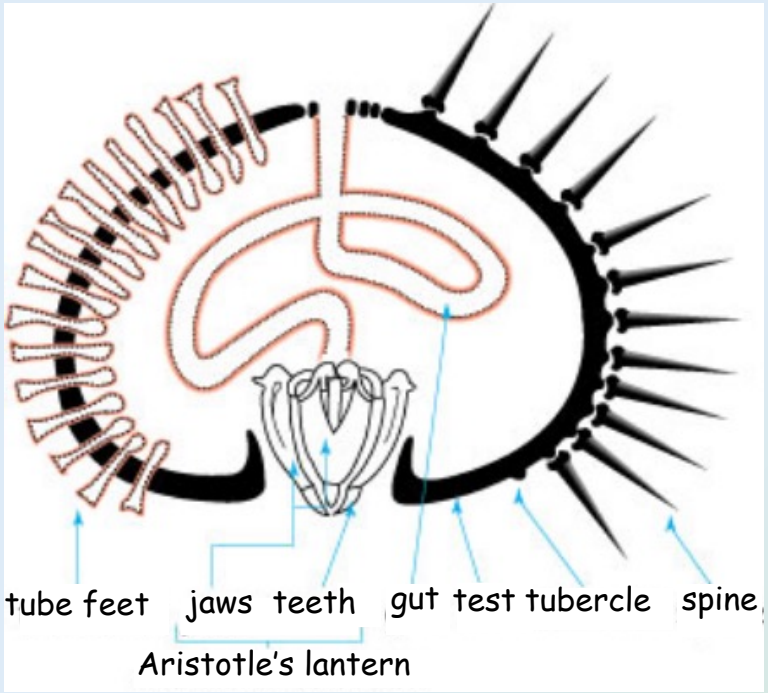
- *Turritellidae* (tower shells) is a taxonomic group of small to medium-sized sea snails
- they are filter feeders with high spiral shells
- there are more than 400 known species
- they are sand-dwelling carnivores that live mainly on small worms
- most species have a venomous barb to stun and immobilise prey

*Turritella*

# Echinoids

- Echinoids → sea urchins belong to the phylum Echinodermata
- they have robust exoskeletons composed of calcite plates covered by calcite spines
- exoskeletons are either globular (regular echinoids) or bilateral (irregular echinoids)
- they most commonly occur in groups in shallow marine environments
- their mode of life varies from mobile to burrowing
- most echinoids are grazers that scrape food from rock surfaces

# Echinoids




Regular echinoid

Irregular echinoid

# Wave erosion

- The Port Campbell coast has been mostly sculptured by wave erosion

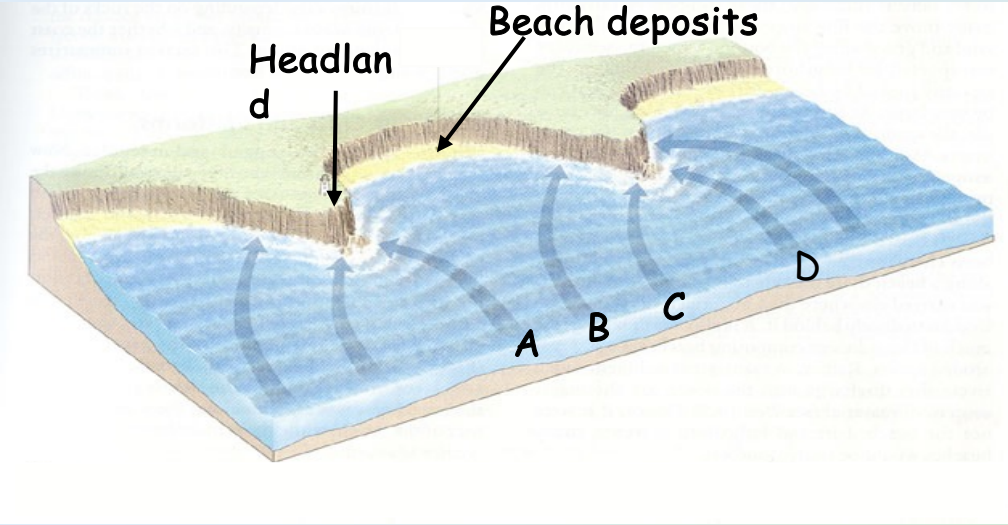
- waves have enormous power, particularly during storms
  - capable of shifting  blocks weighing up to 2,000 tonnes
  - spray can travel at more than 100km/hour
  - can erode cliffs at a rate of up to several metres/year

- wave erosion due to several processes
  - hydraulic action
  - transport of abrasive sediments (sand blasting)
  - solution of limestones

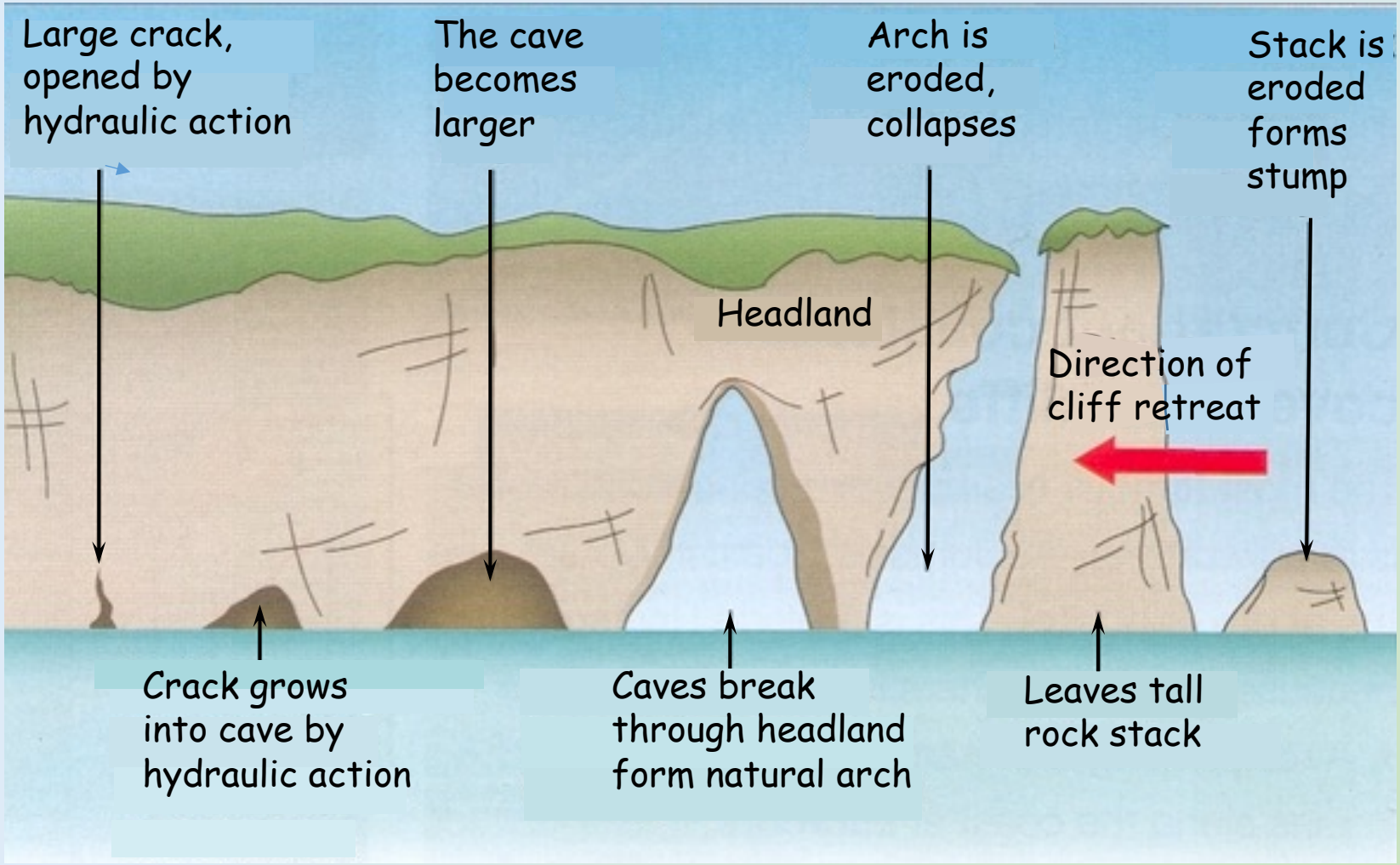
# Wave refraction

- Occurs where there are irregularities along coastline
- waves slow when feel bottom → wave refraction
  - waves travel slowly towards headlands
  - faster into bays

  → wave energy concentrated on headlands, dissipated into bays




# Formation of erosional features



# Erosional features in Port Campbell embayment

- Limestone cliffs in Port Campbell embayment are 30-60m high and almost vertical
- caves are located at many places along the coast
- collapse of caves leads to formation of bays and gorges
- more that 20myr ago the entire coastline was under the sea
- current sea level was established ~6,000 years ago

# Erosional features in Port Campbell embayment

Loch Ard Gorge

Bay of Islands

Twelve Apostles

Castle Rock

# Arch

London Bridge Port Campbell prior to collapsing in 1990

# Concretions

- Concretions → accretionary growths that project from rock surfaces and have carbonate cements (calcite, siderite, ankerite).
- most common shape → spheroid (mainly 0.1 – 0.3m diameter) suggesting concentric structures
- calcite concretions contain 25 – 47% calcite with the matrix containing only a few %
- calcite concretions are the dominant type and where exposed → suffered no obvious weathering except for occasional pitting
- as concretions are denser and heavier, they resist erosion more successfully than does their matrix.

# Concretion formation

- Form inside sediments before they harden into rocks
- minerals within a sediment precipitate in successive layers accreting around a nucleus such as a shell or pebble
- they can form rapidly over as short a period as months or years
- concretions form after sediments are buried but before they are lithified
- concretions can be created by concentric or pervasive growth

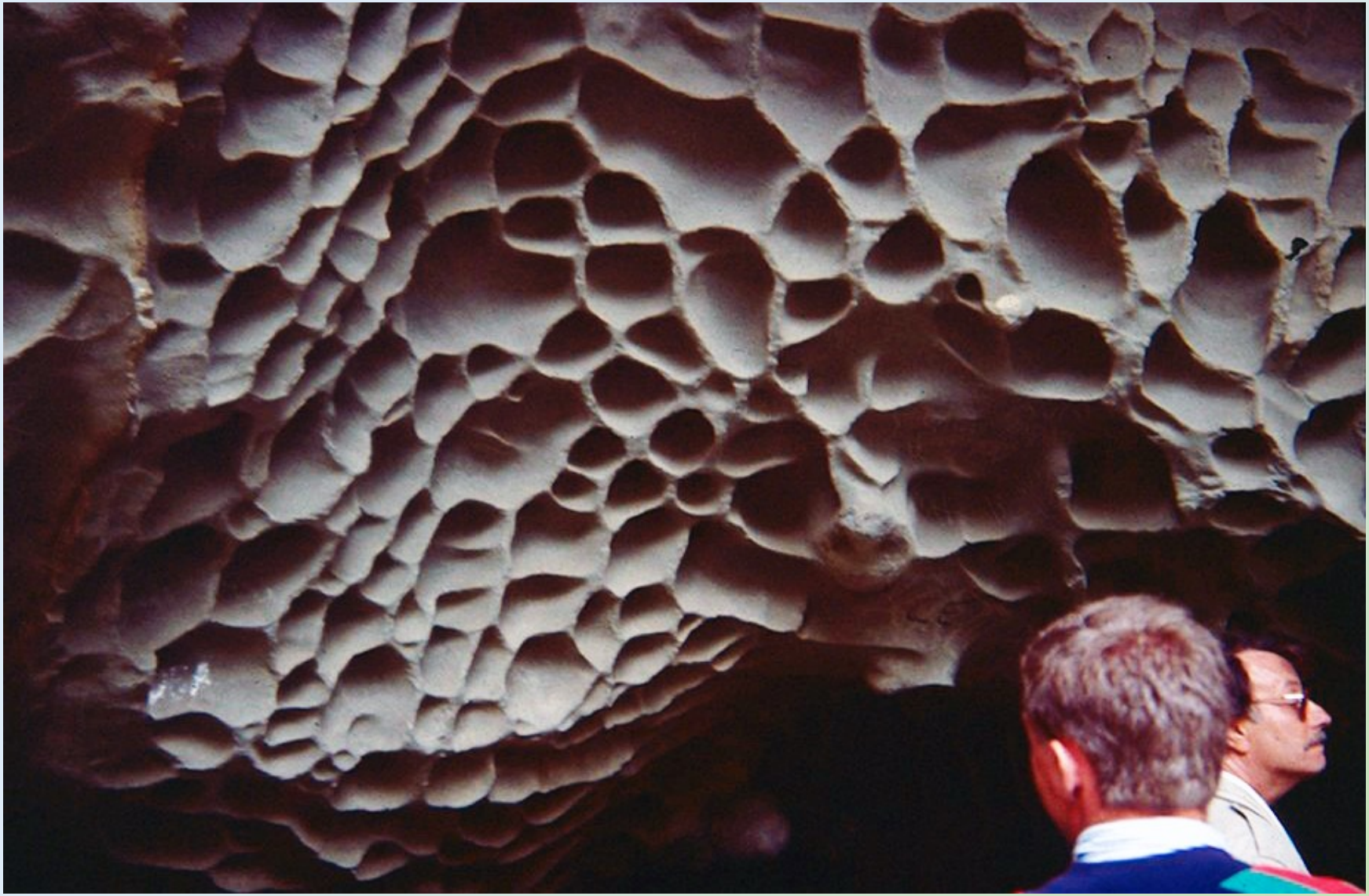
# Concretion, Castle Cove, Vic.

# Concretions, Artillery Rocks Lorne

# Honeycomb weathering

- Honeycomb weathering → consists of regular adjoining cavities in weathered bedrock with honeycomb structure
- typically develops in siliceous, coarse-grained sandstone
- weathering is typical in salt-rich environments with dessicating conditions e.g. deserts, coastal zones
- probably form by saltwater entering pores, salt crystallising and expanding and plucking out grains

# Honeycomb weathering
# Swallow's cave near Lorne



**Draft Itinerary – Port Campbell excursion**

**Wednesday November 15th**

am Twelve Apostles
Loch Ard Gorge and The Razorback
Lunch in Port Campbell
pm Bay of Islands
Bay of Martyrs
The Grotto
London Bridge (remnant)

**Thursday November 16th**

am Castle Cove
Free time (e.g. Cape Otway, Tree walk)
~4pm Marengo Beach

**Friday November 17th**

am Artillery Rocks
Cumberland River
Lorne