



Australian Government
Geoscience Australia

Exploring for
the Future

Australian Salt Basins – Options for Underground Hydrogen Storage

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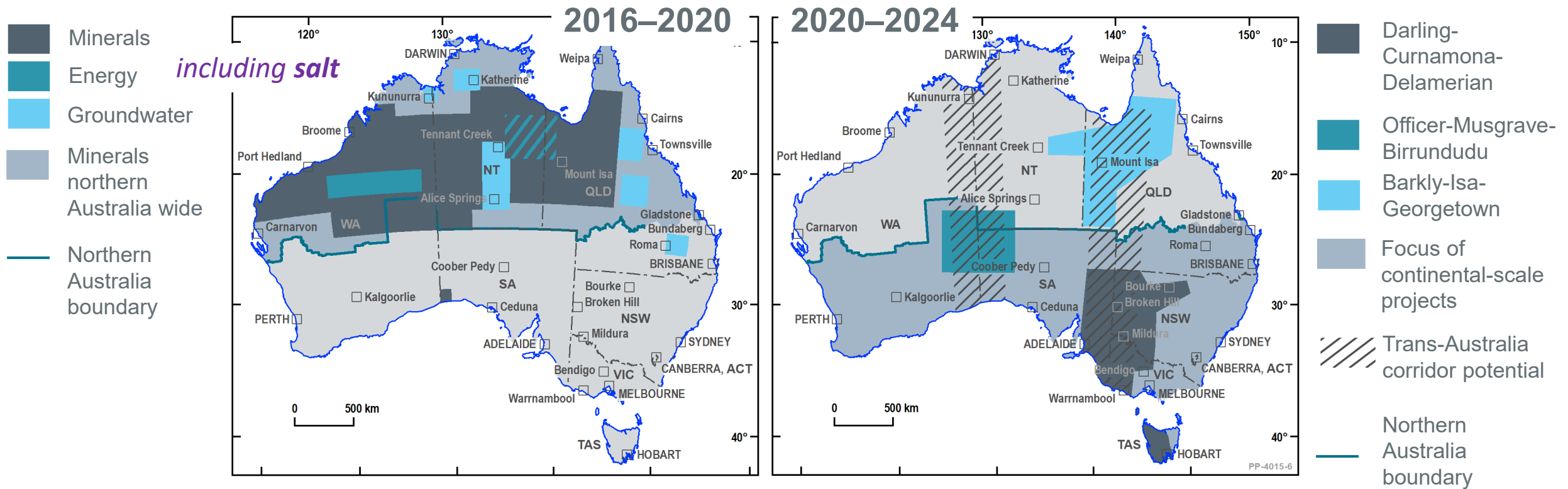


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Earth sciences for Australia's future | ga.gov.au

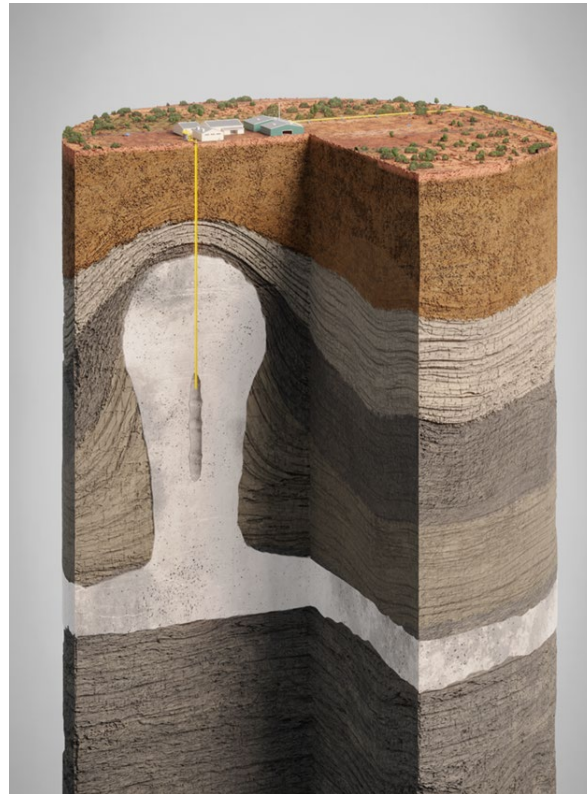
Australia's Exploring for the Future program - \$225m investment

VISION: To support a **strong economy, resilient society** and **sustainable environment** for the benefit of Australians via an integrated geoscience understanding of our mineral, energy and groundwater potential



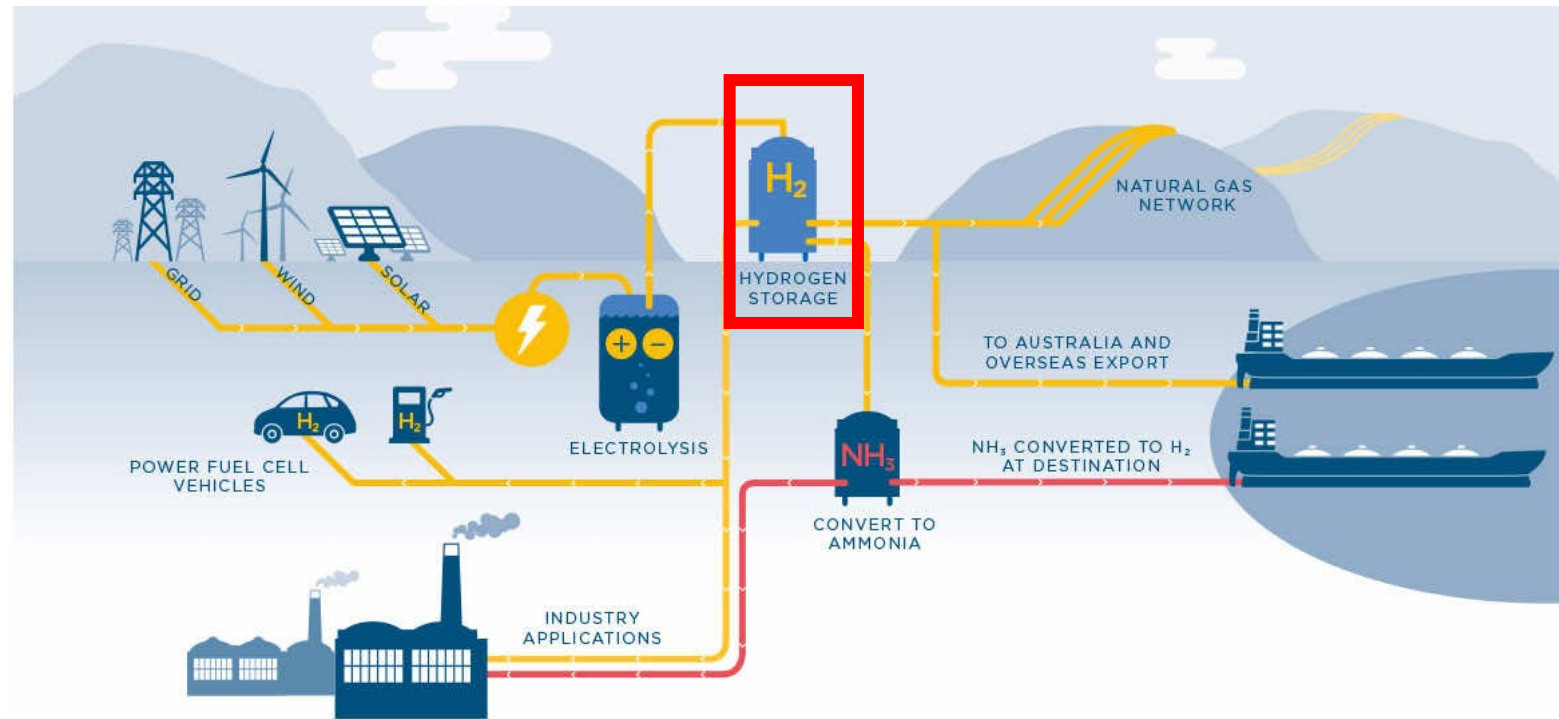
Outline

- *Why hydrogen?*
- *Why salt?for underground hydrogen storage (UHS)*
- *How do salt accumulations form?*
- *Where is the salt in Australia?*
- *How do we find some more?*



Why Hydrogen ?

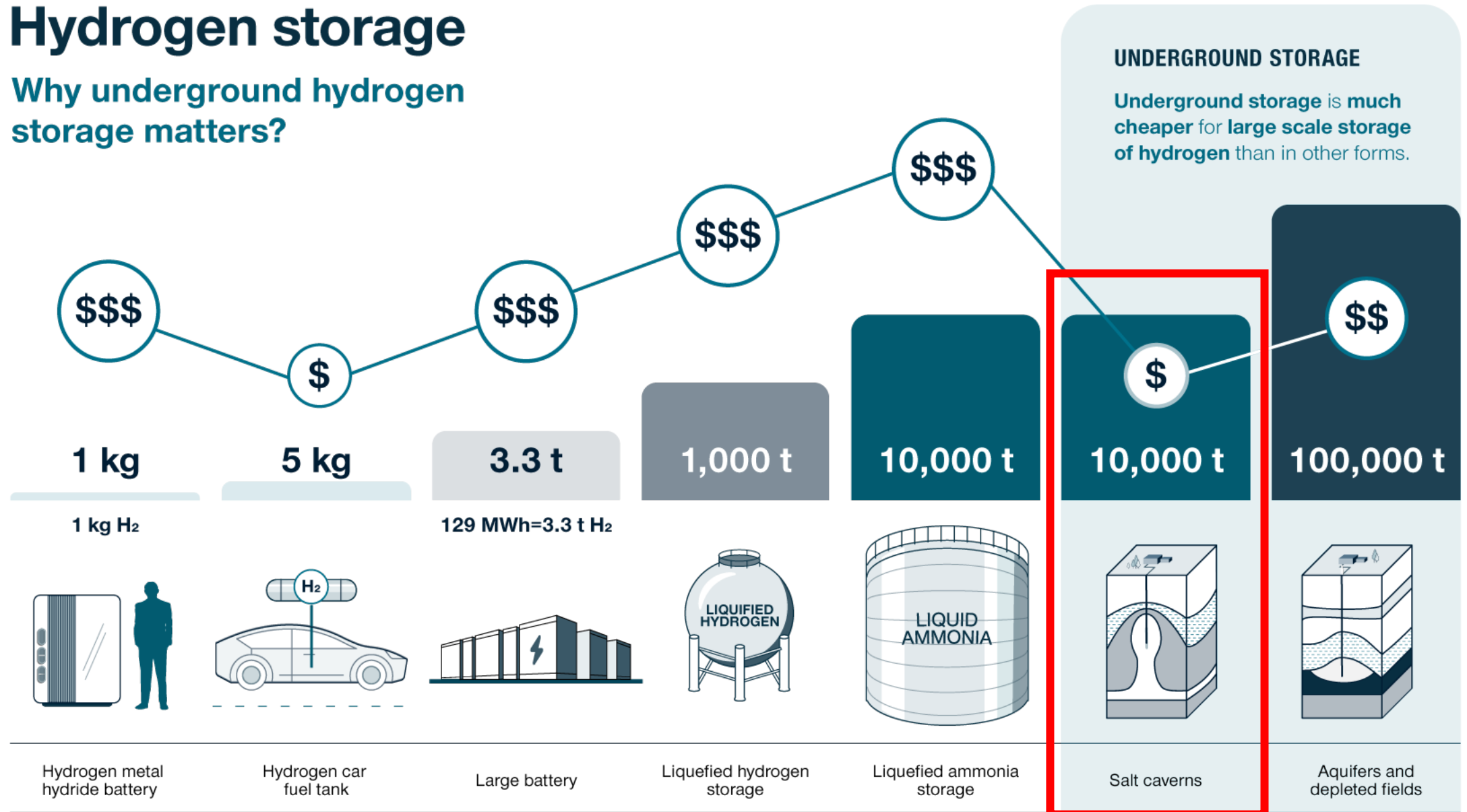
- as a energy carrier and for *energy storage*
- For hard to electrify uses and direct chemical feedstock
- As an energy export:
 - H₂
 - NH₃
 - embodied energy products – **green** steel / iron / aluminium



Value chain of green hydrogen. Source: Herbert Smith Freehills [epcmholdings.com](https://www.epcmholdings.com).

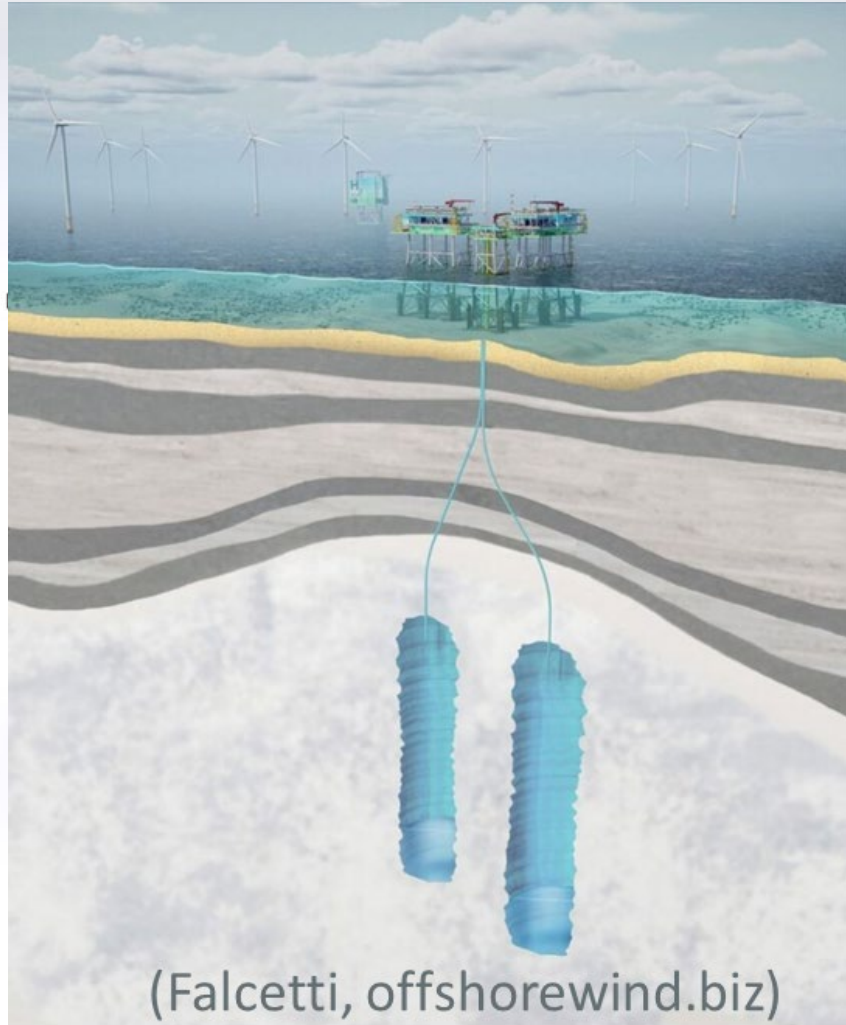
Hydrogen storage

Why underground hydrogen storage matters?



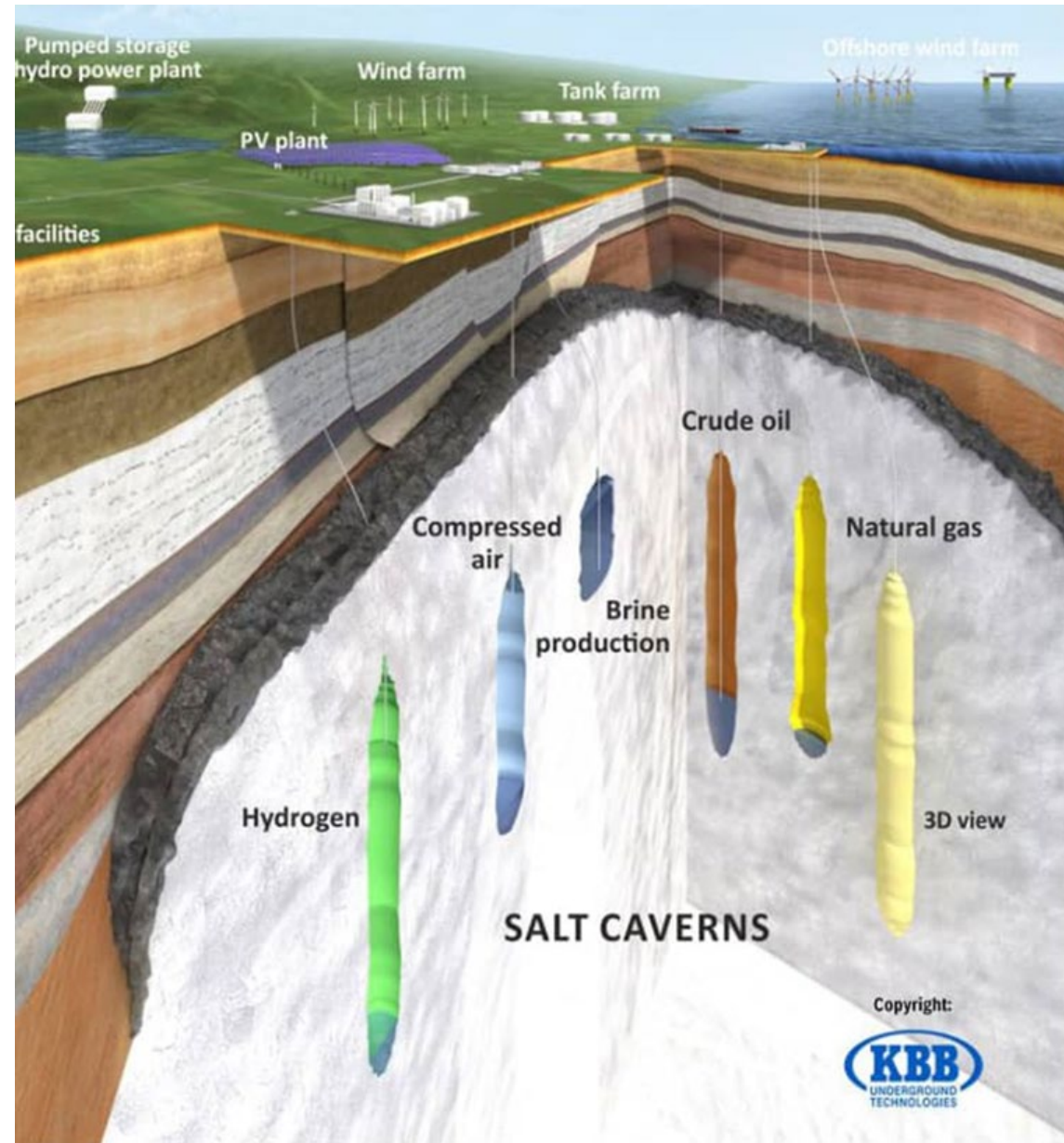
Engineered Salt caverns

- Created in the subsurface by dissolving salt with freshwater and extracting the resulting brine



Why Salt ?

- *Cost effective at scale*
- *Deliverability - large scale, short & long duration storage*
- *Chemically inert to hydrogen*
- *Ductile - high integrity storage*
- *Industrial track record of gas storage in salt over decades in US and Europe*



Salt as hydrogen storage

- Solution mining process
- Brine management:
 - production of salt products
 - deep disposal injection
 - solar evaporation

Site	Depth (m)	Since	Net energy stored (GWh)	Hydrogen Conc. (%)	Capacity (m ³)
Teeside, UK (Sabic Petroleum)	370	30+ years	27	95	3 x 70,000
Moss Bluff, US (Praxair)	850-1,400	2007	123		566,000
Spindletop, US (Air Liquide)	850-1,400	2017	274	95	906,000
Clemens Dome, US (ConocoPhillips)	850	1986	81	95	580,000
Kiel, Germany	1,335	1971		62	32,000

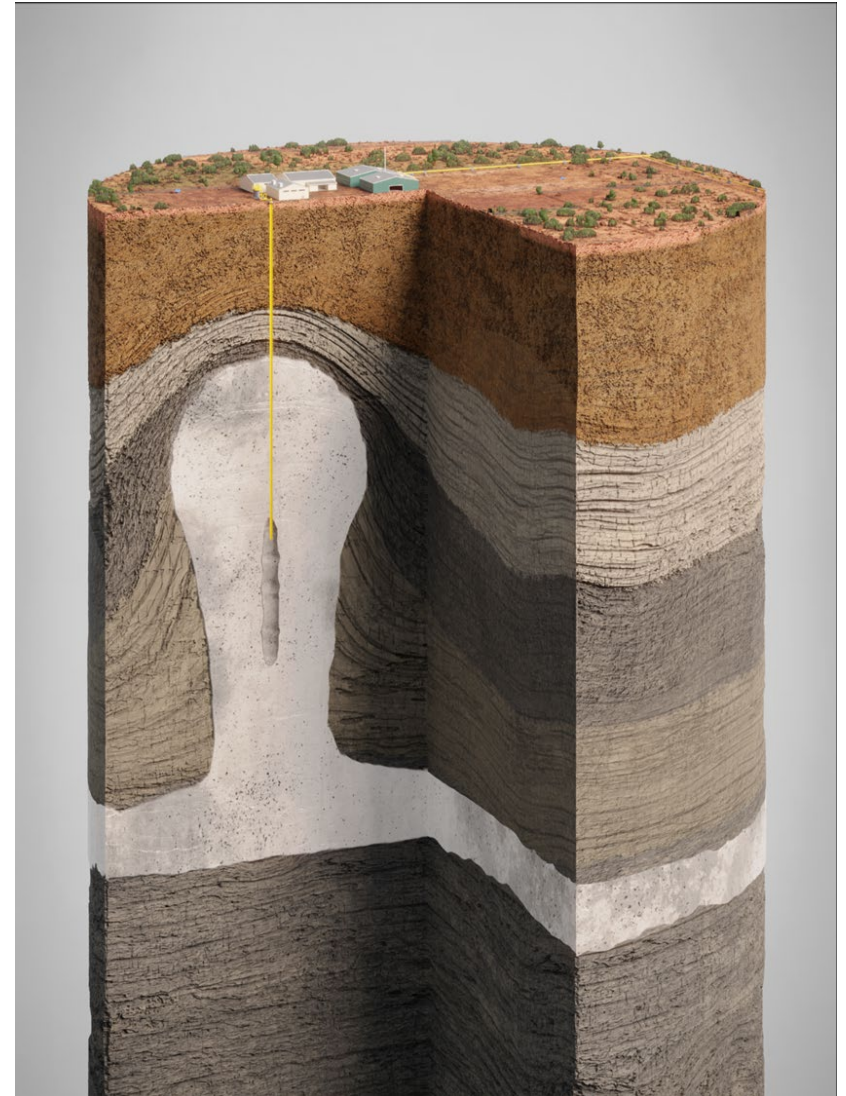
Table 1. Existing underground hydrogen storage in salt formation (Cline, 2023; Ebrahimiyehta, 2017; Malachowska et al., 2022; Panfilov, 2016)

Energy storage capacity (when in operation):

Snowy 2.0	= 350 GWh	(Snowy Hydro, 2020)
Salt caverns, Poldá Basin (conceptual)	= 240 GWh and 665 GWh	(Feitz et al., 2022)

Salt cavern design

- Ideally >200m thick
 - Domal structure
 - Pure (>90%) halite (salt)
 - Depth: 500 – 2000m
- Salt can move in the subsurface
- Creating structures
- Disrupting and incorporating other layers
- Post-depositional processes
 - clean-up and/or contaminate salt units?

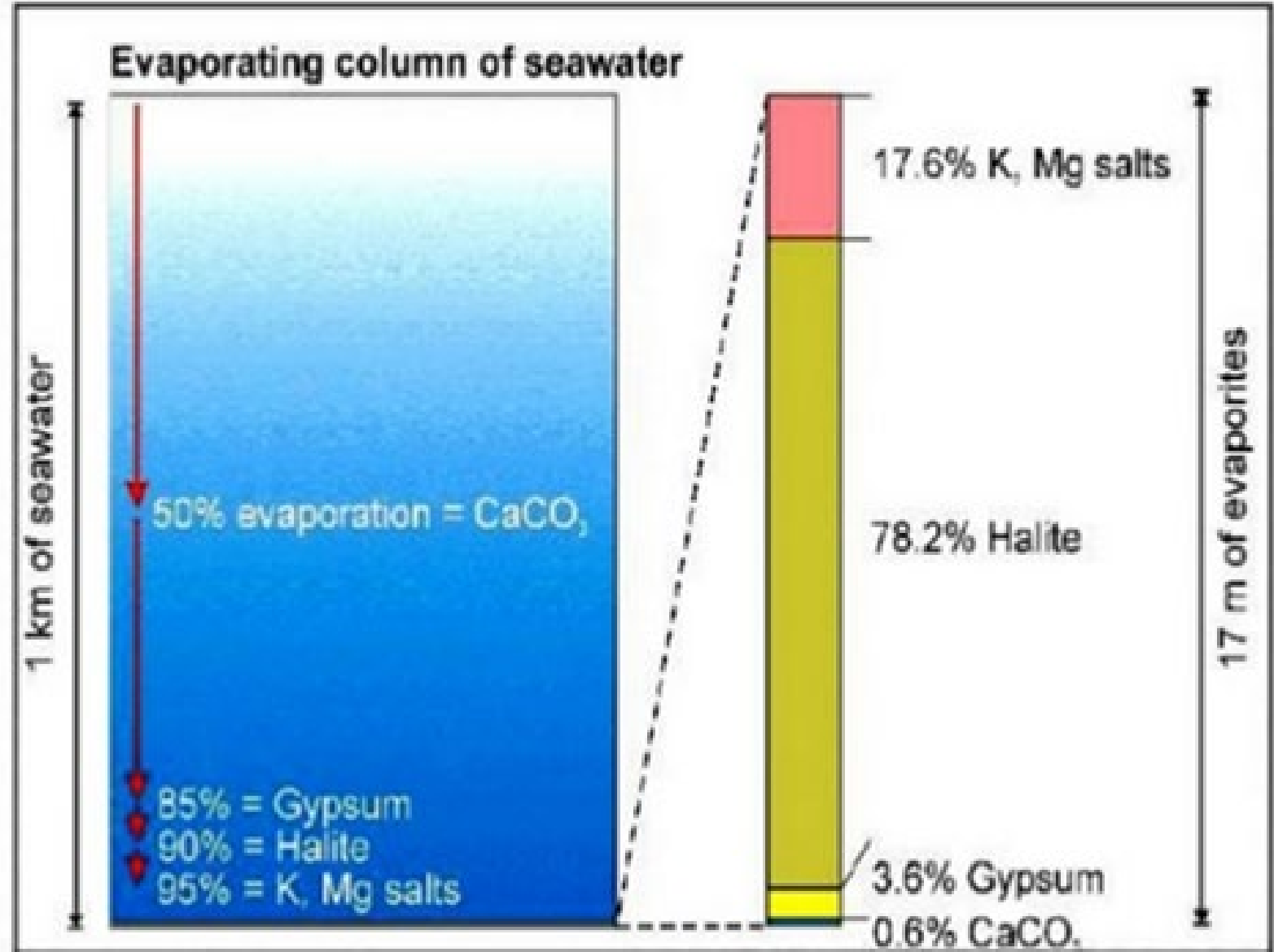


Outline

- *Why Hydrogen ?*
- *Why Salt ?*
- **How do salt deposits form?**

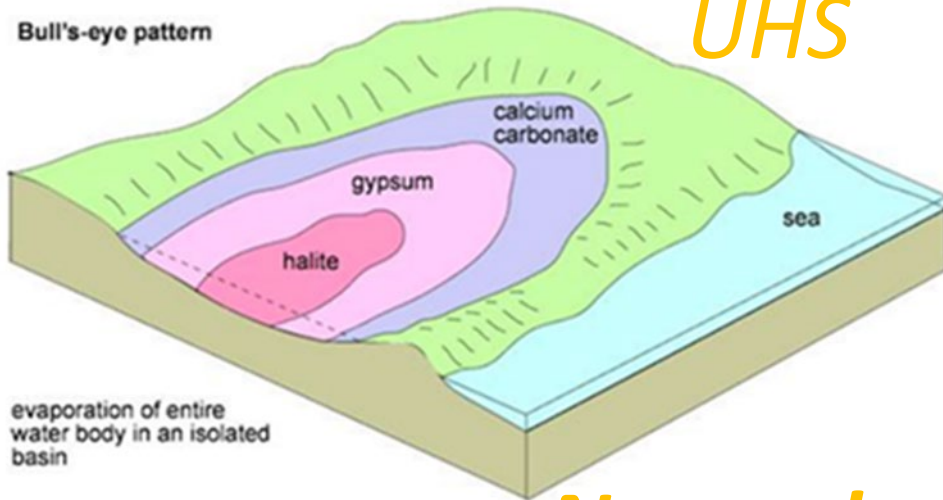
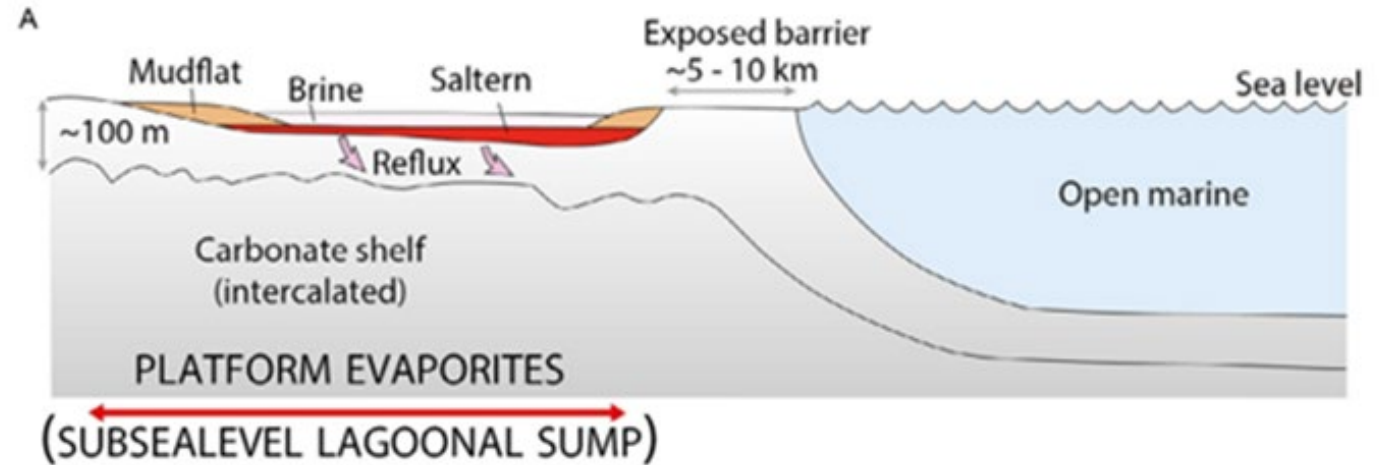
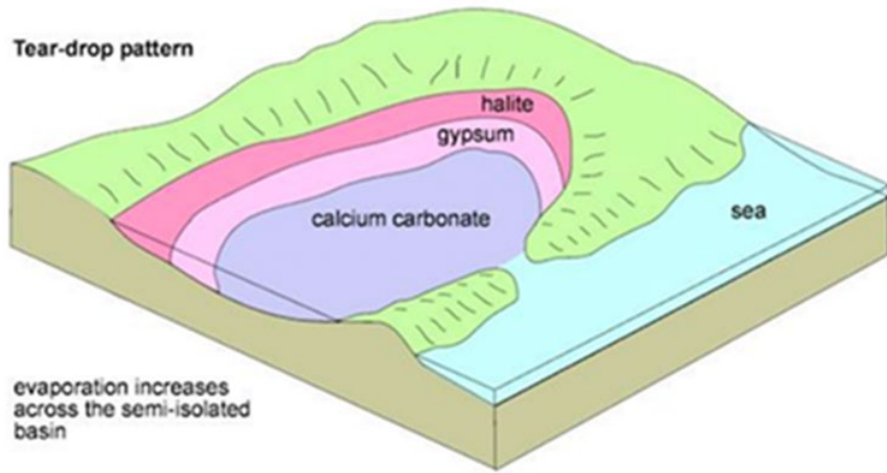


nacc.com.au



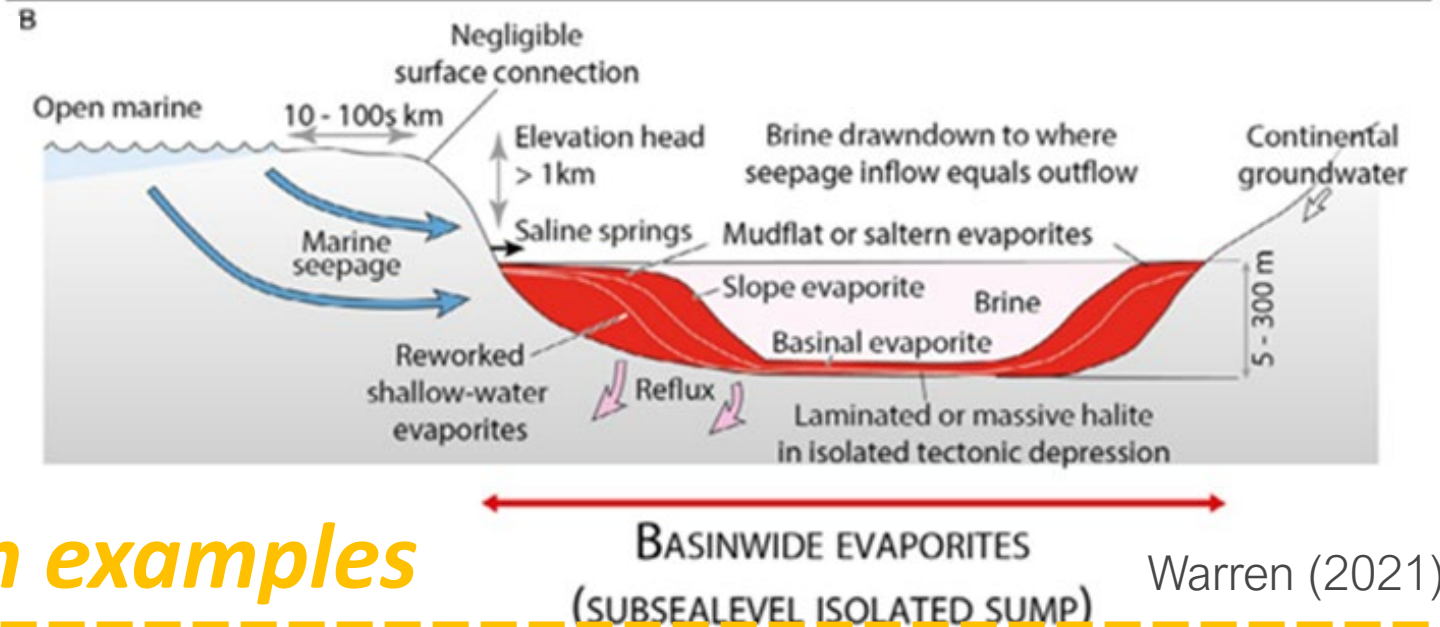
from www.alexstrekeisen.it/english/sedi/evaporites.php

Patterns of salt deposition – marine evaporites



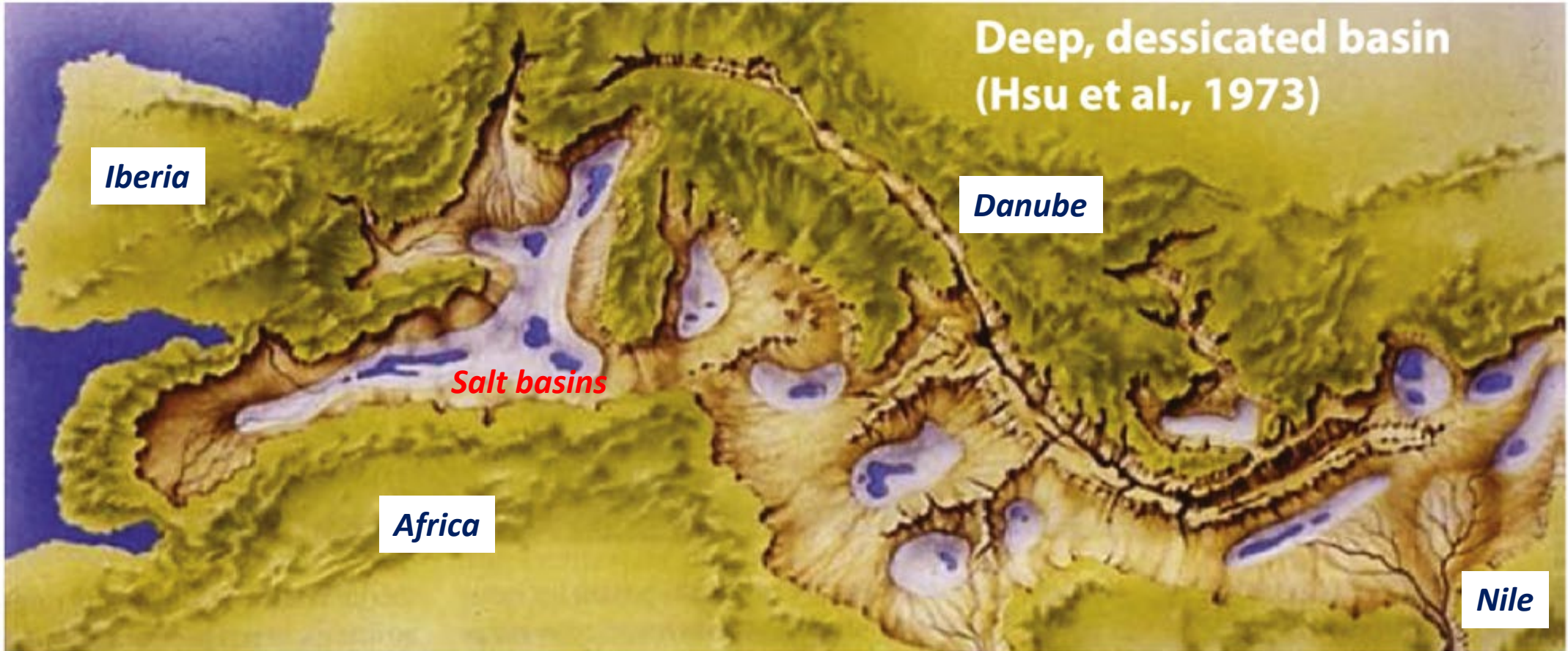
UHS

No modern examples



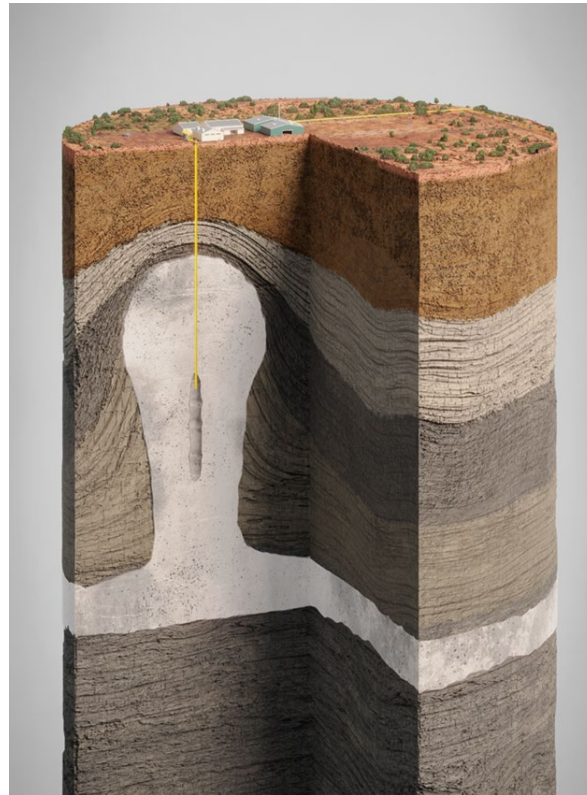
Warren (2021)

The Mediterranean ~5 million yrs ago



Outline

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- ***Where is the salt in Australia?***

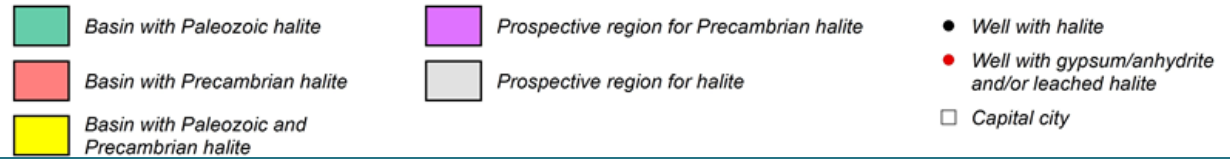
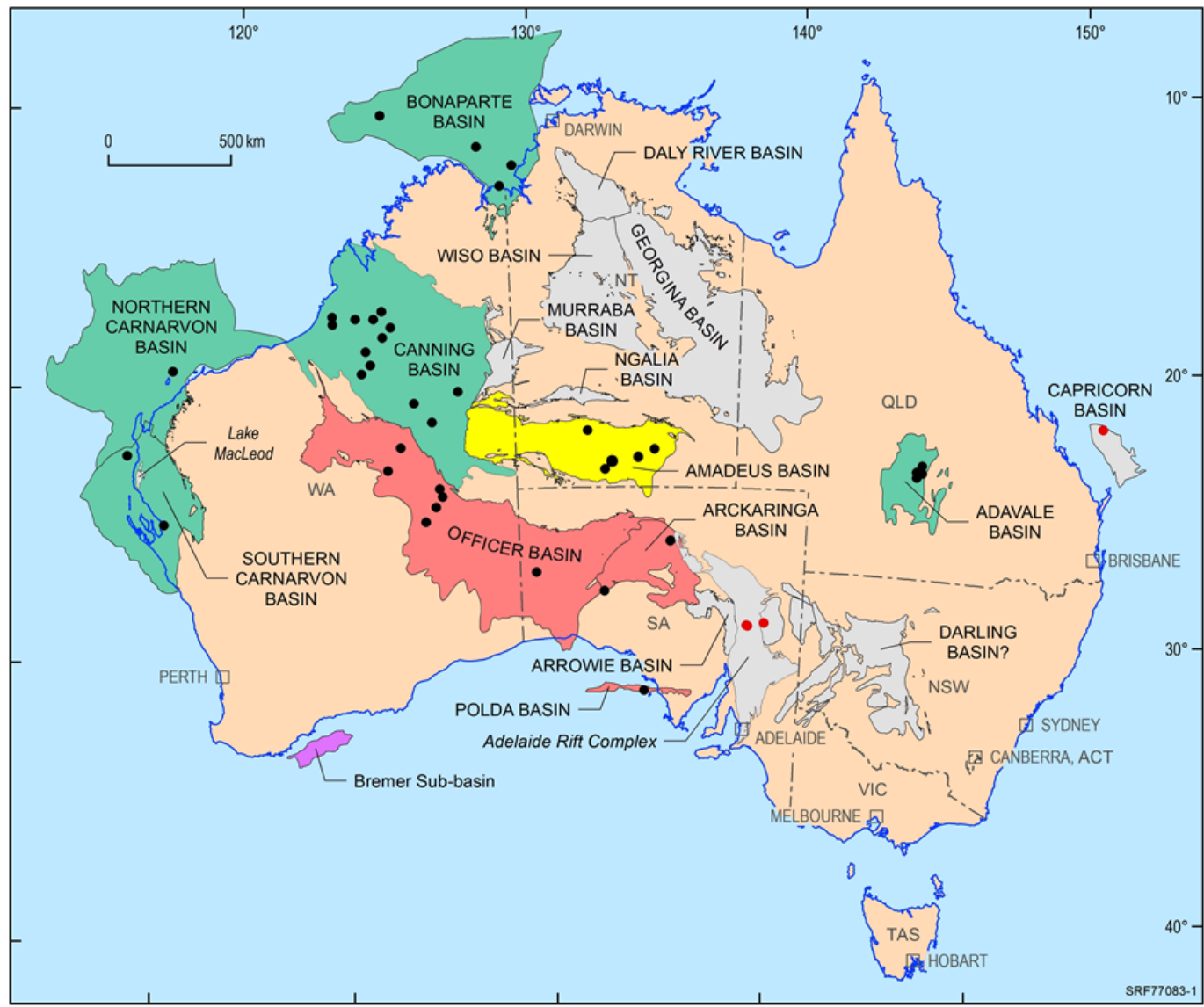


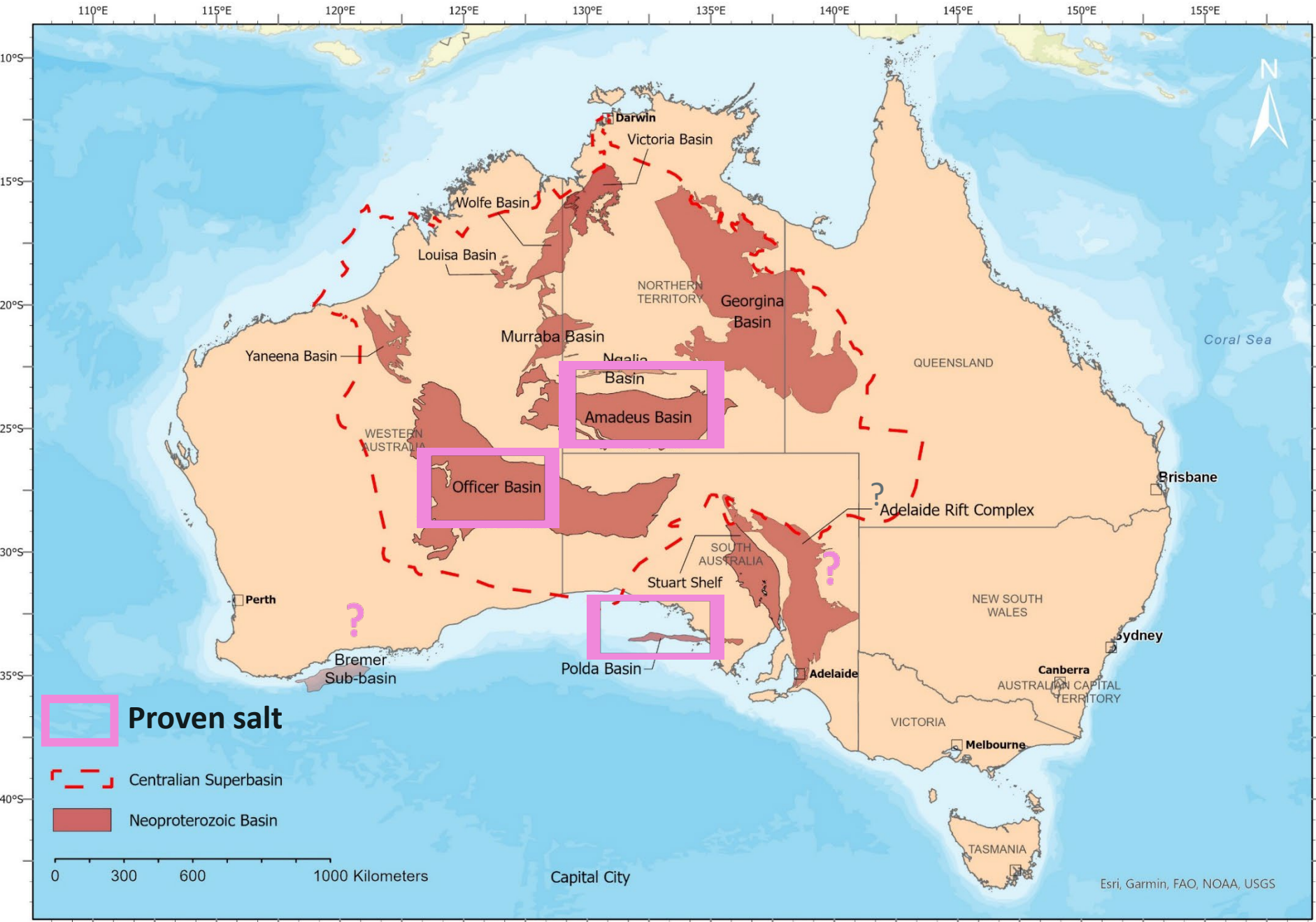
Where is the salt in Australia?

..... in space & time?

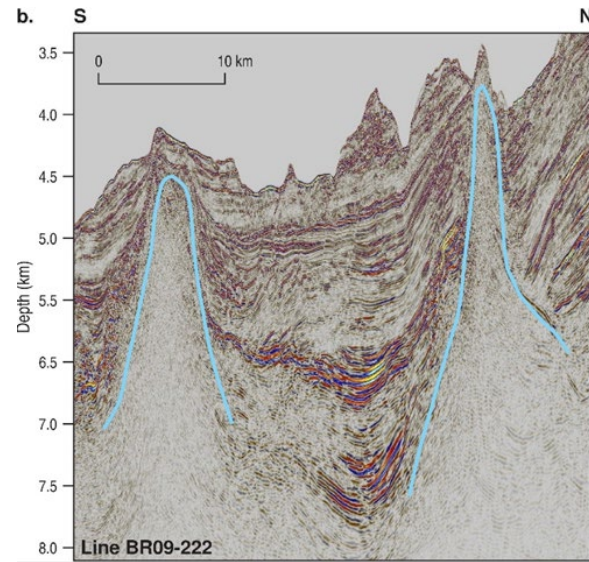
... controls of tectonics & climate

- **Precambrian – Tonian >700 Ma**
- **Paleozoic**
 - Cambrian-Ordovician ~ 500 - 440 Ma
 - Devonian ~ 390 Ma
- **Mesozoic 250 – 65 Ma**
 - Capricorn
- **Cenozoic 65 Ma to today**
 - Lake MacLeod



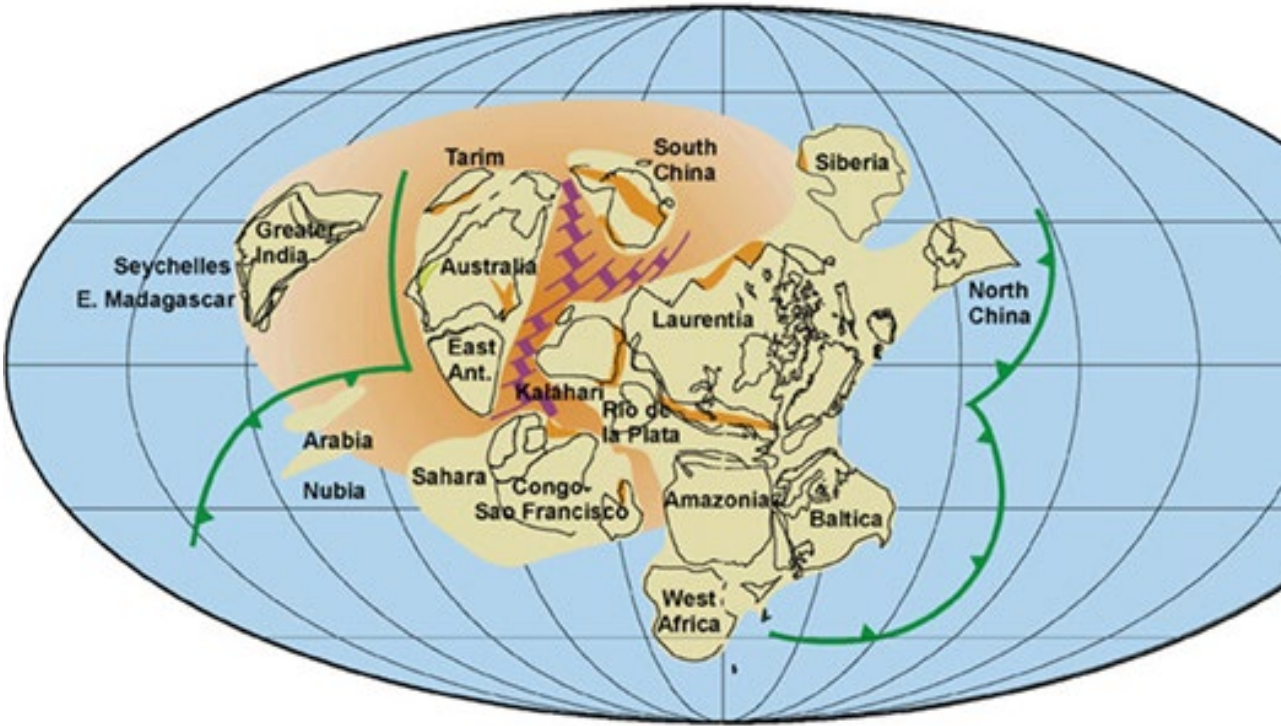


Tonian Salt - Centralian Superbasin & beyond

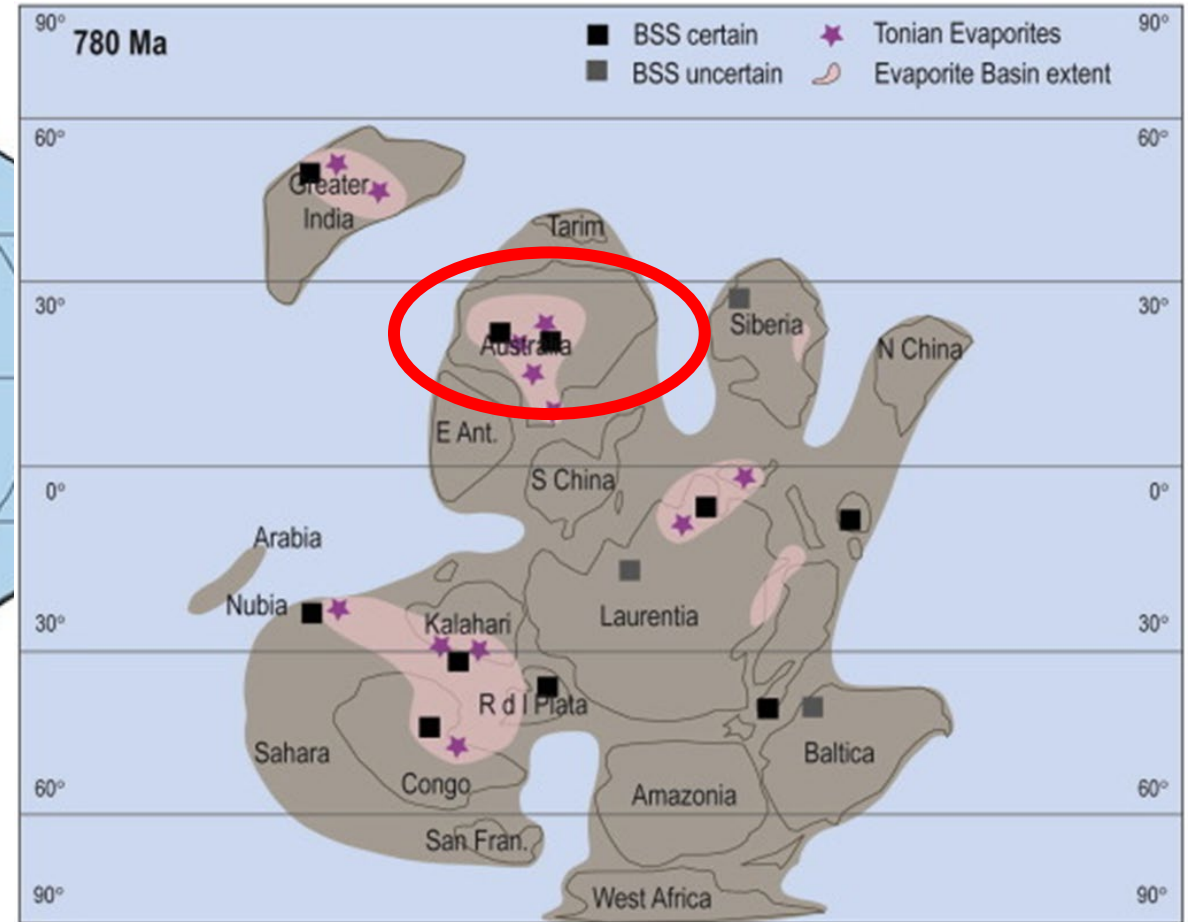


Bremer Sub-basin seismic
? Salt diapirs

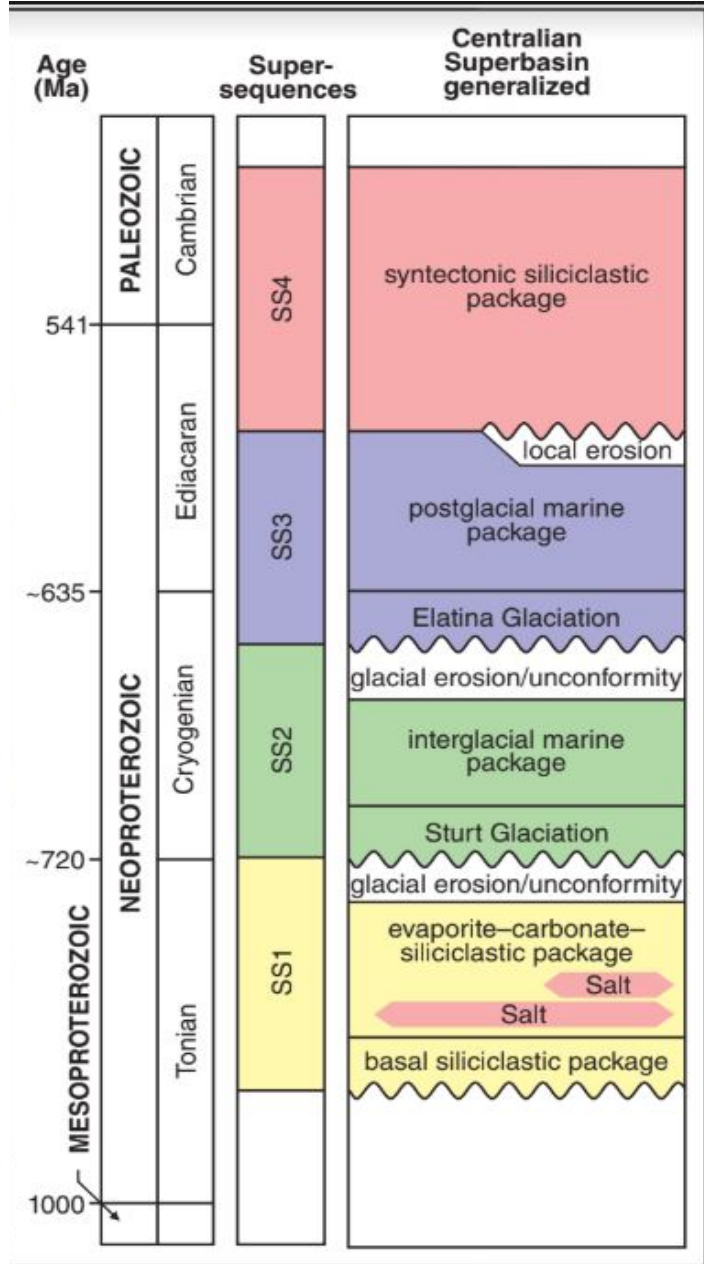
Relationship of salt accumulation to Rodinia breakup and paleo-latitude



(Li et al., 2008; Schmid 2017)



(BSS - Bitter Springs Stage negative isotopic excursion)

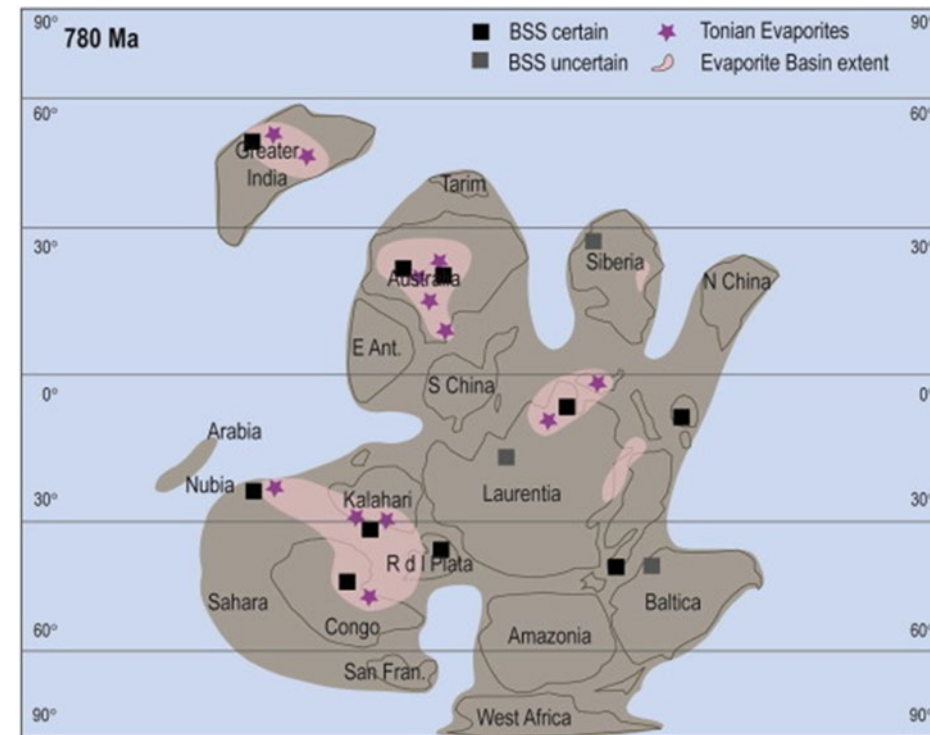


18.12.19

Snowball Earth



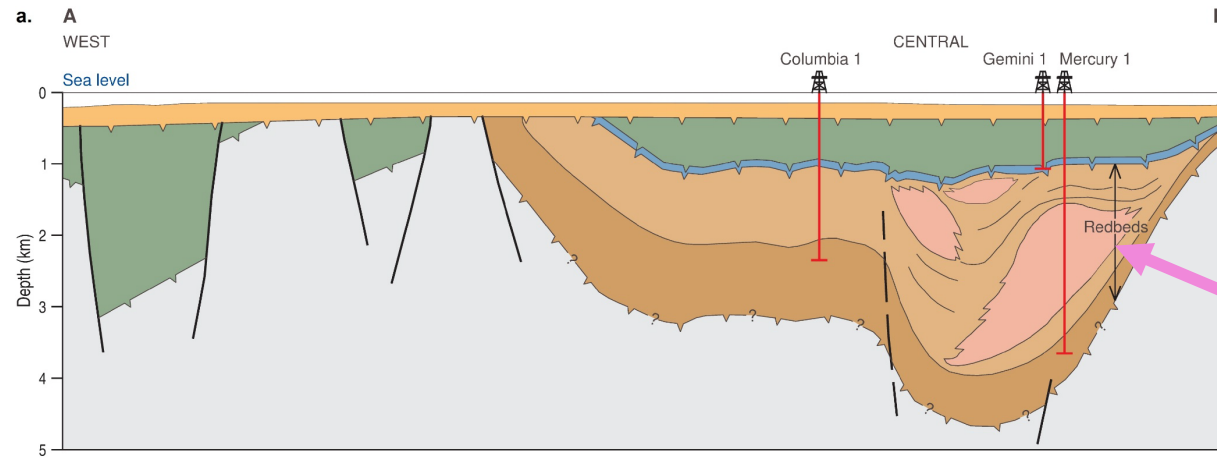
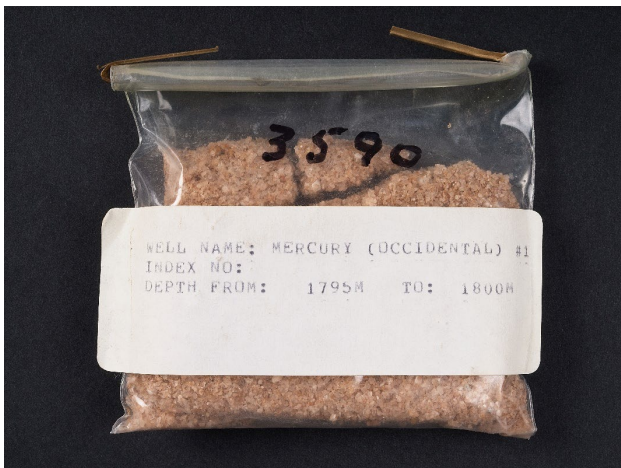
Increased albedo = triggers the Big Freeze???



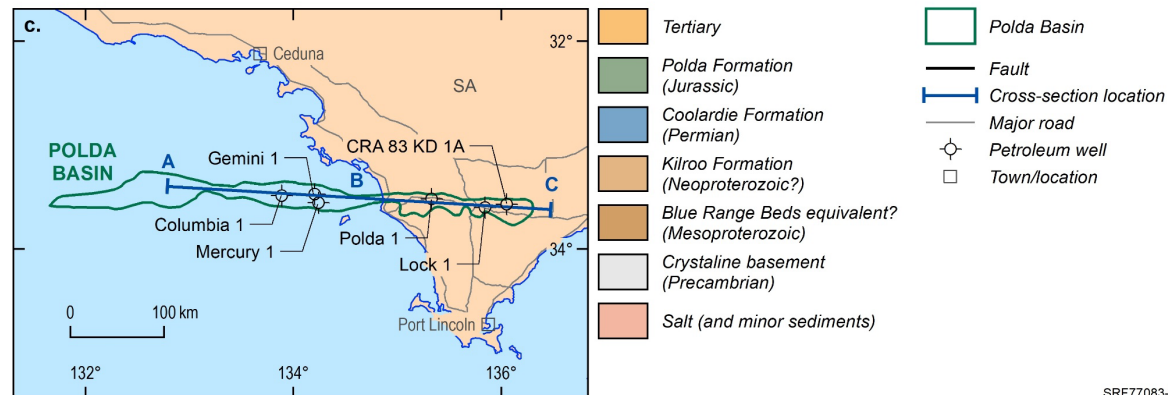
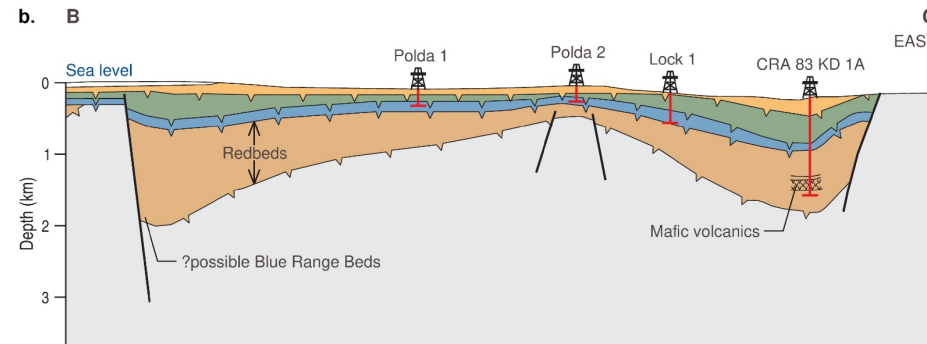
(Schmid 2017)

Offshore UHS option - Polda Basin

Mercury 1 cuttings

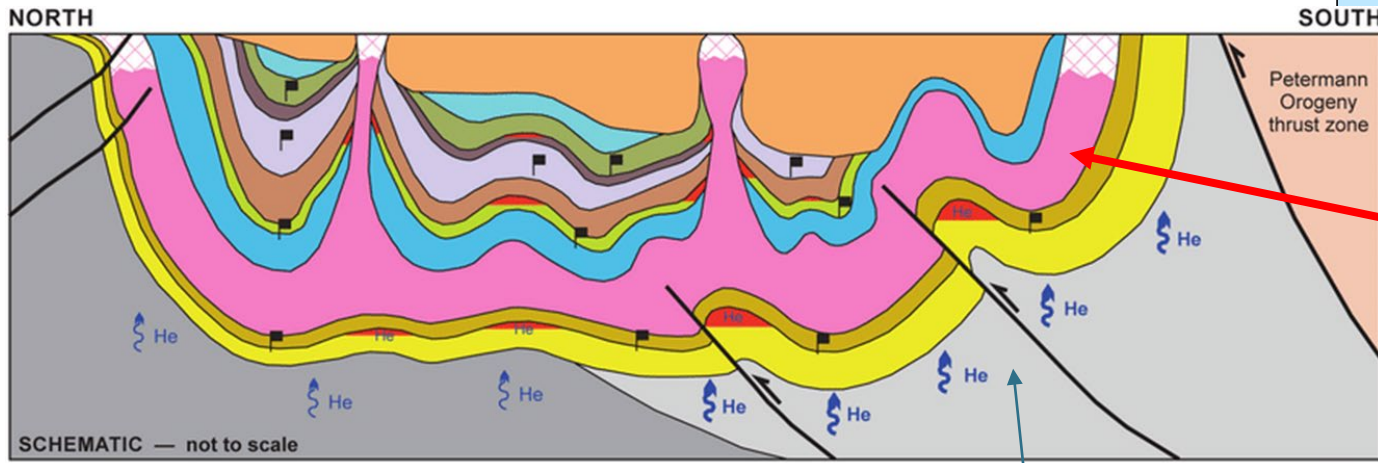


1000m halite (salt)
in Mercury 1



SRF77083-8

Tonian salt Gillen Fm Amadeus Basin

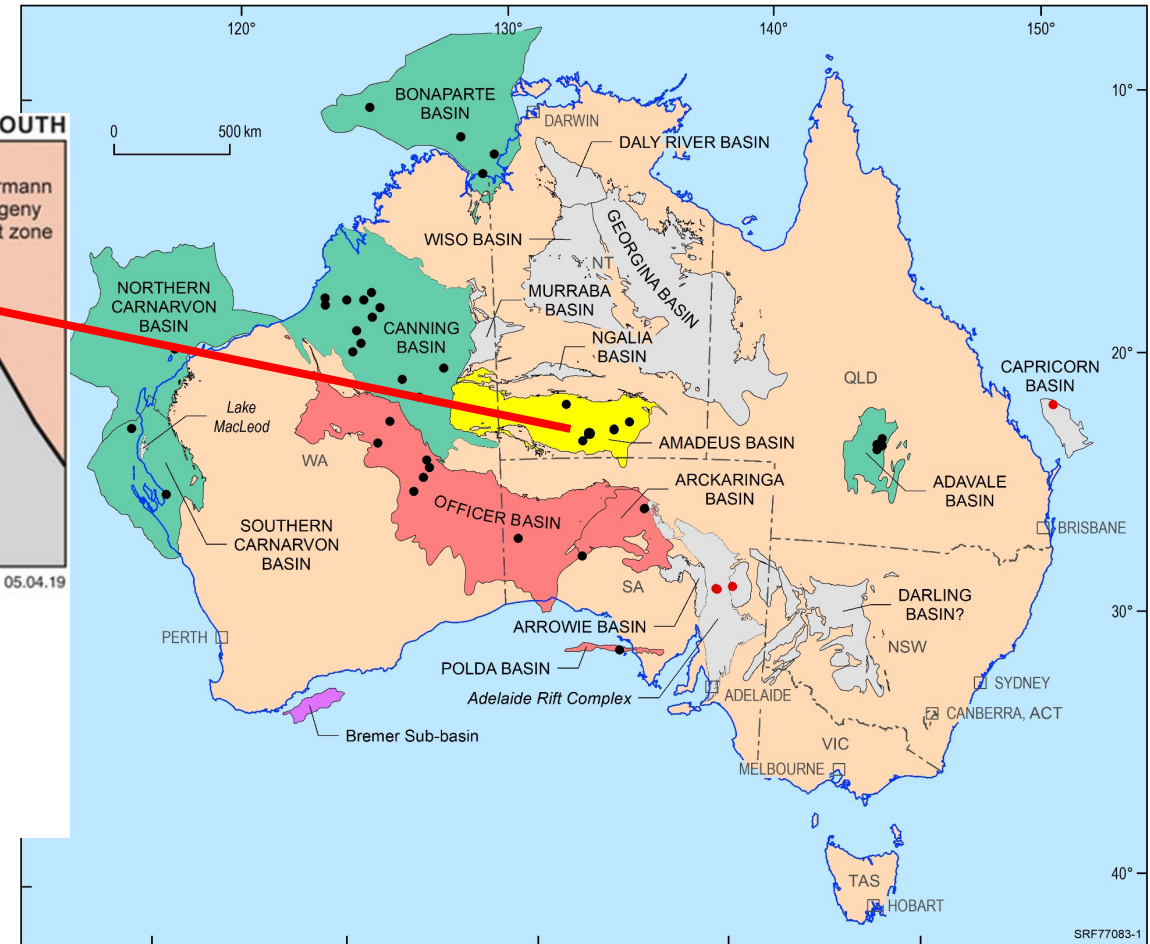


PWH201

05.04.19

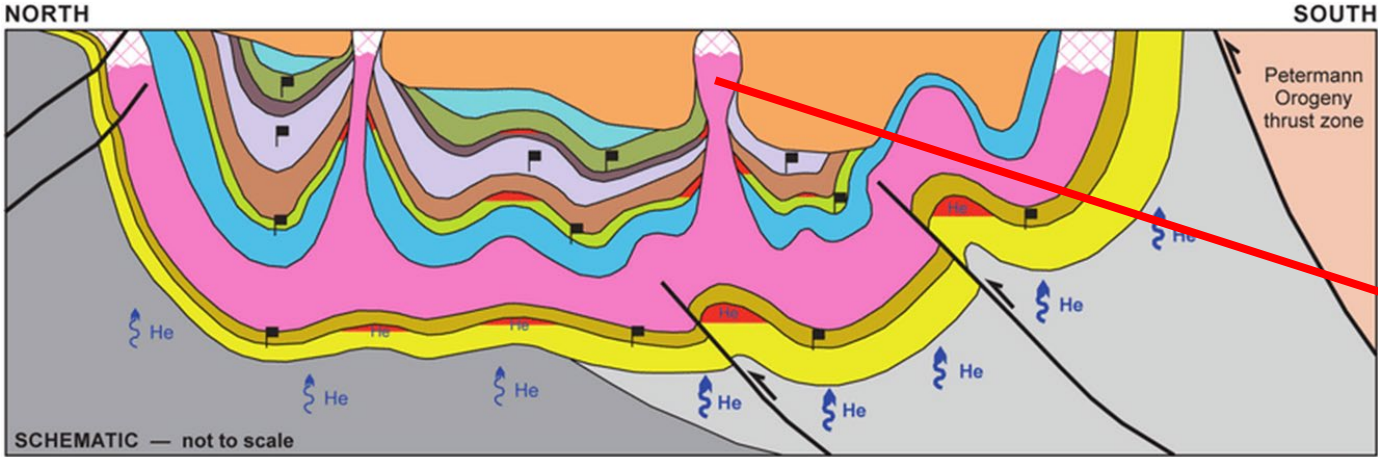
- | | | |
|-------------------------------|--|---|
| Tjauwata Group, Bentley Basin | Wallara Formation | syn-Petermann Orogeny siliciclastic units |
| Arunta Orogen | upper Bitter Springs Group | Julie Formation |
| Potential source rock | Gillen Formation, evaporite unit, dissolution breccia near surface | Pertatataka Formation |
| Hydrocarbon trap | Gillen Formation, lower shale | Olympic Formation |
| Helium in trap | Heavitree Formation, Kulail Sandstone, Dean Quartzite | Aralka Formation |
| Helium migration | | Areyonga Formation |

(Haines & Allen 2020)



- | | | |
|---|---|--|
| Basin with Paleozoic halite | Prospective region for Precambrian halite | Well with halite |
| Basin with Precambrian halite | Prospective region for halite | Well with gypsum/anhydrite and/or leached halite |
| Basin with Paleozoic and Precambrian halite | | Capital city |

Tonian salt Gillen Fm Amadeus Basin – remobilised salt



PWH201 05.04.19

- | | | |
|------------------------------|--|---|
| Tjawata Group, Bentley Basin | Wallara Formation | syn-Petermann Orogeny siliciclastic units |
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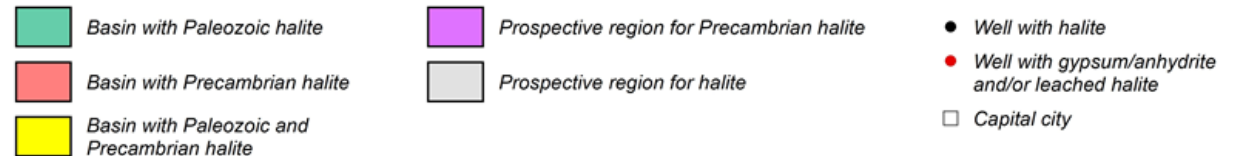
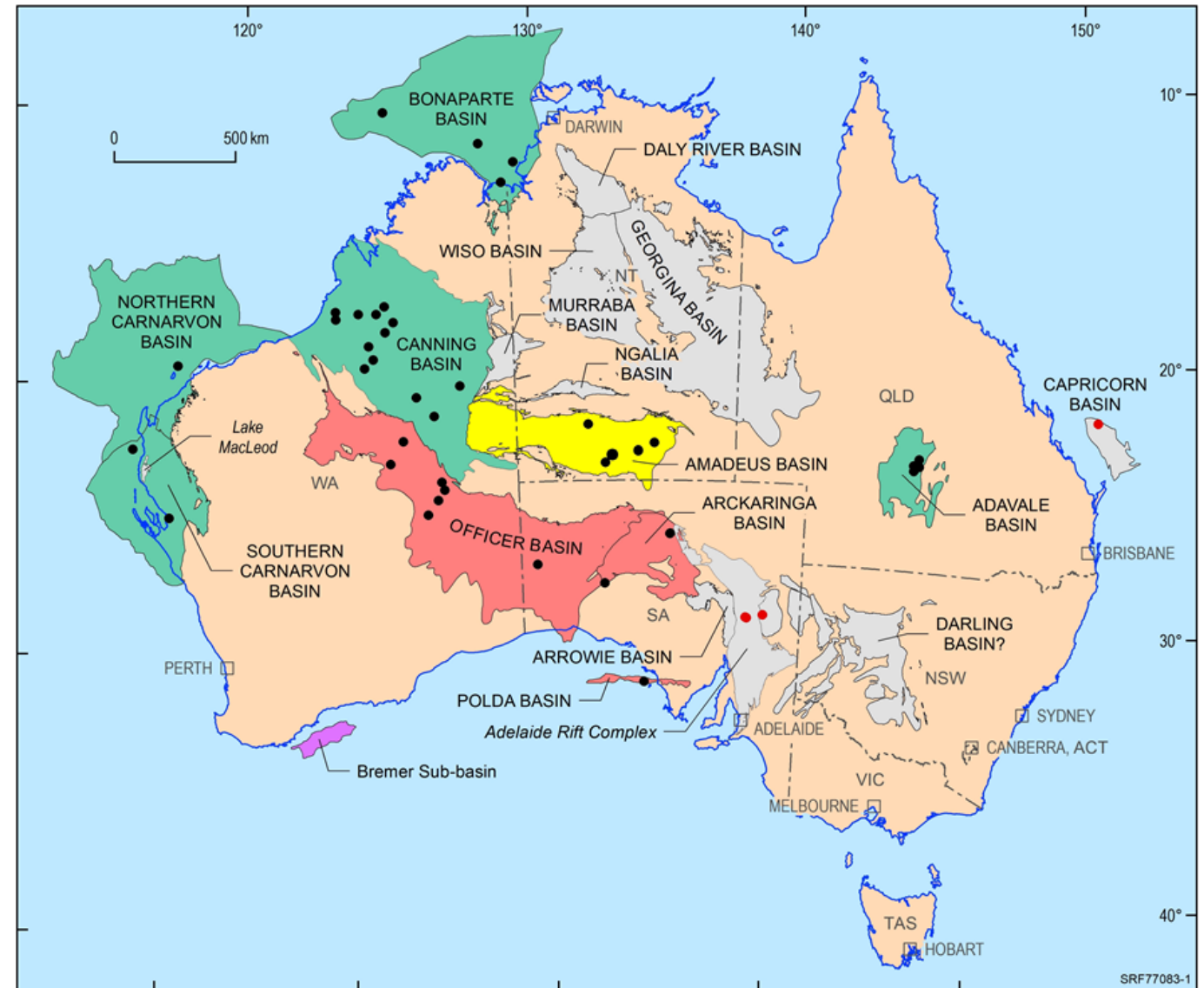
(Haines & Allen 2020)

Mount Charlotte 1 core salt & carbonate



Where is the salt in Australia?

- **Precambrian – Tonian >700 Ma**
- **Paleozoic**
 - Cambrian-Ordovician ~ 500 - 440 Ma
 - Devonian ~ 390 Ma

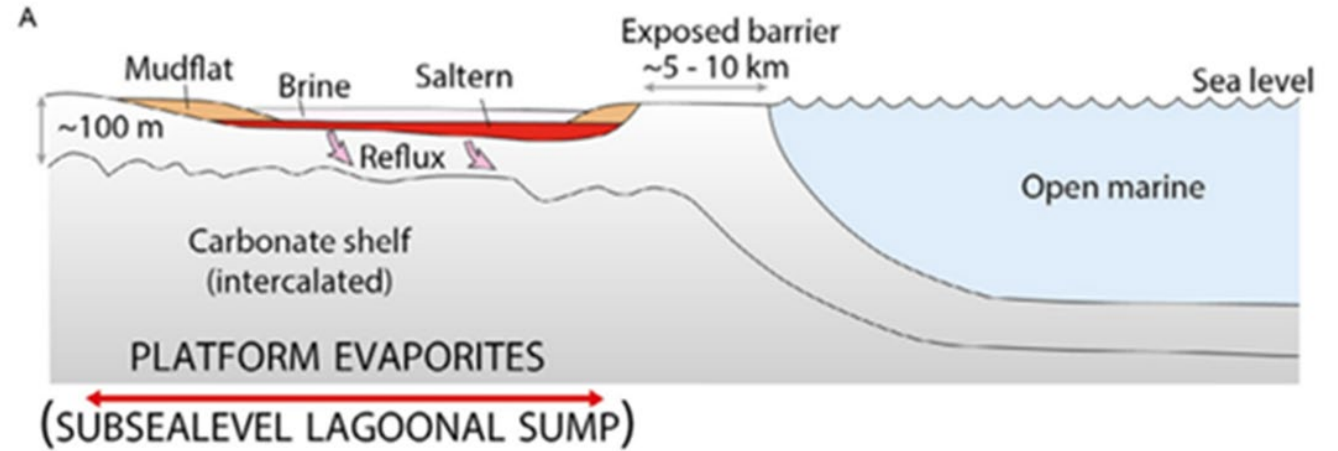


Early Paleozoic Larapintine Regime ~ 500 million yrs

- shallow tropical seaways

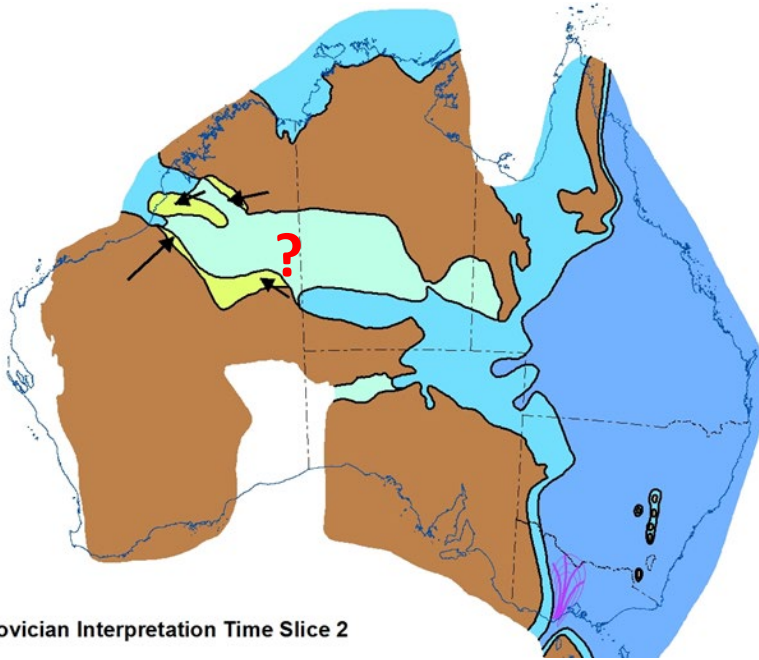


Map 44 Early Ordovician (early Tremadoc, 500 Ma)

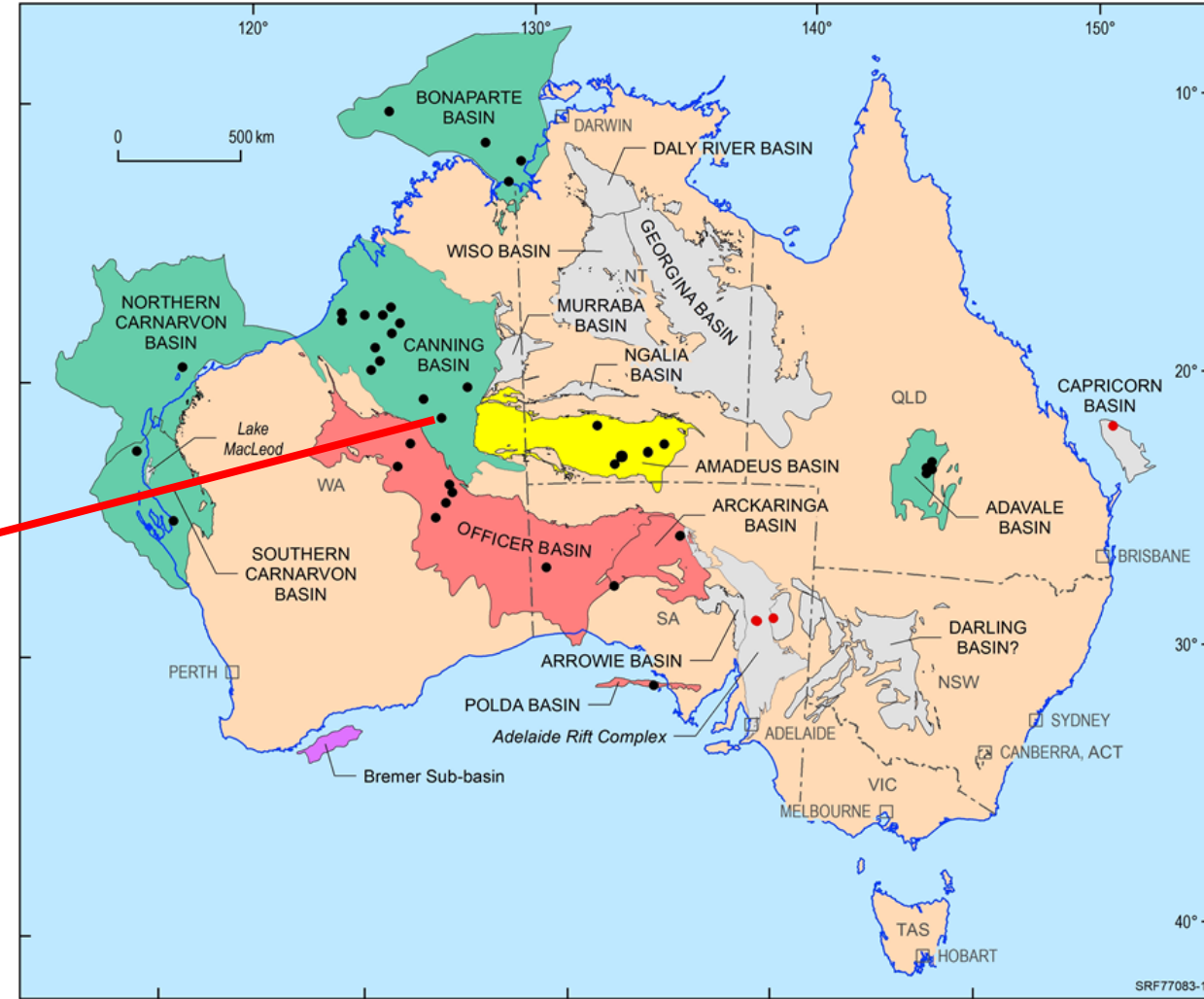


Early Palaeozoic salt basins

- Cambrian-Ordovician-early Silurian
- Amadeus, Canning, Carnarvon & Bonaparte
- Location of marine connections?



Kidson 1-
red beds & salt



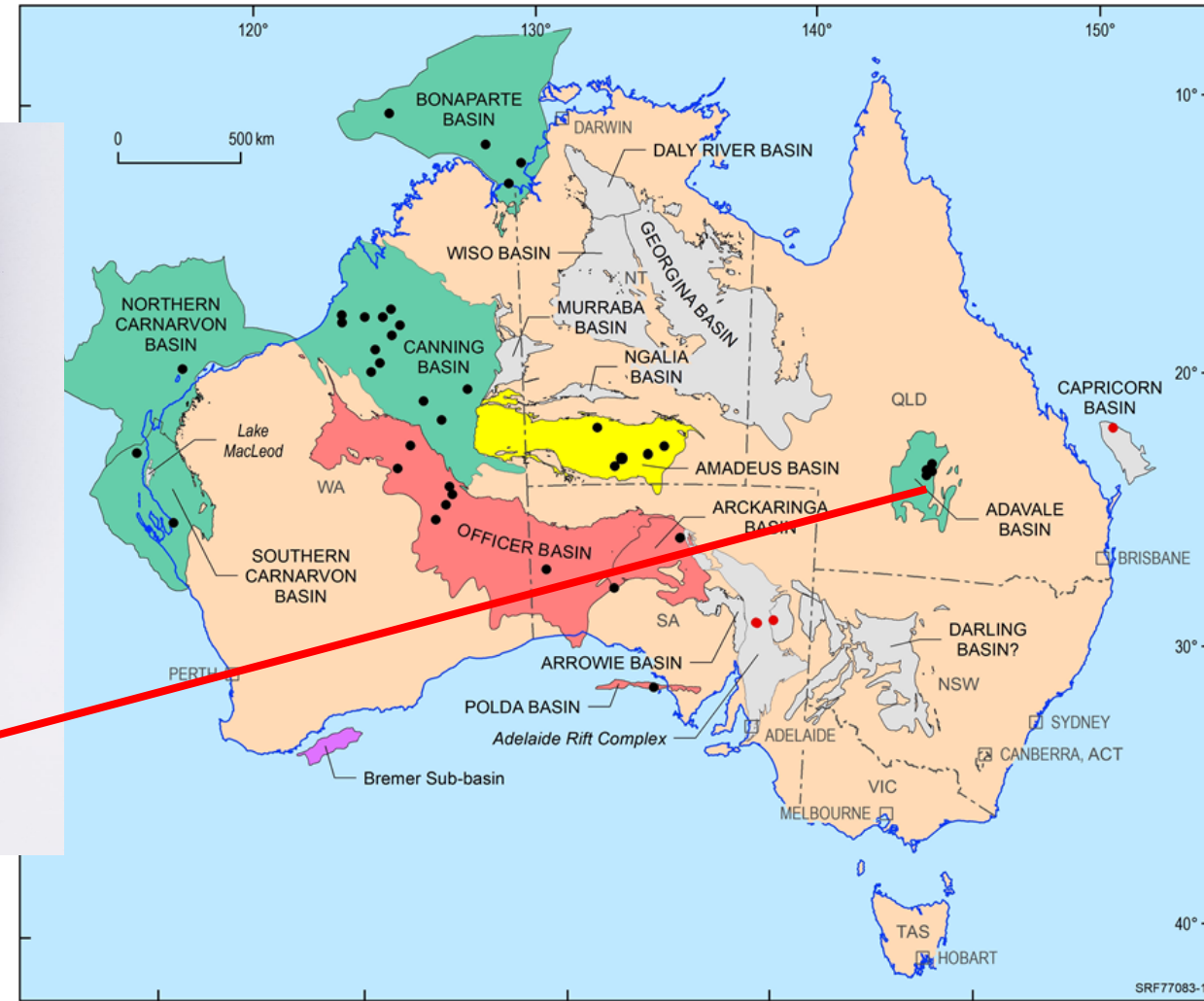
- Basin with Paleozoic halite
- Basin with Precambrian halite
- Basin with Paleozoic and Precambrian halite
- Prospective region for Precambrian halite
- Prospective region for halite
- Well with halite
- Well with gypsum/anhydrite and/or leached halite
- Capital city

Devonian salt basins

- *Adavale*
- *Canning?*
- *Darling???*



Bury 1 salt



- Basin with Paleozoic halite
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Map 35 Late Devonian (middle Famennian, 363 Ma)

Devonian Palaeogeographies

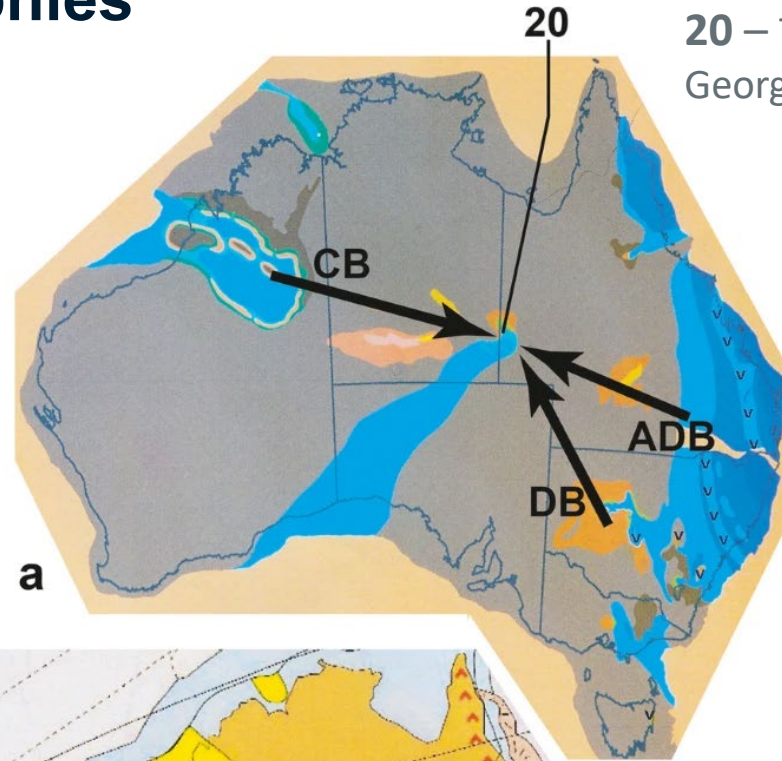
.....play scale

Devonian seaways redefined
from fossil fish data

Young & Lu, 2020

a 1980s map

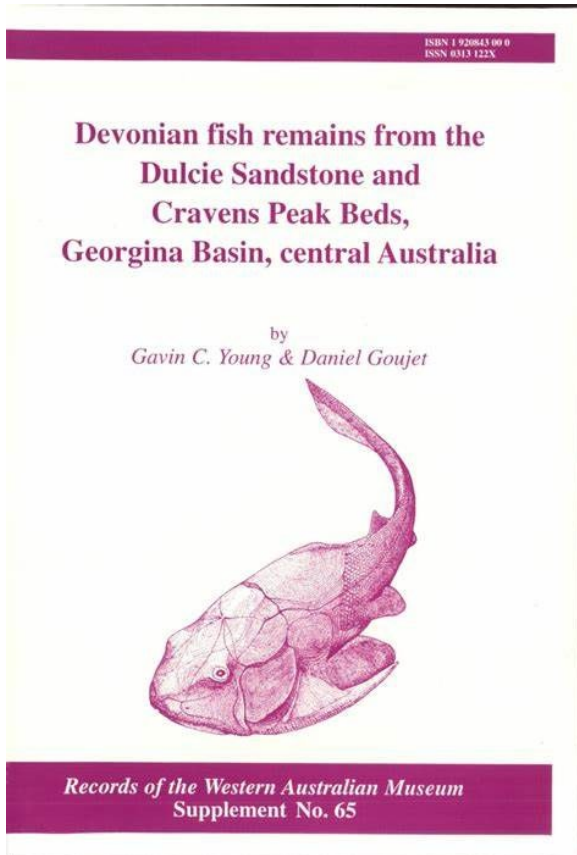
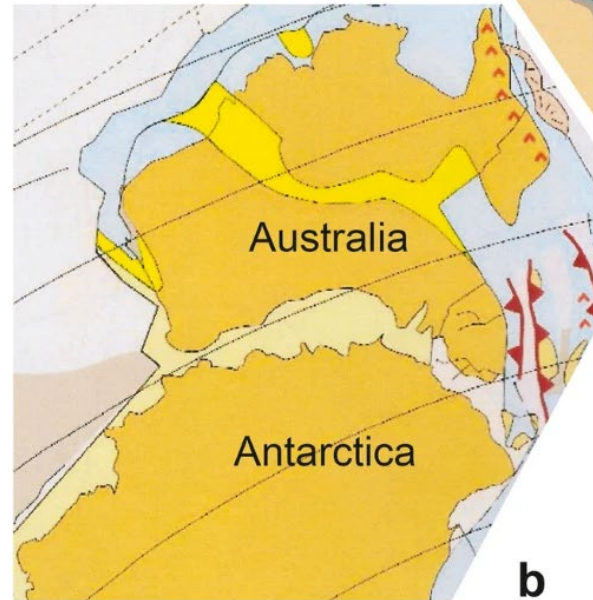
b 2020 map



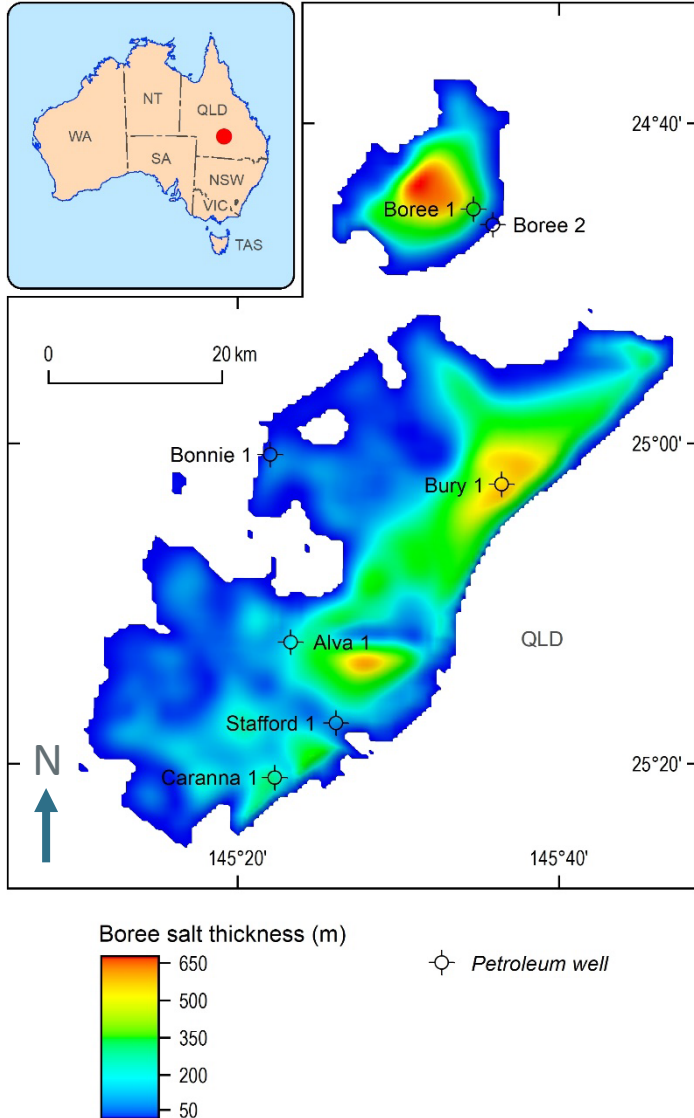
20 – Toomba Ck, Carven Peak,
Georgina Basin

Adavale Basin (**ADB**)
proven thick salt (500 m)

Darling Basin (**DB**) similar
location along convergent
margin & marine
connections – possibility
of salt deposits ?



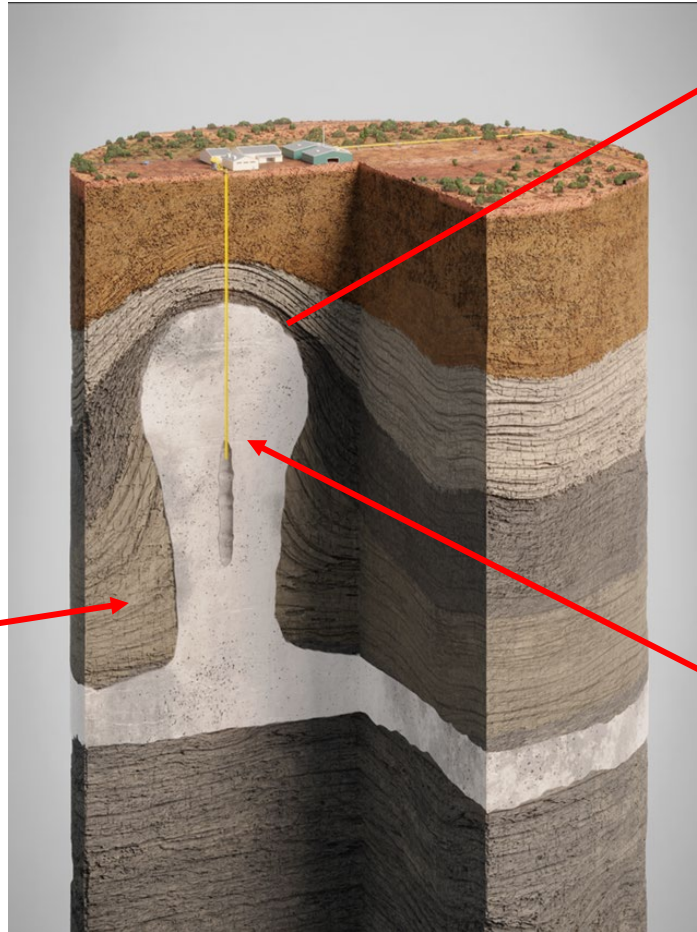
Adavale Basin – Boree Salt*prospect scale*



- Preliminary 3D model identified 3 main salt bodies.
- Halite up to 555m thick
- Strategic location to infrastructure
- Thick salt intersected at >1800m at Bury 1.
- Seismic suggests that salt could be ~1600m deep.

Adavale Basin – Boree Salt drilled in 1960s

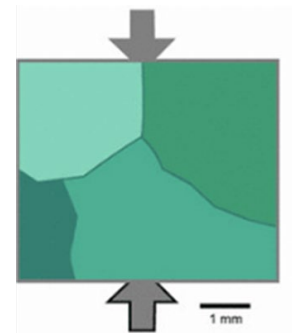
Bury 1 – primary salt fabric? with minor displacement of layers



Bury 1 – brecciated units above salt



Boree 1 – remobilised salt? interlocking halite crystals

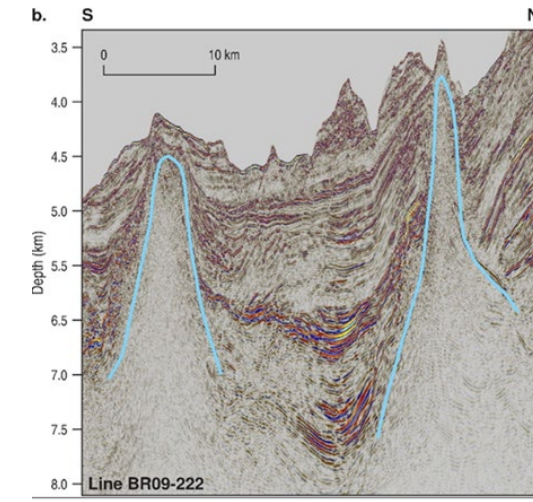
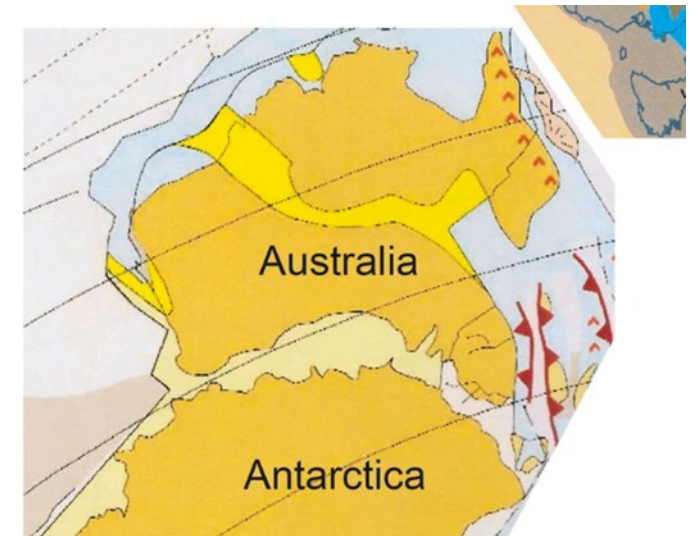


Pressure solution

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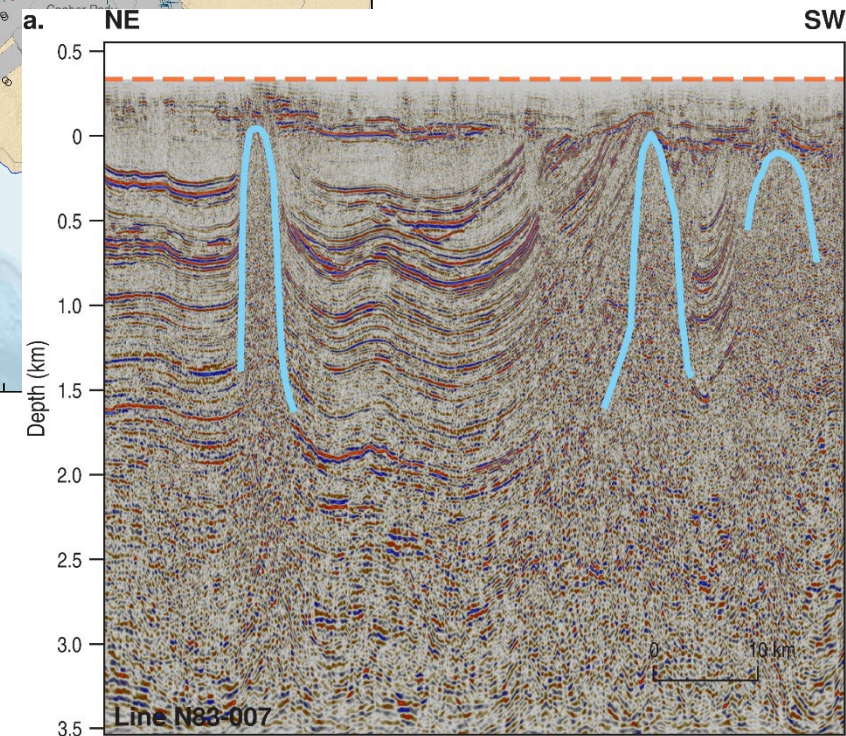
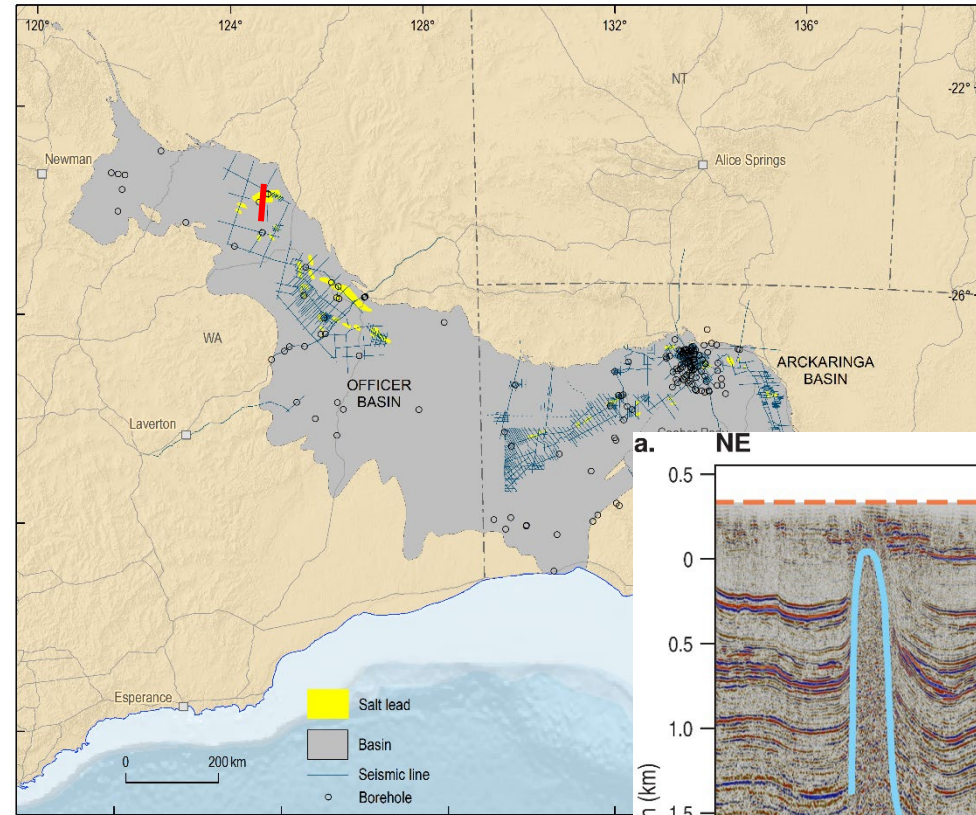
- ***How do we find some more?***
 - geological setting to narrow the search
 - Tectonics, climate, palaeogeography
 - reconnaissance hydro-geochemistry
 - ***reconnaissance geophysics***
 - Seismic
 - AEM
 - Gravity + ?



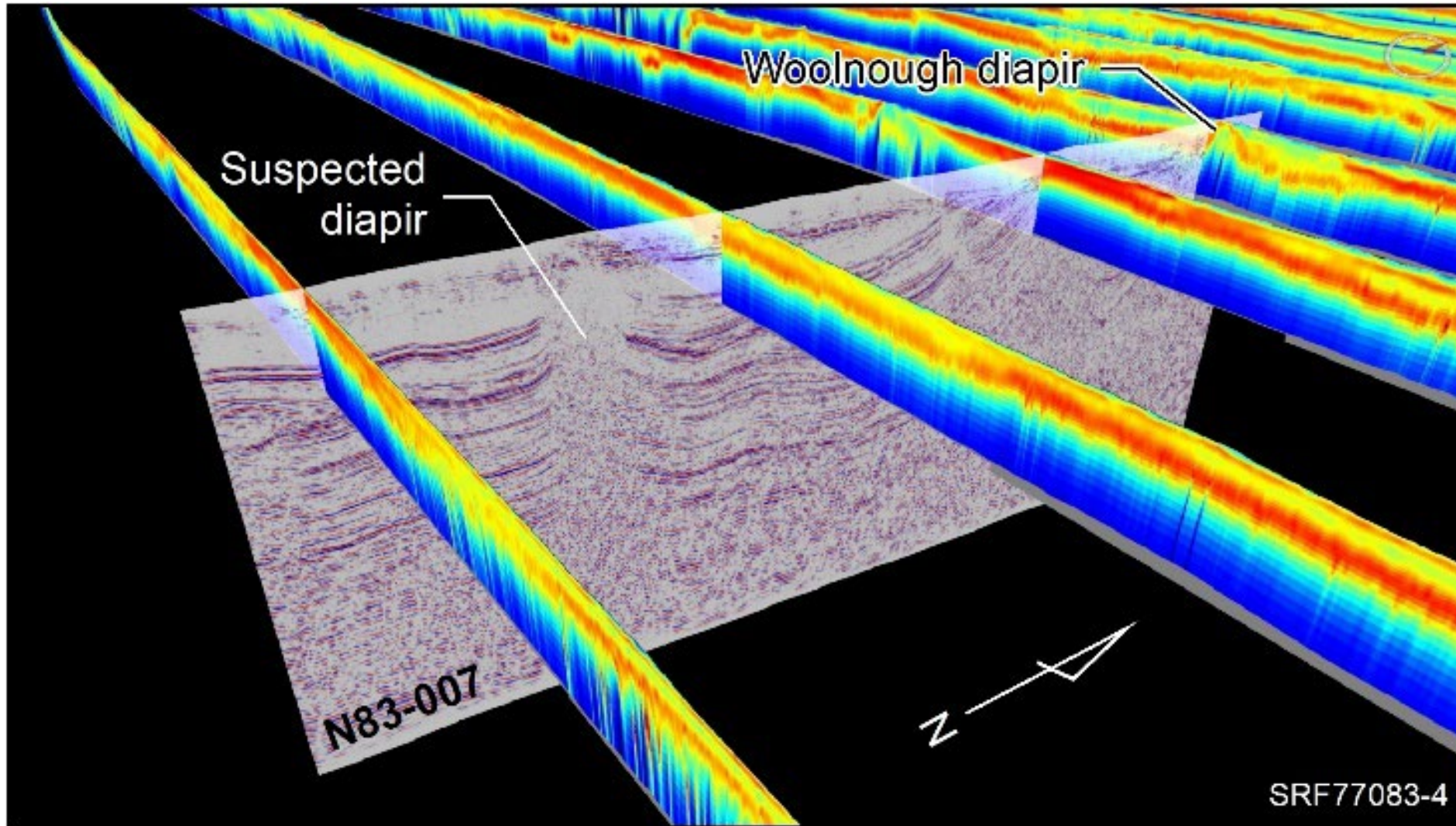
Bremer Sub-basin seismic
? Salt diapir

Officer and Arckaringa Basin – salt leads

- Limited seismic and wells
- Seismic and AEM identified salt leads
- High potential for new discoveries
- New AEM acquisition over SA and WA is underway



Officer Basin – salt features – AEM & seismic data

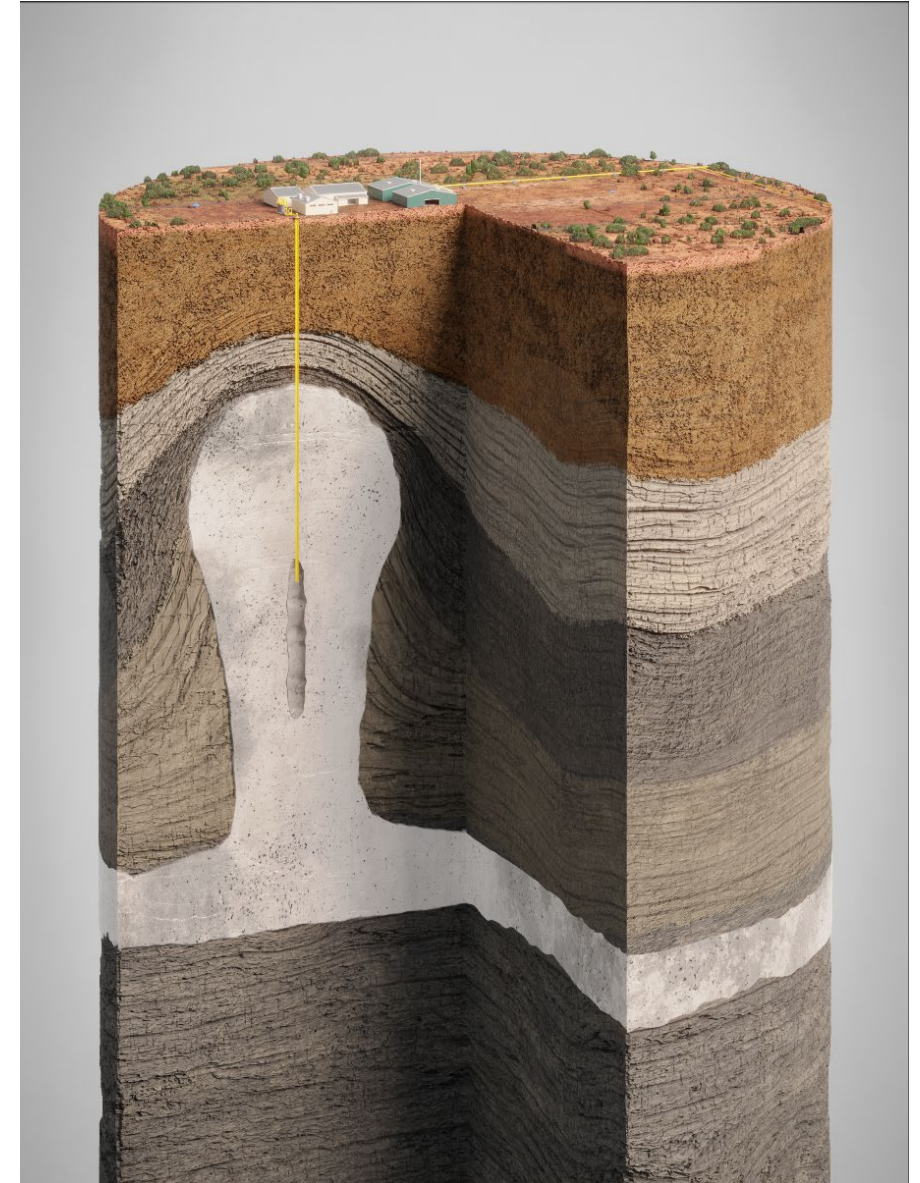


Conclusion

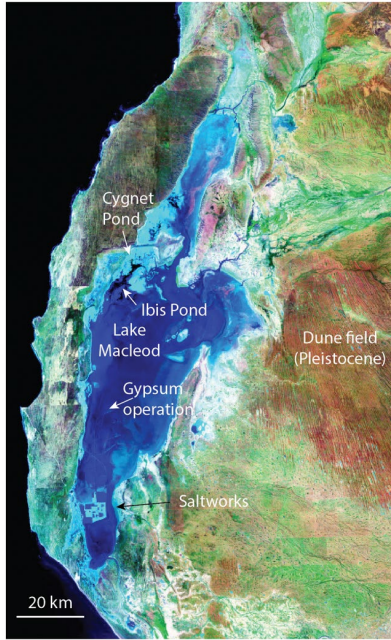
- Australia has examples of **thick halite** structures that may be suitable for **UHS**
- **Geophysics** (seismic, AEM) - the primary exploration tool, followed by **drilling, 3D seismic**
- Existing datasets, skills and exploration strategies can be repurposed to look for salt in the subsurface

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ausgeodata@ga.gov.au



Come and see us and some **salt** at: **Booth No .93**



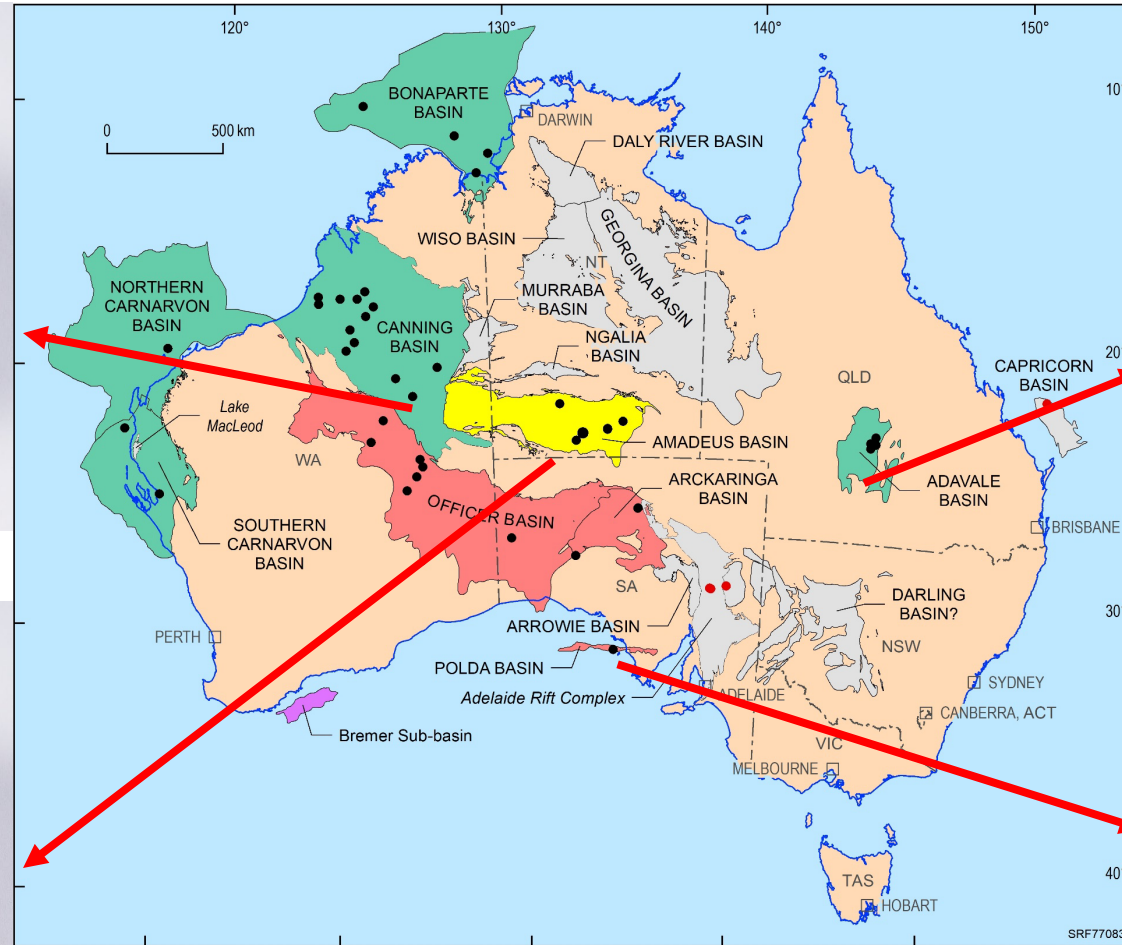
Holocene, Lake Macleod



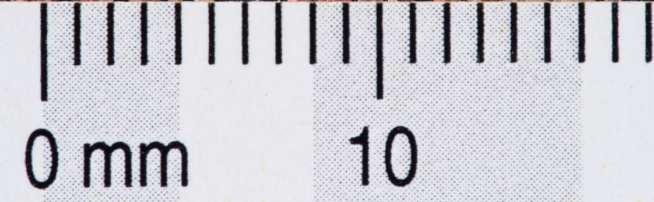
Neoproterozoic, Amadeus



Salt prospectivity through the EFTF program - *Exploring for the Future*



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Exploring for the Future 2023 Showcase

Online, 15-17 August

ga.gov.au/showcase

