The sedimentary-hosted copper system of the Stuart Shelf, South Australia

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Acknowledgement of Country

As guests here on Aboriginal land, the Department for Energy and Mining (DEM) acknowledges everything this department does impacts on Aboriginal country, the sea, the sky, its people, and the spiritual and cultural connections which have existed since the first sunrise. Our responsibility is to share our collective knowledge, recognise a difficult history, respect the relationships made over time, and create a stronger future.

We are ready to walk, learn and work together.

SOUTH AUSTRALIA

Government of South Australia

Department for Energy and Mining

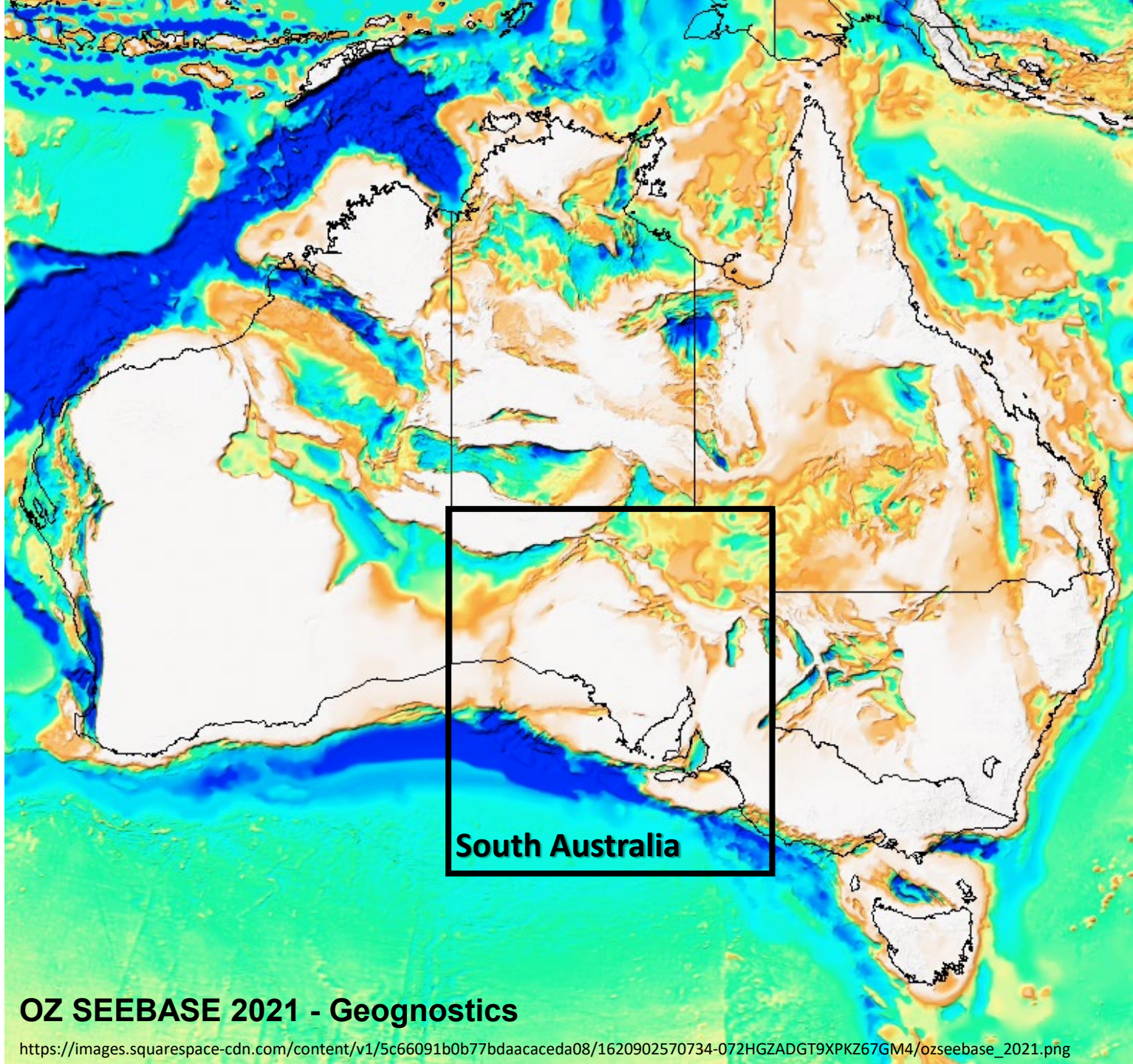
Background

- Australia has lots of basins of various ages that host base metal mineralisation

→ **proven mineral provinces with mature and active frontier exploration**

- wide range of basin styles, clastics and carbonates, black shales and redbeds
- many are relatively undeformed, outcrop or under shallowcover
- but many are also very deformed and intruded, mineralised, deeply eroded and deep under cover

→ **using approaches commonly used in the energy industry has the potential to provide new insights for exploration mineral targets within these basins**



Petroleum System Approach

Many concepts are similar for **Mineral Systems,** but different terms used and extra processes present (magmatic, hydrothermal...)

Petroleum System

Generation ⇨ **Migration** ⇨ **Entrapment** ⇨ **Retention** ⇨ **Recovery**

Generation	Migration	Entrapment	Retention	Recovery
Source rock type	Vertical	HC charge	Top seal	Oil/gas quality
Total Organic Carbon	Lateral	Trap and type of trap	Lateral seal	Recovery efficiency
Yield curve	Timing	Trap history	Bottom seal	Reservoir quality
Maturity	Migration loss	Timing	Timing	PVT conditions
Drainage area	Remigration	Reservoir	Transformation	Overpressure
Geohistory graph		Dynamic entrapment		Economics
Time of migration		PVT conditions		

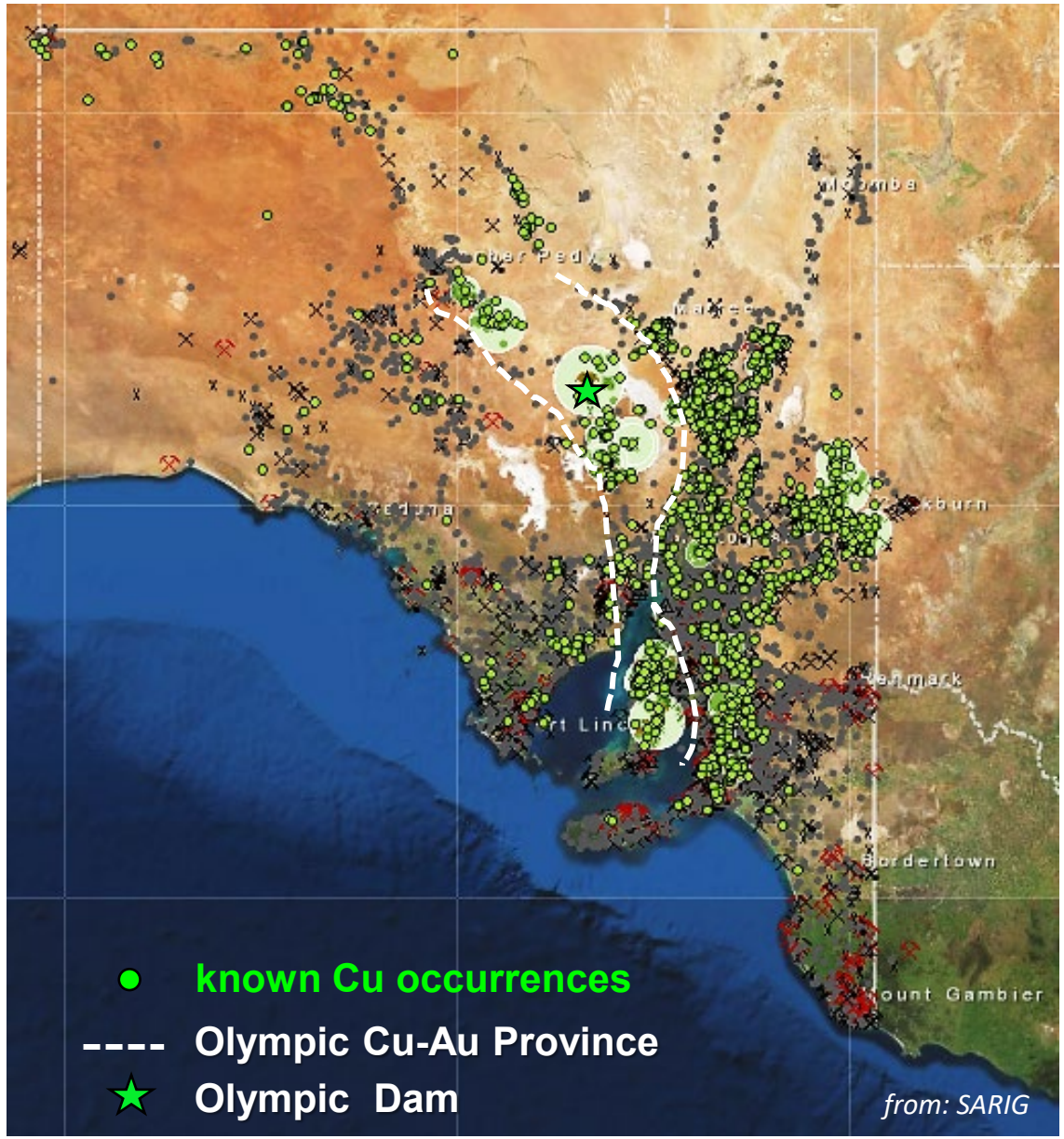
https://www.mhnederlof.nl/images/petroleumsystem.jpg

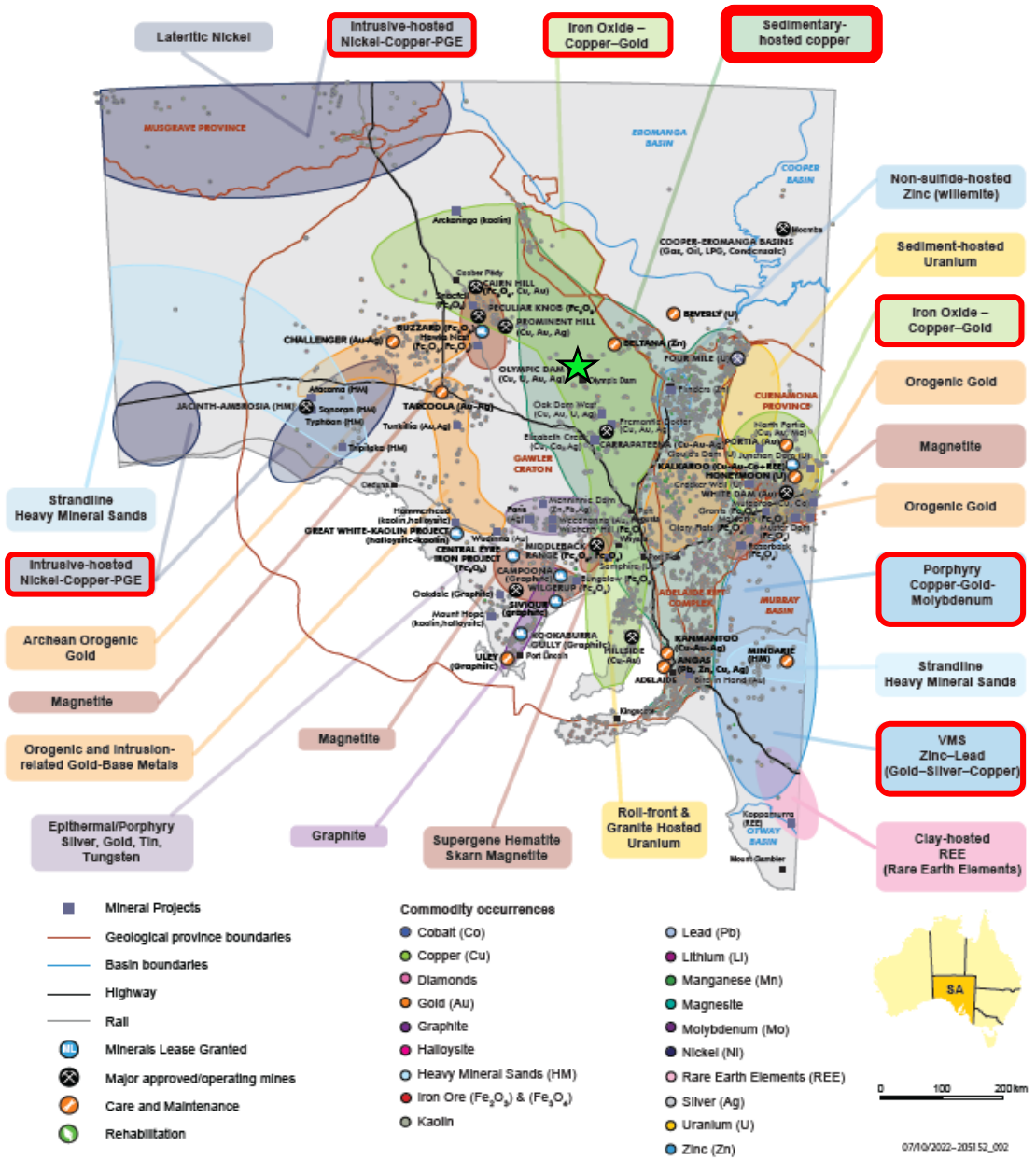
Mineral System

Source ⇨ **Pathway** ⇨ **Trap** ⇨ **Preservation**

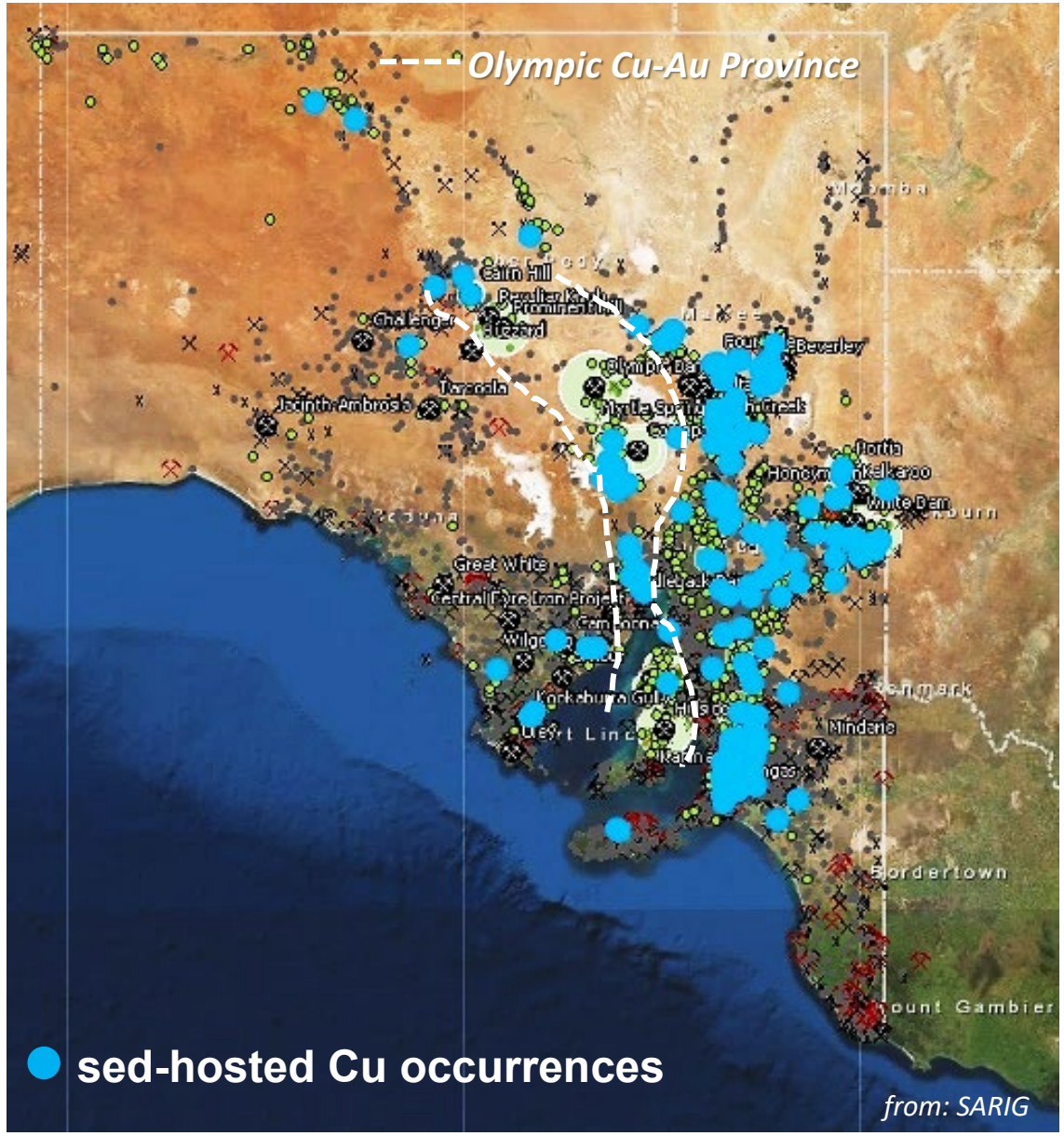
Source	Pathway	Trap	Preservation
ore components transport fluids energy	conduits along with metals and fluids transported from source to sink	physical or chemical mechanisms deposit ore component at sink	processes permitting preservation of mineralisation in crust up to present time

Copper in South Australia





Sediment-hosted copper in South Australia

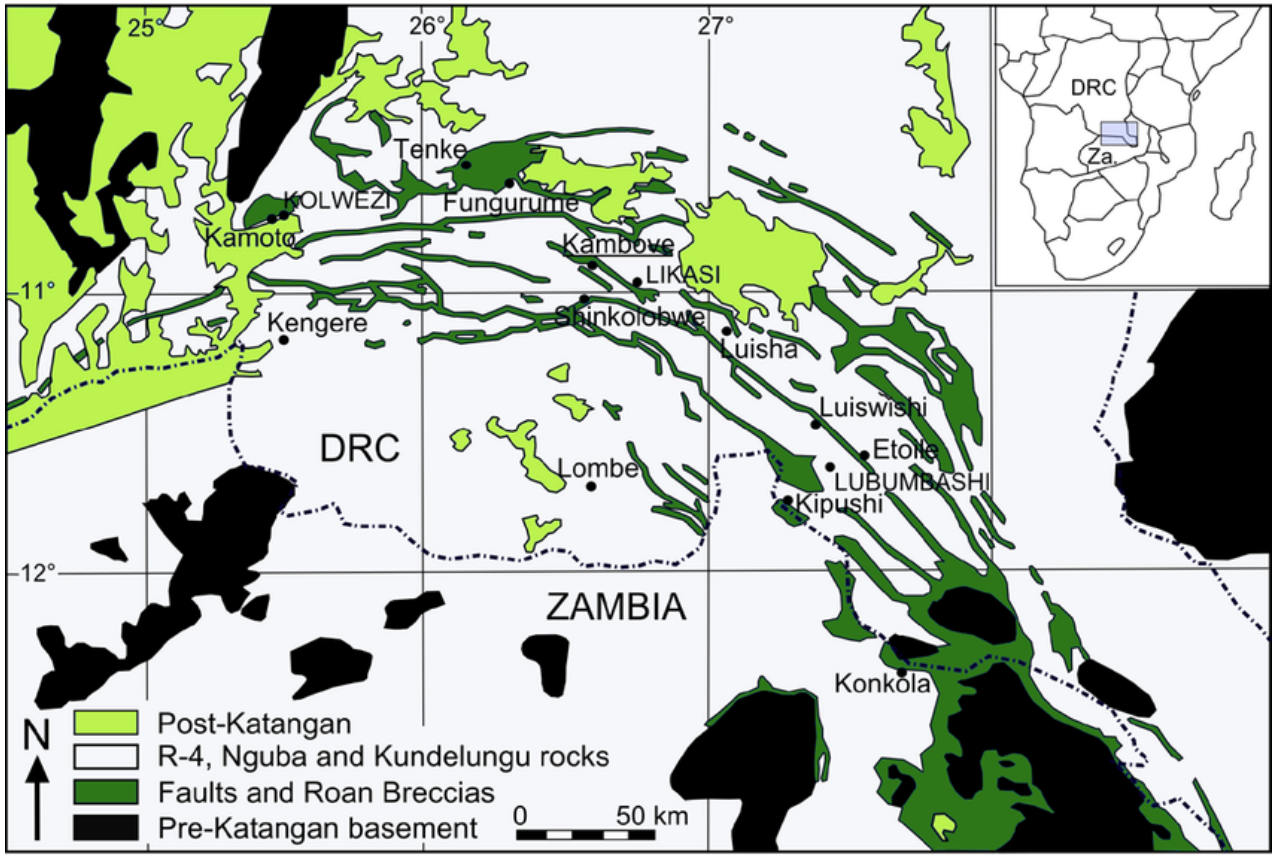


~40% of copper occurrences in South Australia are sediment-hosted

Deposit	Ore (Mt)	Cu (%)	Cu (kt)	Co (%)	Past production (Cu - kt)
Emmie Bluff	40.2	1.27	511	**0.06**	-
Windabout	17.65	0.77		**0.05**	-
MG14	1.83	1.24		**0.033**	-
Gully	0.9	0.9	8.1	**0.01**	-
Sweet Nell	0.35	1.2	4.2		Neg
Cattlegrid	15	0.67	100	**0.01**	>156
Main Open Cut	3.3	0.51	17		16
Kapunda	3.7	1.2	47		14
Mountain of Light	1.2	0.82	10		0.6
Blinman	?0.21	>3.5-15			9.9
Burra	2.7	3.3			90

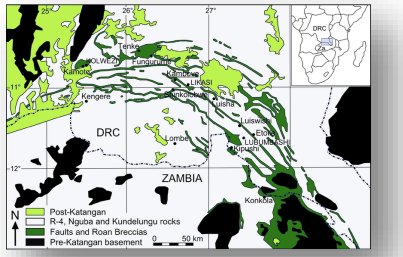
→ **just how prospective is South Australia for sediment-hosted Cu deposits and where are the 'giant' ones?**

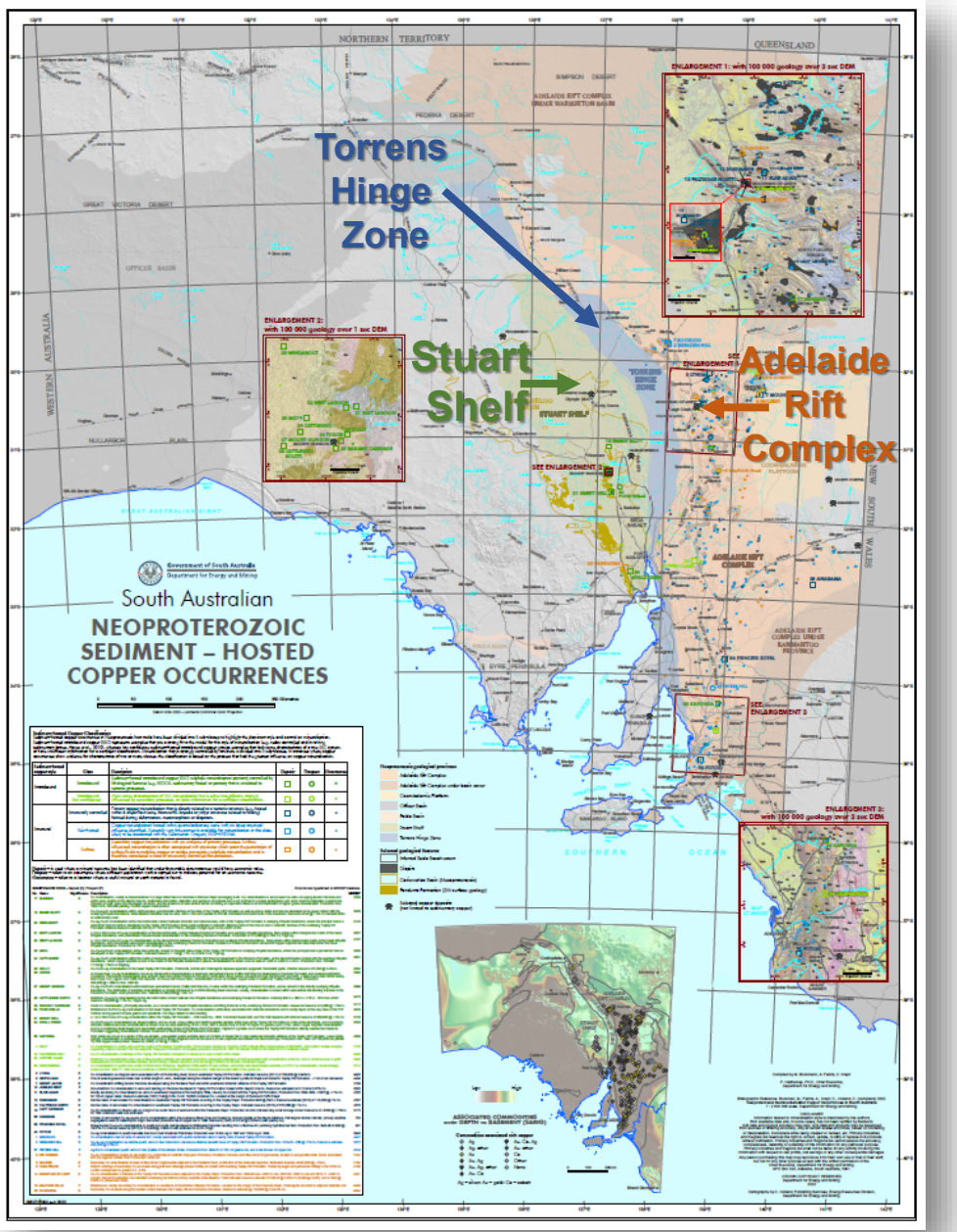
Comparison Central African Copperbelt (CACB) - South Australia



from: Van Langendonck et al. , 2013

to scale

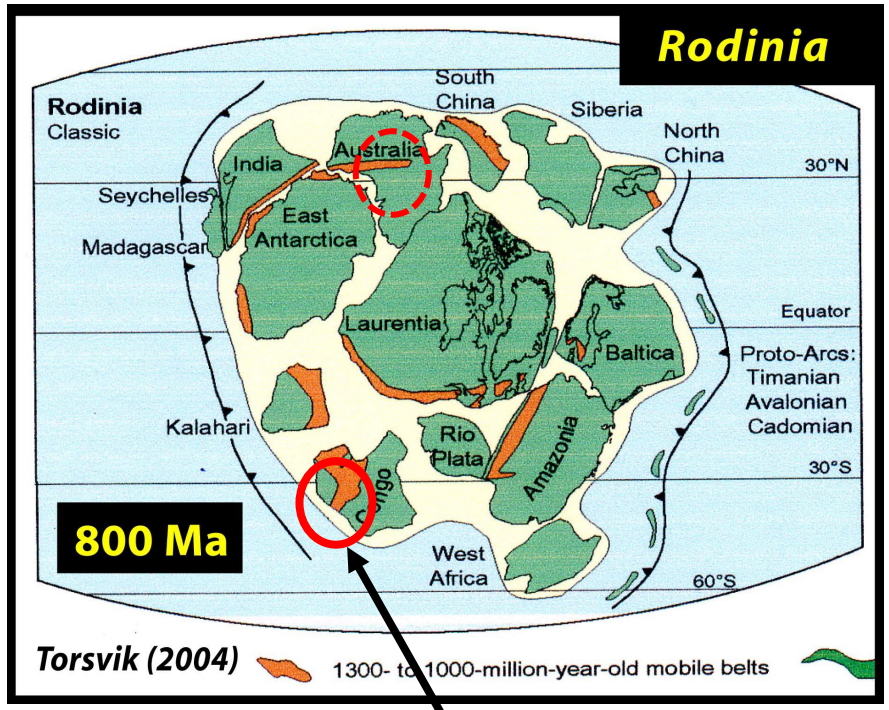




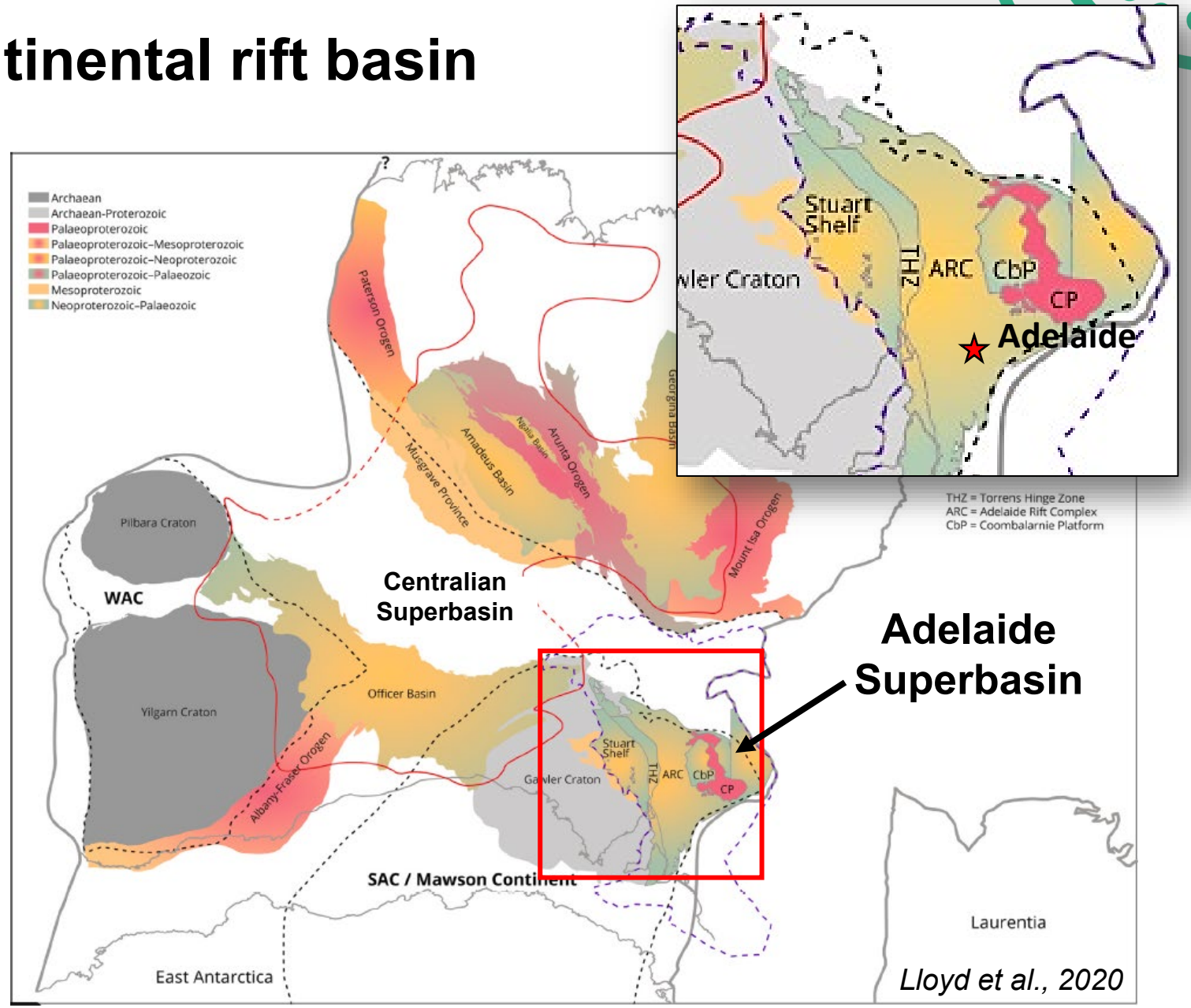
Bockmann et al., 2022

Comparison Central African Copperbelt (CACB) - South Australia

Tectonic setting → intracontinental rift basin



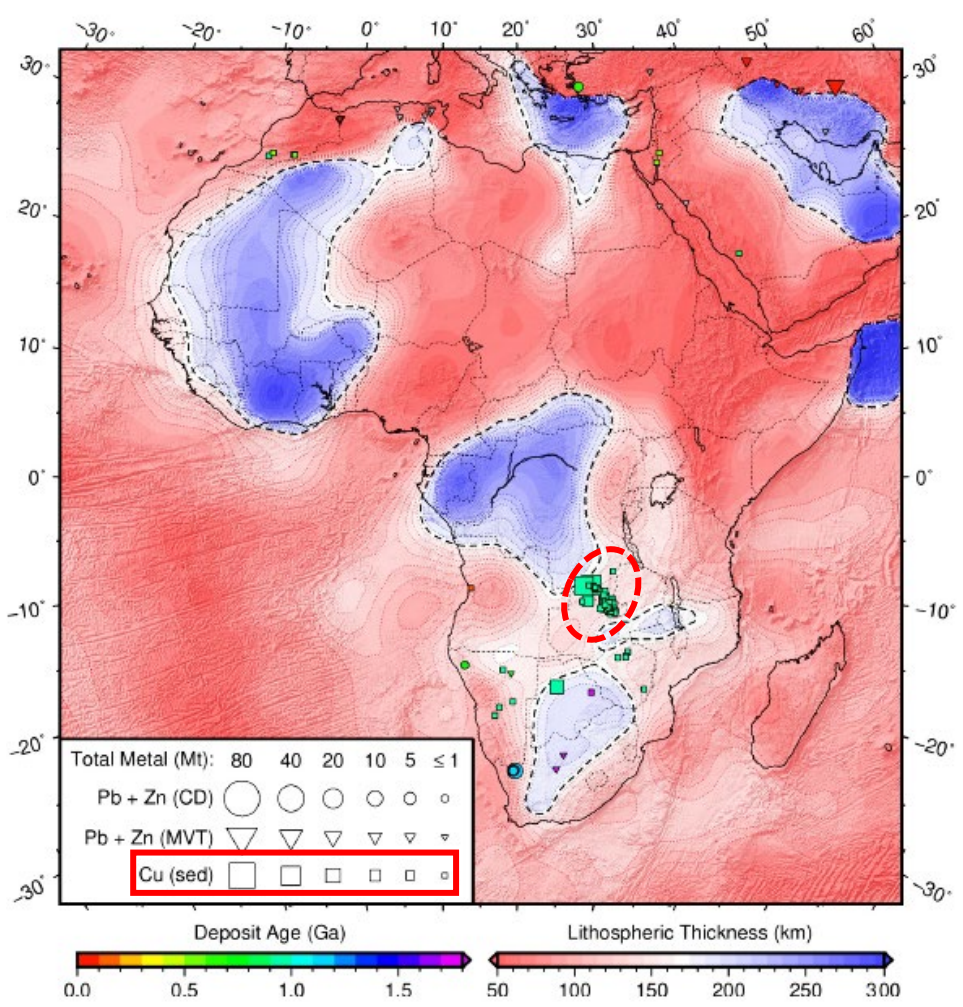
Katanga Basin

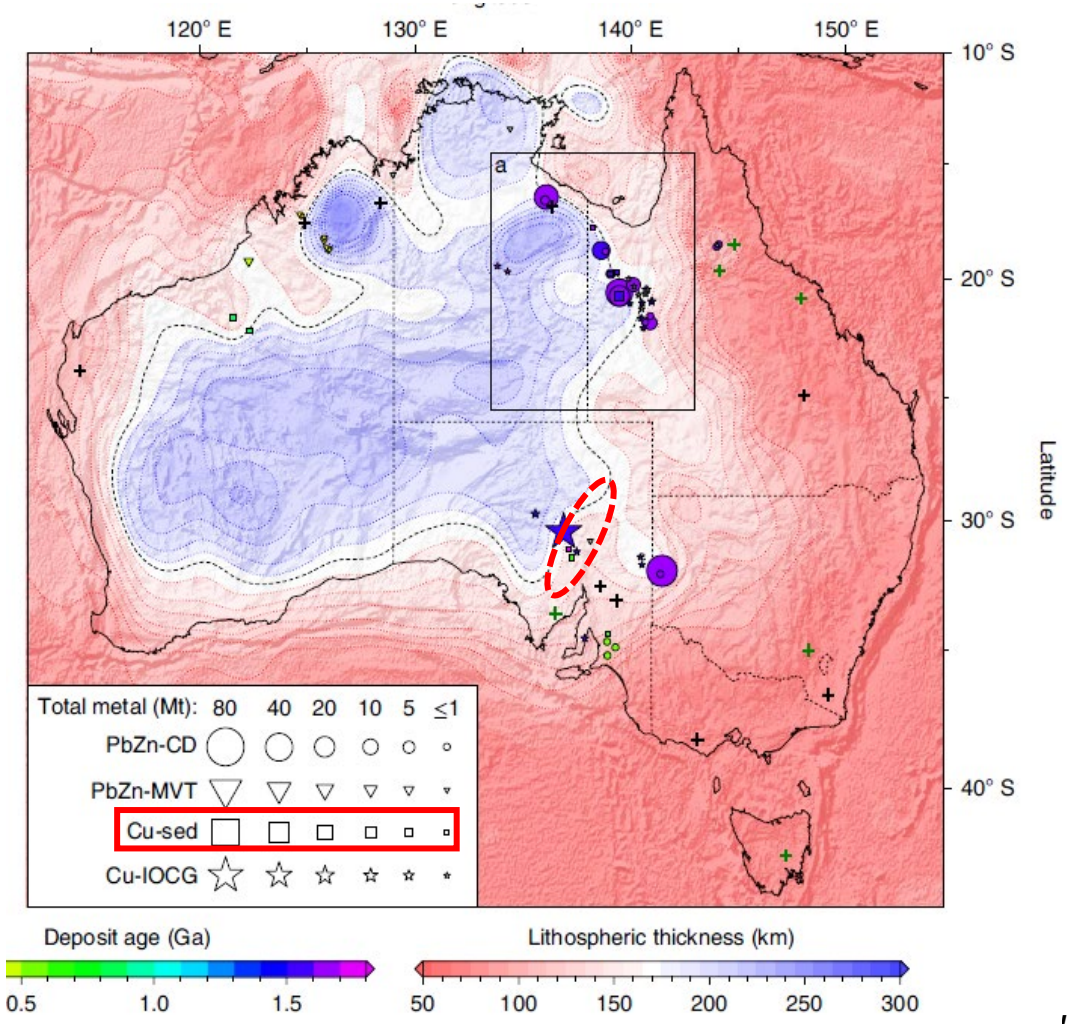


Comparison Central African Copperbelt (CACB) - South Australia

Continental margins - lithosphere thickness model (Hoggard et al., 2020)

→ *both have enriched sub-continental lithospheric mantle (SCLM)*

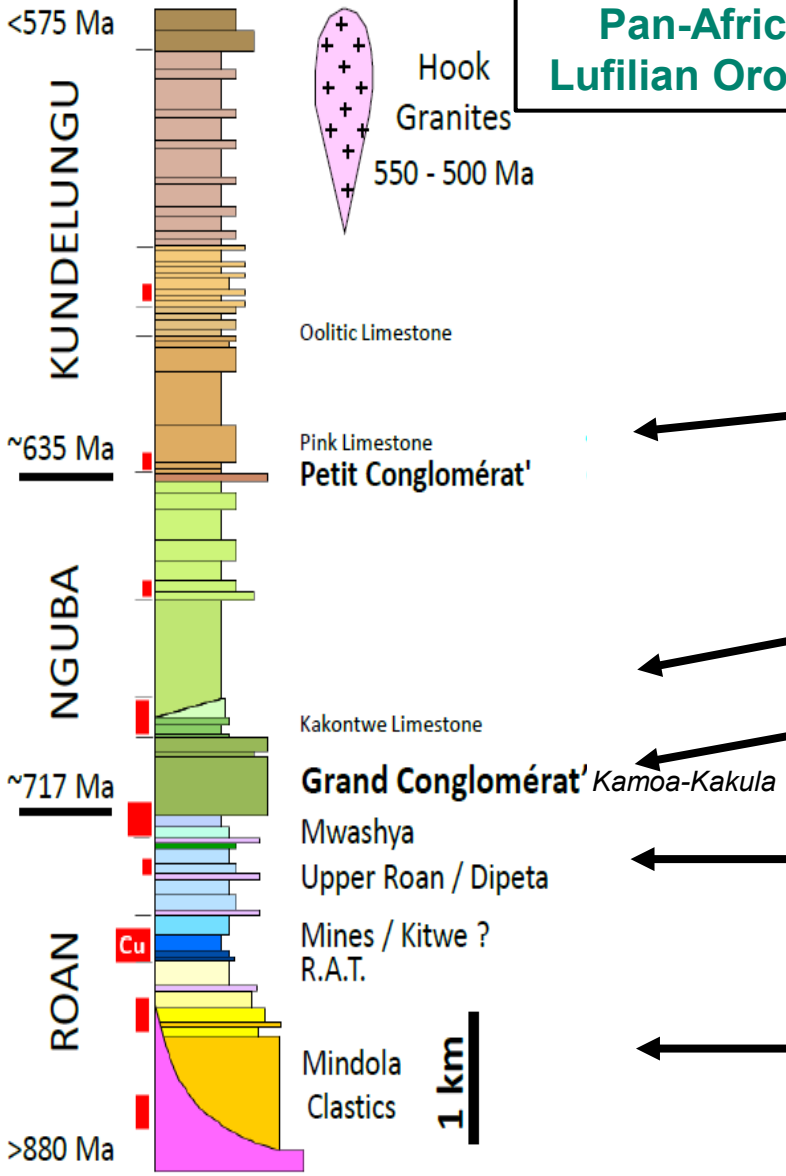




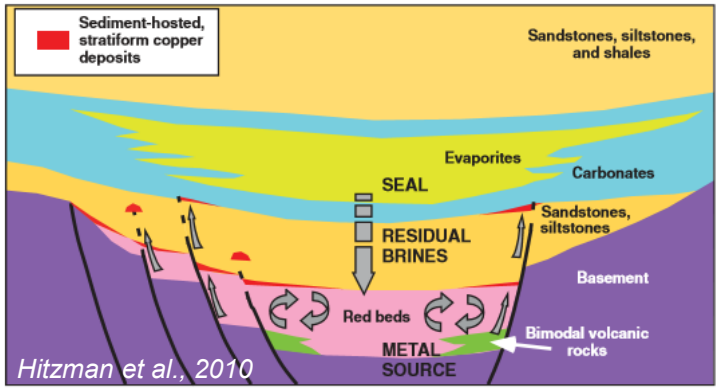
Hoggard et al., 2020

Basin evolution

Katangan Supergroup



Woodhead, 2020



Cap carbonate
post-Marinoan glaciation

Seal/trap
→carbonate

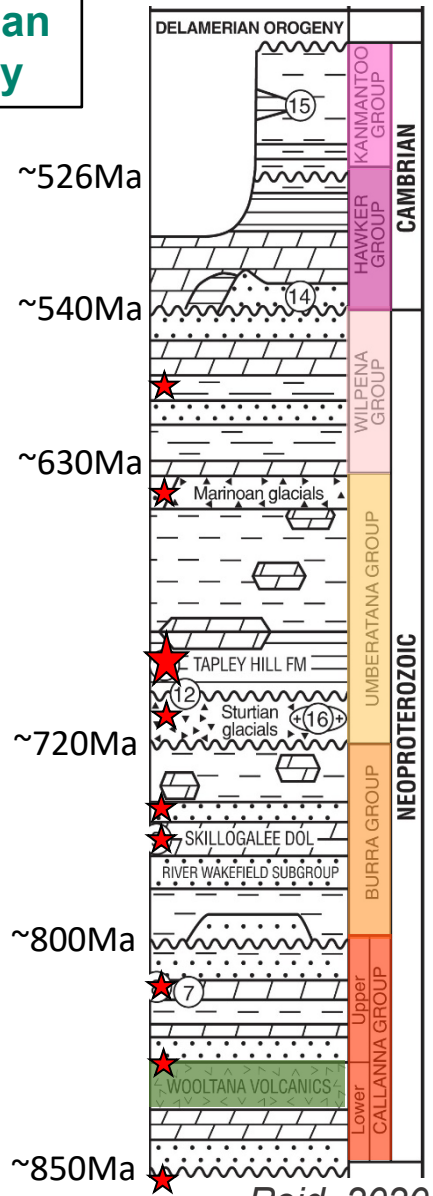
Sturtian glacials

Renewed extension
→ finer-grained clastics and carbonates

Rift phase
→ coarse clastics, evaporites, carbonates, mafic igneous rocks

Adelaide Superbasin

Delamerian Orogeny

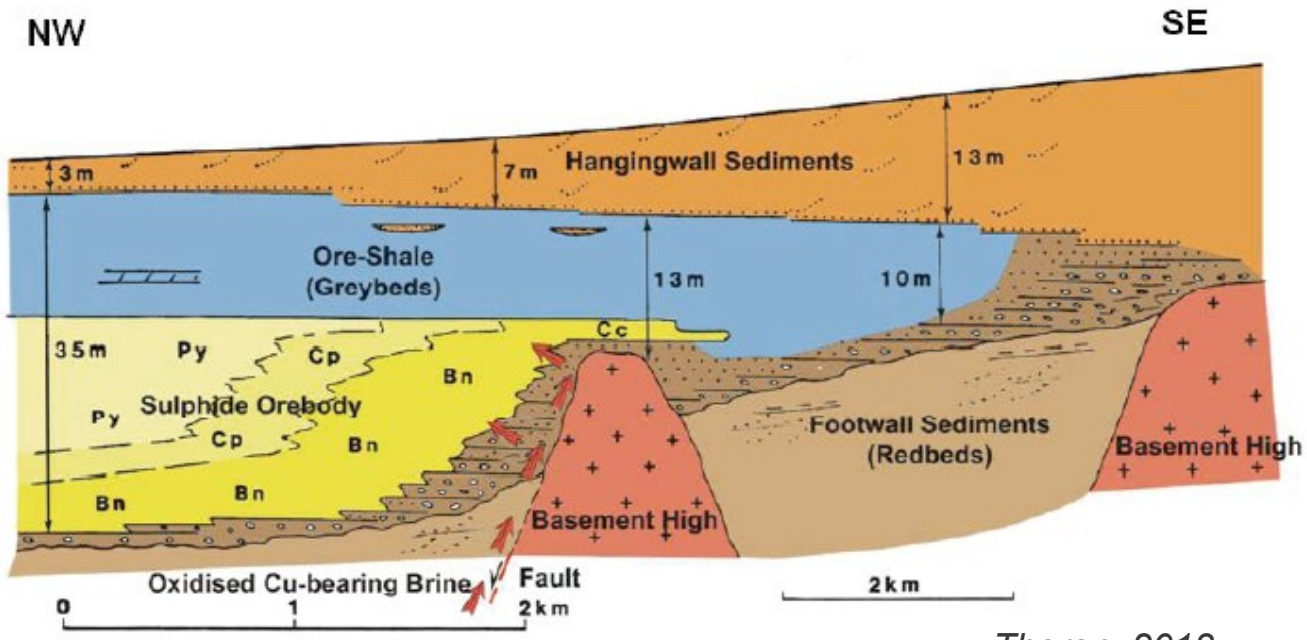


Reid, 2020

Comparison Central African Copperbelt (CACB) - South Australia

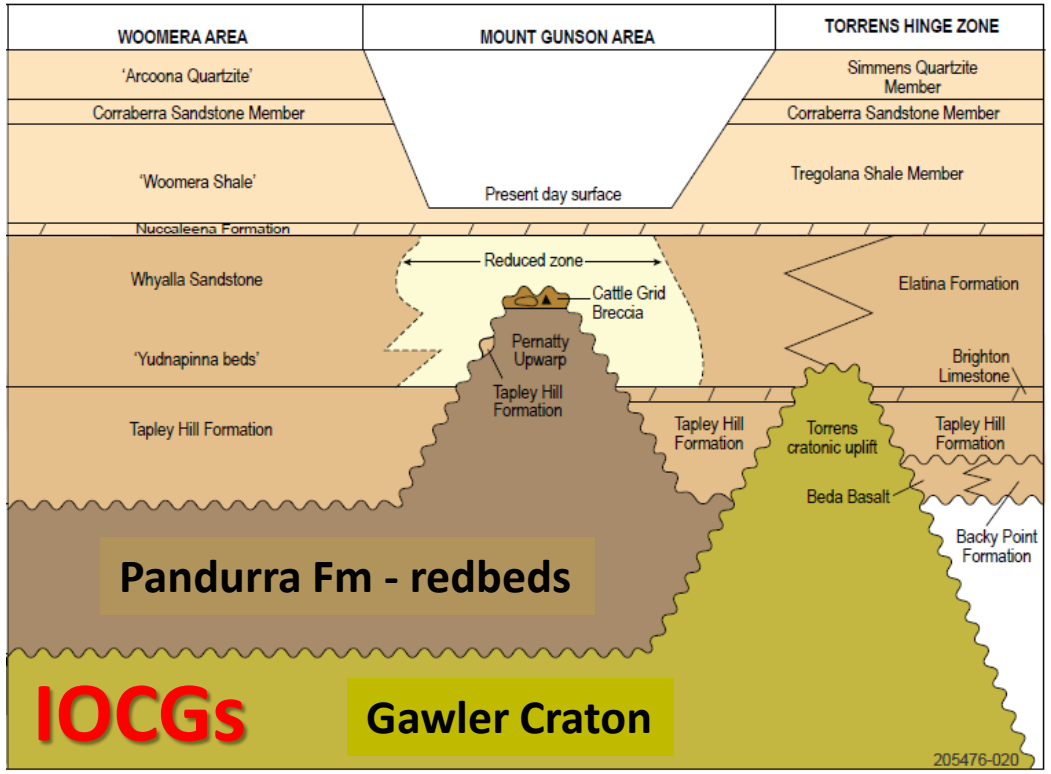
Basement highs play important role

Basement-proximal Zambian Copperbelt



Theron, 2013

Stuart Shelf



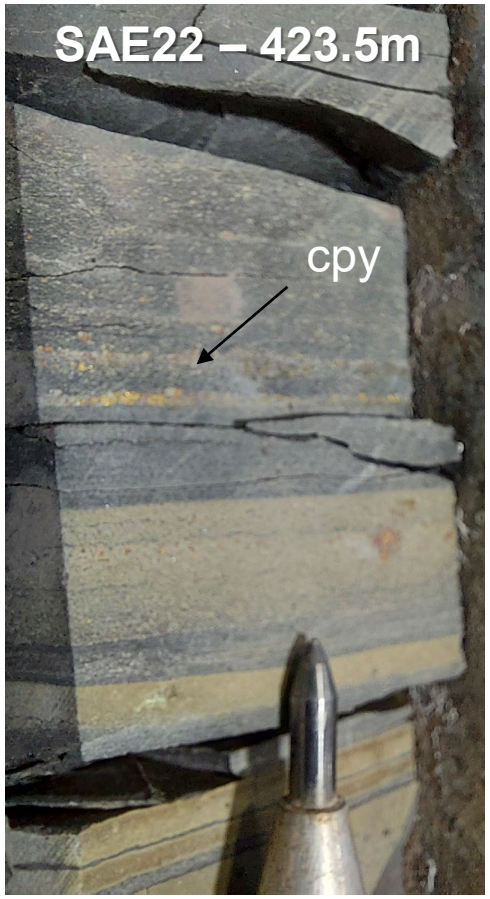
Tonkin and Wallace, 2021

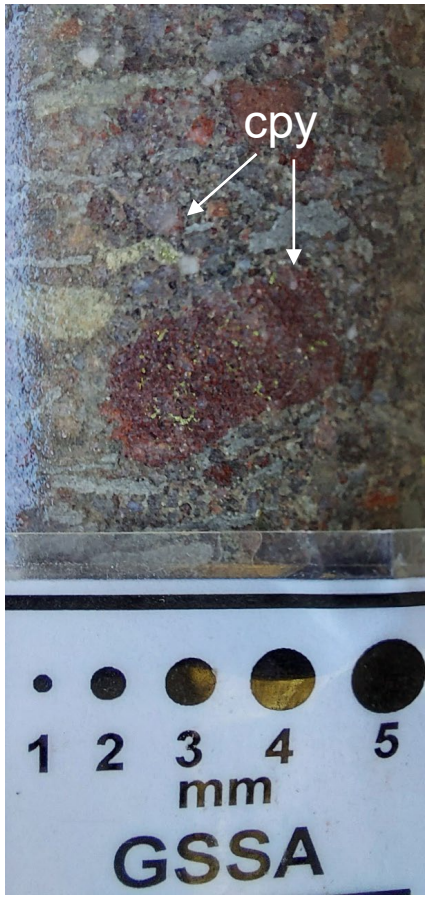
Sed-Cu mineralisation in SA

Ore textures

replacement (laminae, clasts), cements, veins

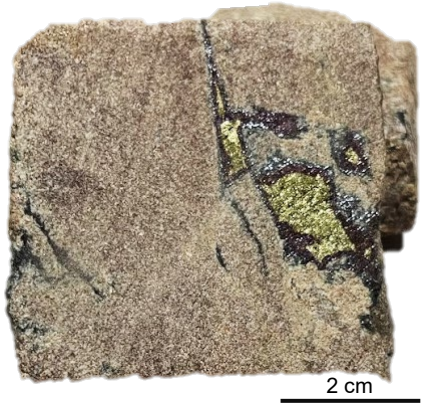
DH HWD 1
disseminated sulphides in
mineralised basal Tapley Hill Fm



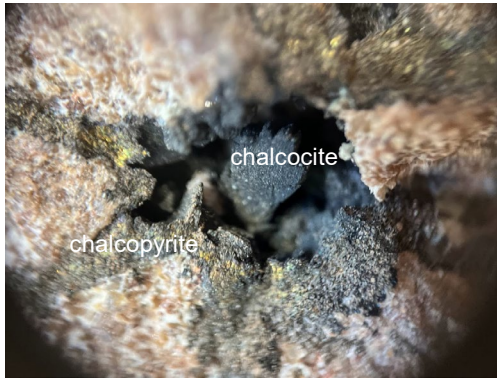


Emmie Bluff – clast and matrix cpy, replacement textures

DH M350-250 @39m
permafrost breccia
Whyalla Sandstone
Cattlegrid deposit



Sigmoidal vein with infill sulphides
DH N450-350 @38m
Pandurra Formation, Cattlegrid deposit



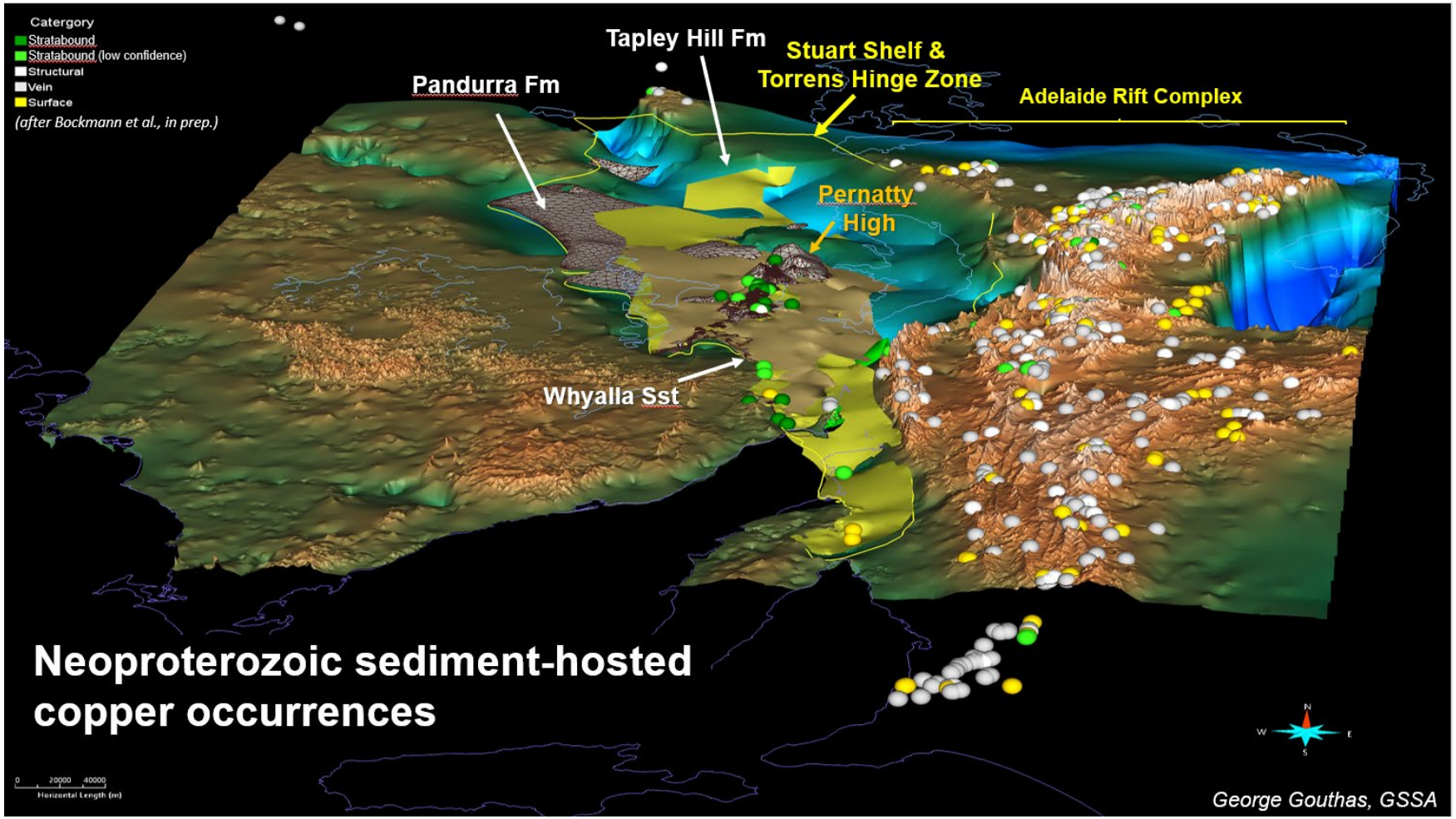
Infill sulphides in DH M350-250 @35m
Pandurra Formation, Cattlegrid deposit

Sed-Cu mineralisation in SA

Permafrost breccia Cattlegrid

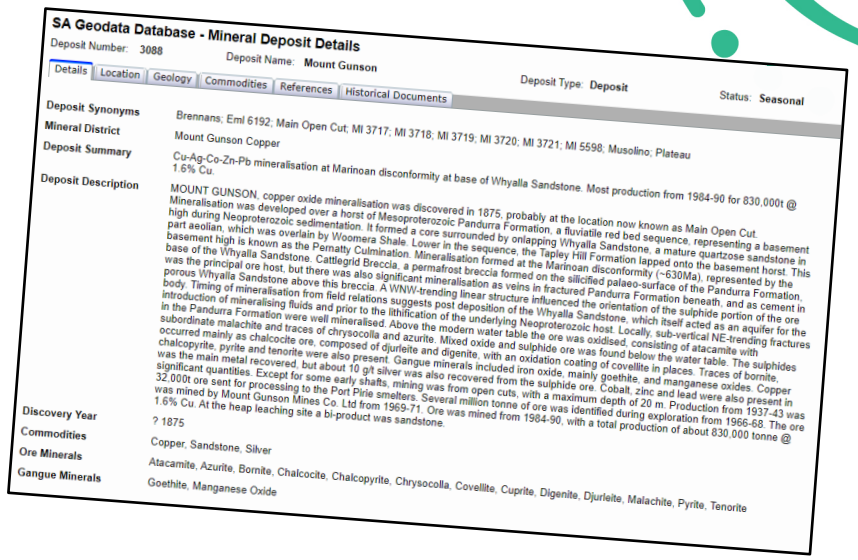
Mineral systems components for SedCu in SA

- ✓ Geological setting
- ✓ Chronostratigraphy
- ✓ Prolonged depositional history
- ✓ Evaporites
- ✓ Host rocks
- ✓ Source rocks
- ✓ Structural traps
- ✓ Basement endowment
- ✓ Demonstrated Cu enrichment



Review of Neoproterozoic SedCu in SA

- **920** records for **Neoproterozoic** SedCu deposits/prospect/occurrences
- **619** after database clean-up
  removal of igneous-related, insignificant occurrences and non-descriptive entries


SA Geodata Database - Mineral Deposit Details

Deposit Number: 3088 Deposit Name: Mount Gunson Deposit Type: Deposit Status: Seasonal

Details | Location | Geology | Commodities | References | Historical Documents

Deposit Synonyms: Brennans; Eml 6192; Main Open Cut; MI 3717; MI 3718; MI 3719; MI 3720; MI 3721; MI 5598; Musolino; Plateau

Mineral District: Mount Gunson Copper

Deposit Summary: Cu-Ag-Co-Zn-Pb mineralisation at Marinoan disconformity at base of Whyalla Sandstone. Most production from 1984-90 for 830,000t @ 1.6% Cu.

Deposit Description: MOUNT GUNSON, copper oxide mineralisation was discovered in 1875, probably at the location now known as Main Open Cut. Mineralisation was developed over a horst of Mesoproterozoic Pandurra Formation, a fluviatile red bed sequence, representing a basement high during Neoproterozoic sedimentation. It formed a core surrounded by onlapping Whyalla Sandstone, a mature quartzose sandstone in part aeolian, which was overlain by Woomera Shale. Lower in the sequence, the Tapley Hill Formation lapped onto the basement horst. This basement high is known as the Pernatty Culmination. Mineralisation formed at the Marinoan disconformity (~630Ma), represented by the base of the Whyalla Sandstone. Cattlegrid Breccia, a permafrost breccia formed on the silicified palaeo-surface of the Pandurra Formation, was the principal ore host, but there was also significant mineralisation as veins in fractured Pandurra Formation beneath, and as cement in porous Whyalla Sandstone above this breccia. A WNW-trending linear structure influenced the orientation of the sulphide portion of the ore body. Timing of mineralisation from field relations suggests post deposition of the Whyalla Sandstone, which itself acted as an aquifer for the introduction of mineralising fluids and prior to the lithification of the underlying Neoproterozoic host. Locally, sub-vertical NE-trending fractures in the Pandurra Formation were well mineralised. Above the modern water table the ore was oxidised, consisting of atacamite with subordinate malachite and traces of chrysocolla and azurite. Mixed oxide and sulphide ore was found below the water table. The sulphides occurred mainly as chalcocite ore, composed of djurleite and digenite, with an oxidation coating of covellite in places. Traces of bornite, chalcopyrite, pyrite and tenorite were also present. Gangue minerals included iron oxide, mainly goethite, and manganese oxides. Copper was the main metal recovered, but about 10 g/t silver was also recovered from the sulphide ore. Cobalt, zinc and lead were also present in significant quantities. Except for some early shafts, mining was from open cuts, with a maximum depth of 20 m. Production from 1937-43 was 32,000t ore sent for processing to the Port Pirie smelters. Several million tonne of ore was identified during exploration from 1966-68. The ore was mined by Mount Gunson Mines Co. Ltd from 1969-71. Ore was mined from 1984-90, with a total production of about 830,000 tonne @ 1.6% Cu. At the heap leaching site a bi-product was sandstone.

Discovery Year: ? 1875

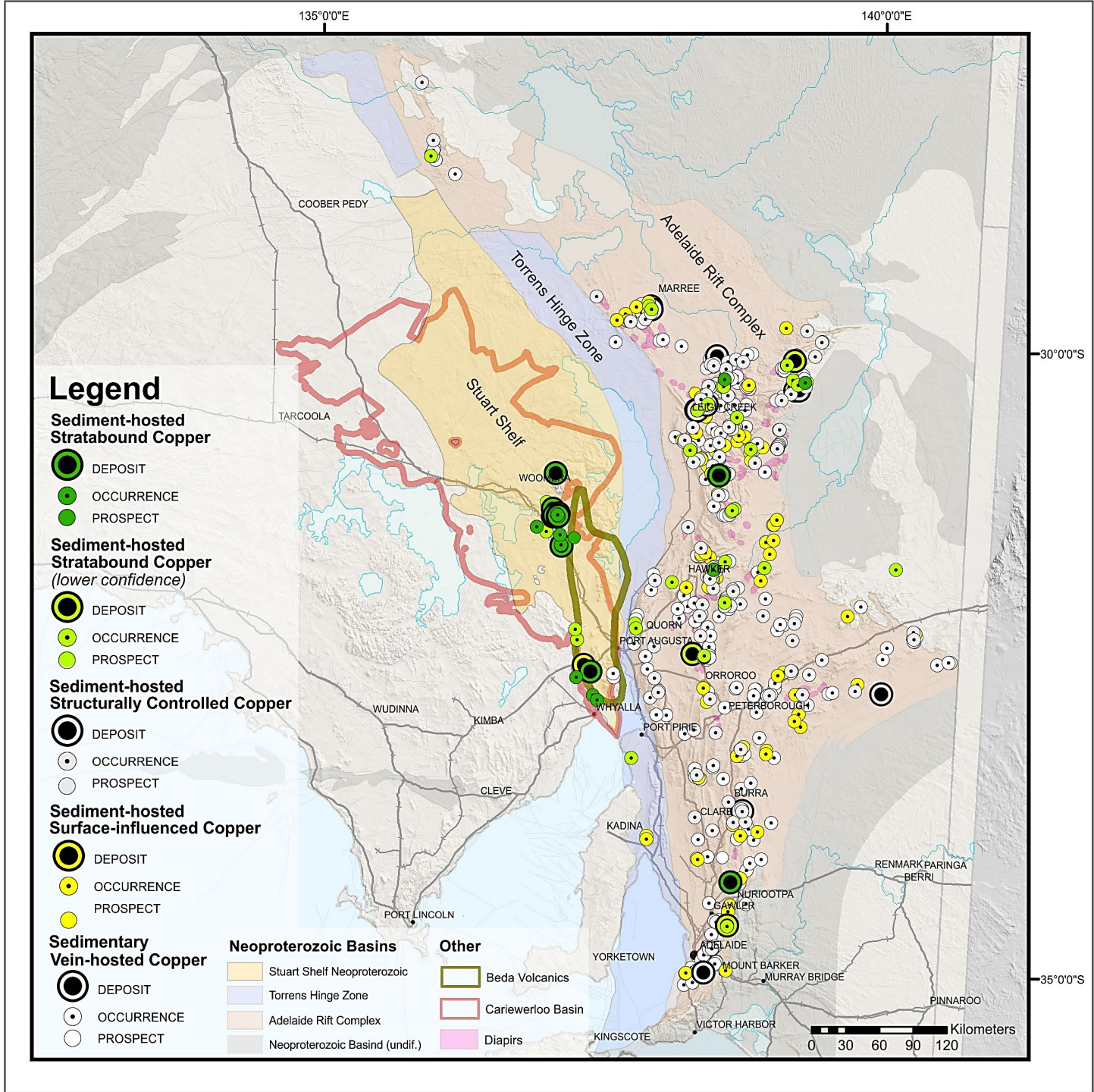
Commodities: Copper, Sandstone, Silver

Ore Minerals: Atacamite, Azurite, Bornite, Chalcocite, Chalcopyrite, Chrysocolla, Covellite, Cuprite, Digenite, Djurleite, Malachite, Pyrite, Tenorite

Gangue Minerals: Goethite, Manganese Oxide

	Class	Description
stratabound	stratabound	Sediment-hosted stratabound copper sulphide mineralisation primarily controlled by lithological features (e.g. REDOX stratigraphic trap) or porosity that is unrelated to tectonic processes (e.g. permafrost breccia horizon).
	stratabound (low confidence)	Sediment-hosted stratabound copper mineralisation controlled by lithological features (e.g. REDOX stratigraphic trap) or porosity that is unrelated to tectonic processes (e.g. permafrost breccia horizon), but mineralisation is either insignificant, formed by secondary processes, or lacks information for a confident classification.
structural	structurally-controlled	Evidence for primary copper mineralisation that is directly related to a tectonic structure (e.g. hosted within shear/fault zone, breccia or within structures related to folding). Many deposits in this class are also hosted within structures related to diapirism.
	vein-hosted	Copper mineralisation hosted within quartz/carbonate veins, with no identified structural influence. Generally very little context is able to be provided for mineralisation in this class.
	surface	Copper mineralisation dominated by secondary copper minerals with no evidence of primary processes. Surface influenced mineralisation may be structurally controlled, but not vein hosted, as mineralisation in quartz veins requires higher temperatures than what can occur at the surface.

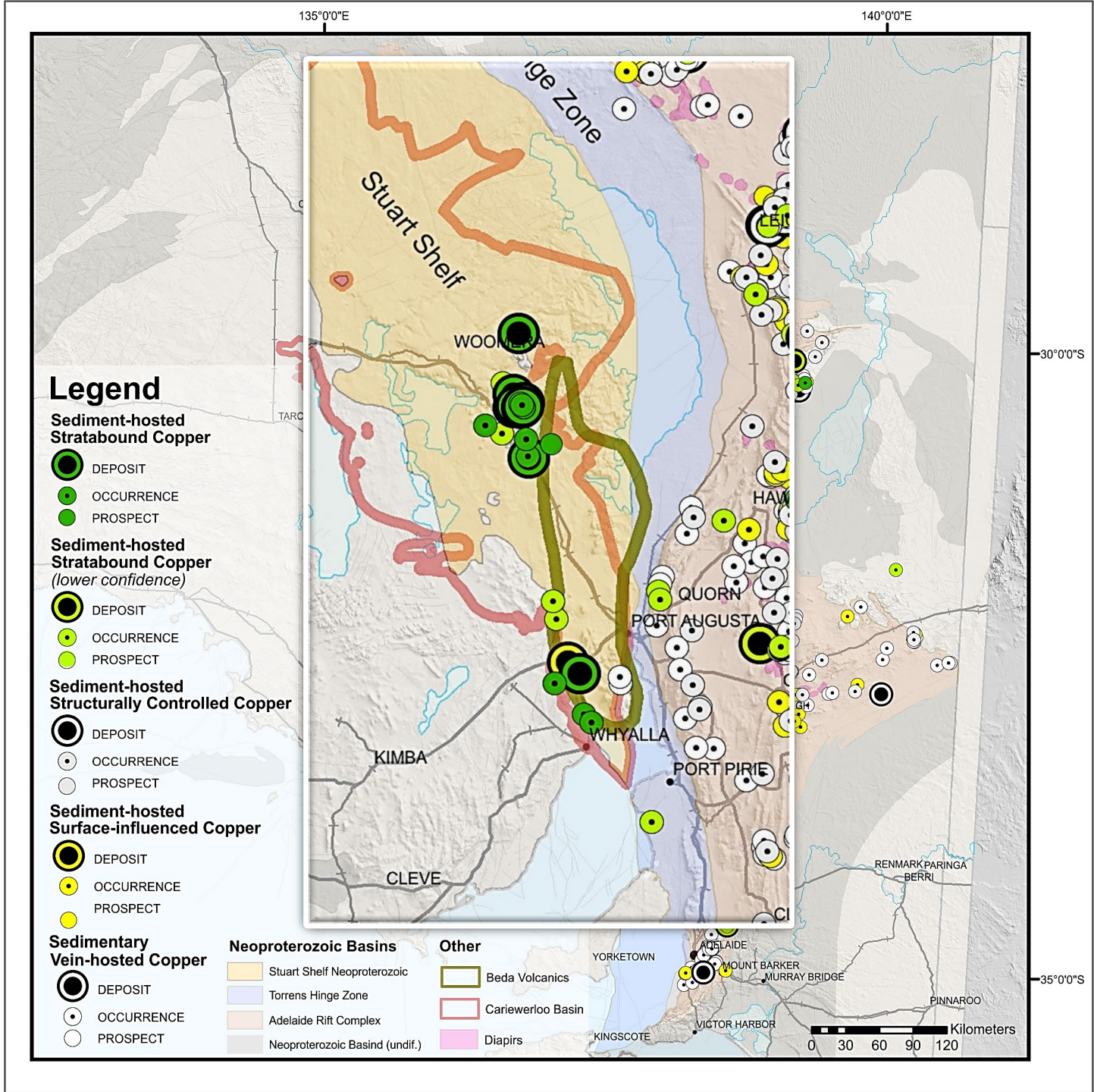
Neoproterozoic SedCu deposits in SA



Neoproterozoic SedCu deposits in SA

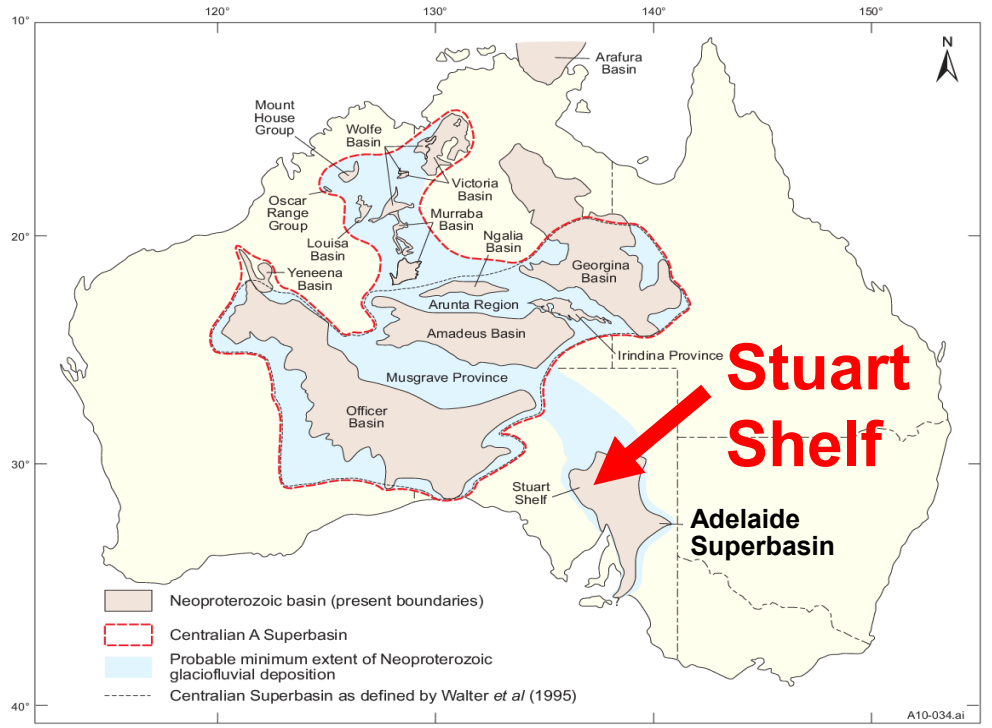
Emerging patterns on Stuart Shelf

- dominantly hosted in Tapley Hill Fm and permafrost breccia developed at contact Mesoproterozic Pandurra Fm and Neoproterozoic Whyalla Sandstone
- around Pernatty High (basement high)
- along western margin of Beda Basalt
- within extent of underlying Cariewerloo Basin (redbeds of Pandurra Fm)



Why the Stuart Shelf?

- renewed and increased exploration interest
- known sediment-hosted Cu (Co-Pb-Zn) deposits
- overlies world-class Olympic Cu-Au Province
- similarities to Central African Copper Belt



from: NTGS 2013

Mineralisation:

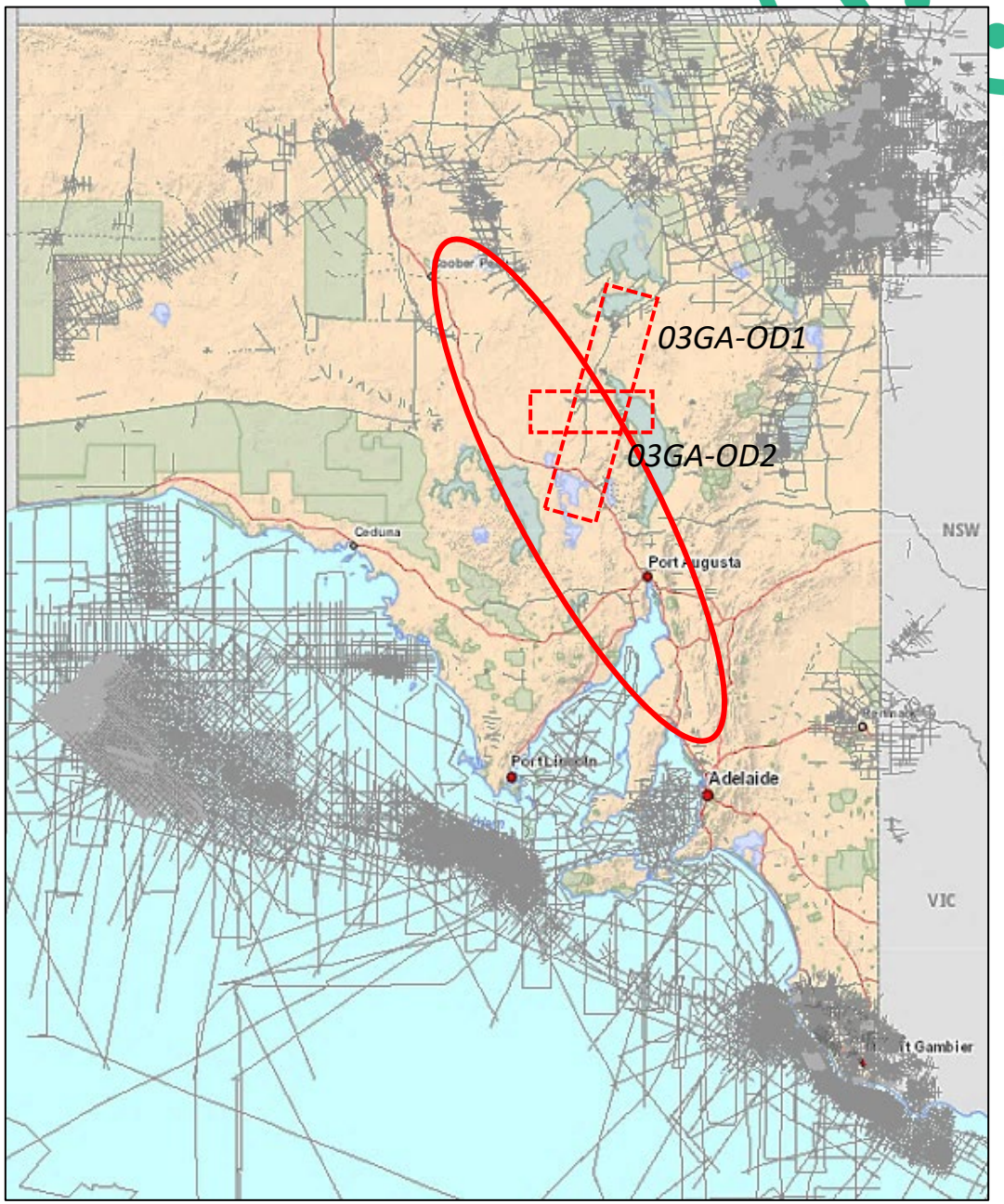
- Neoproterozoic Tapley Hill Fm (mainly at base)
- permafrost breccia at contact between Mesoproterozoic redbeds of Pandurra Fm and Neoproterozoic aeolian sandstones of Whyalla Sandstone
- palaeo-basement highs (e.g. Pernatty High)

Stuart Shelf sediment-hosted mineral potential

→ Applying an energy system approach to unravel sedimentary-hosted mineral deposits in the world-class Olympic Cu-Au Province of South Australia

GSSA/CSIRO Sedimentary Cu project

with a strong focus on basin evolution and architecture using a litho- and sequence stratigraphic approach



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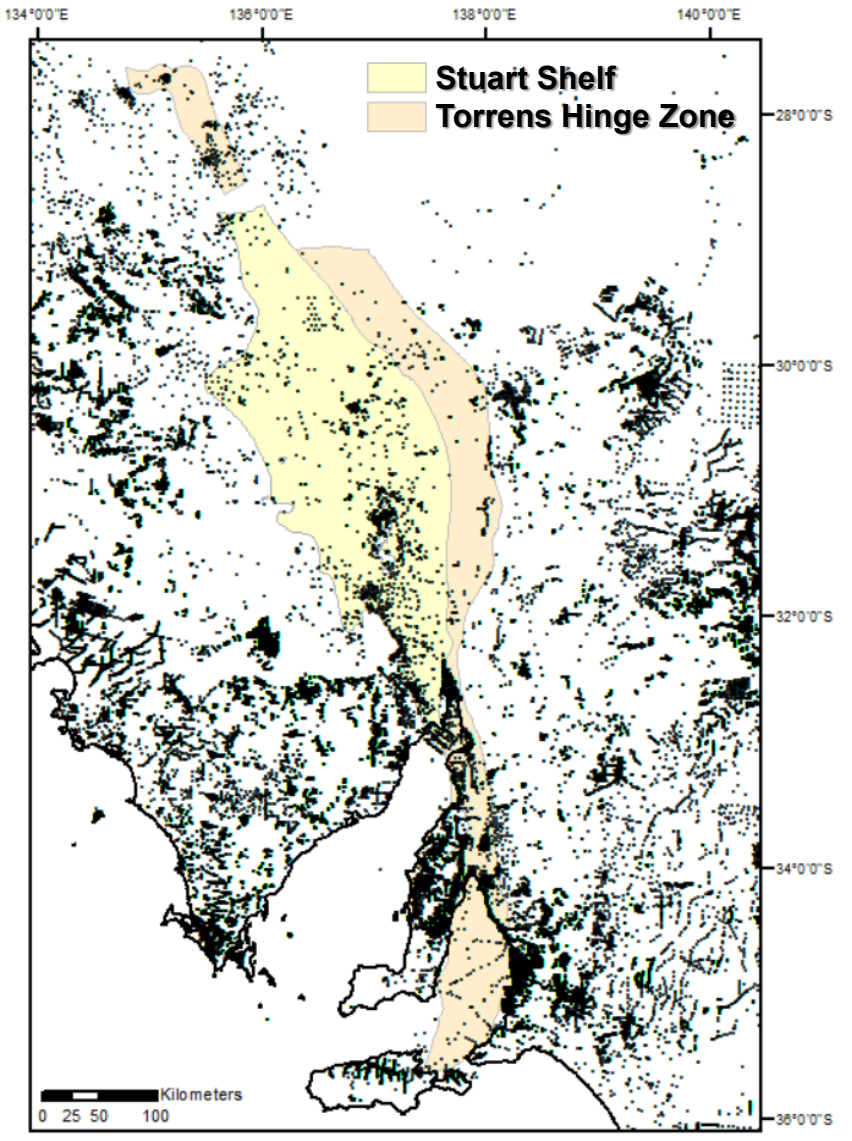
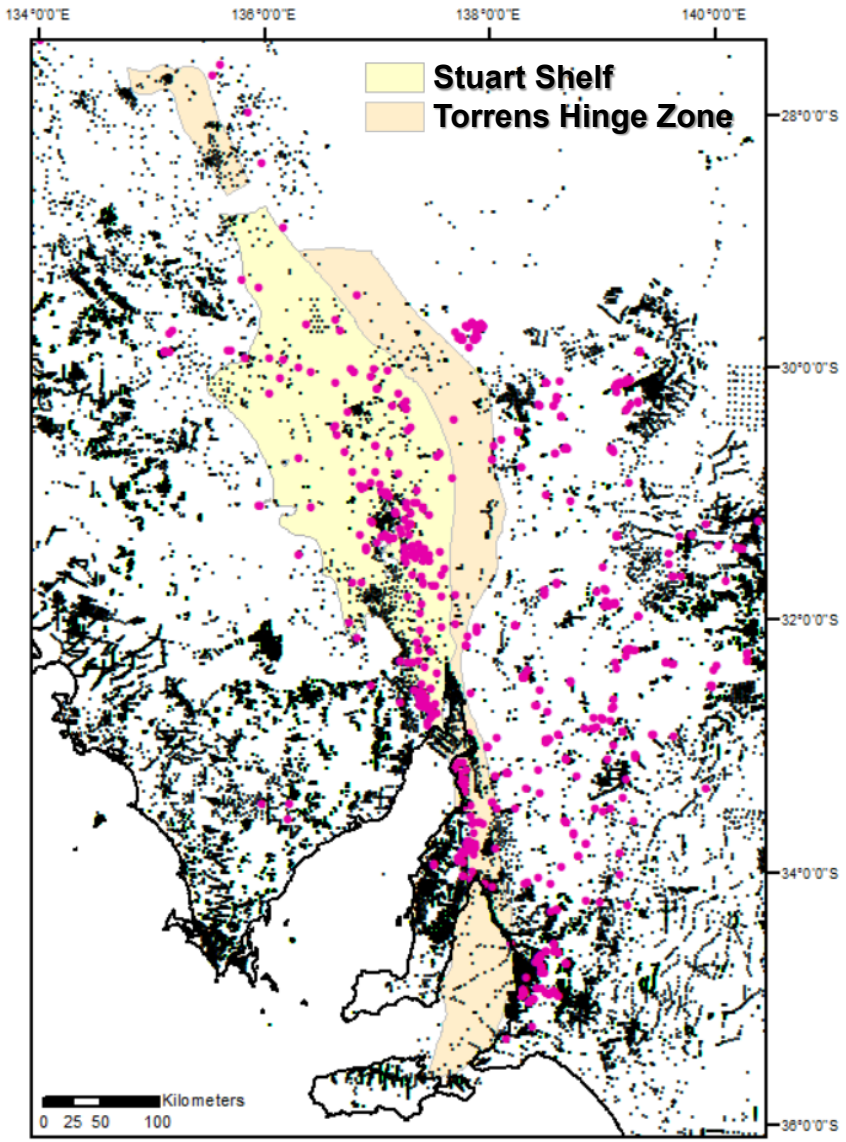
Stuart Shelf data availability – drillholes

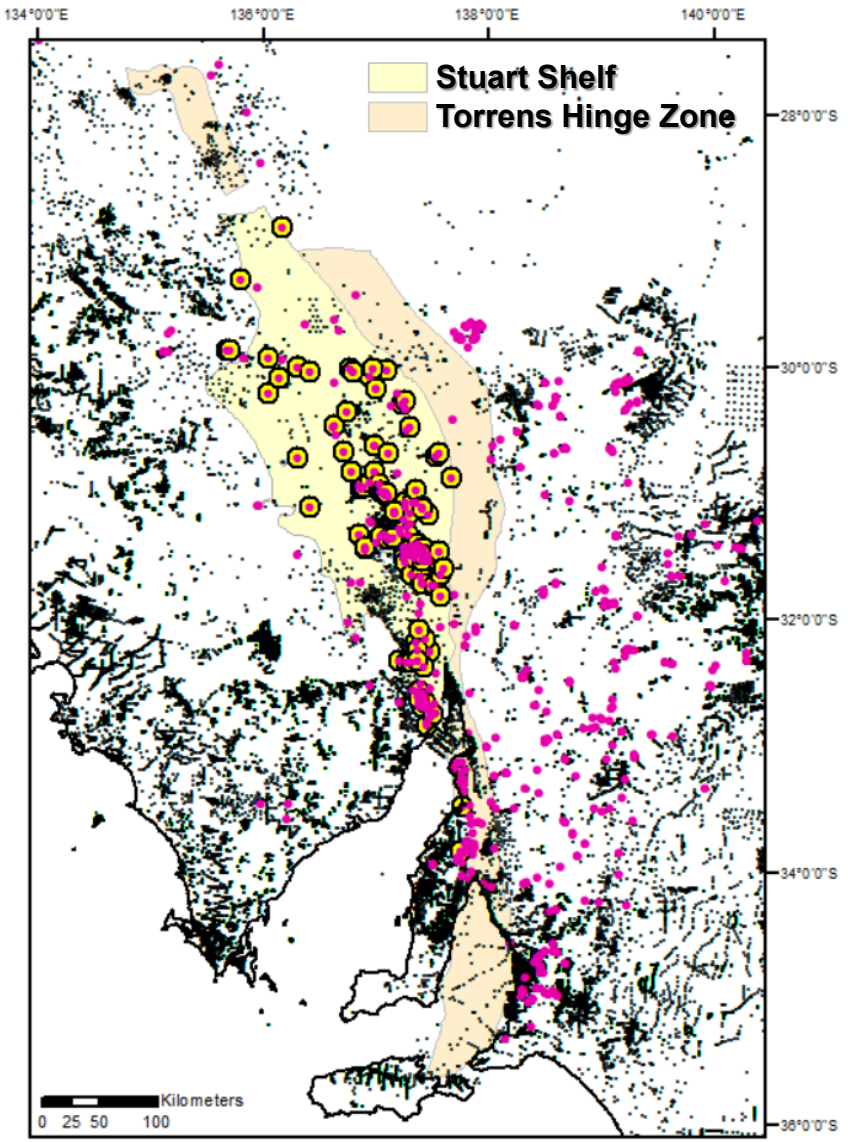
- all mineral drillholes

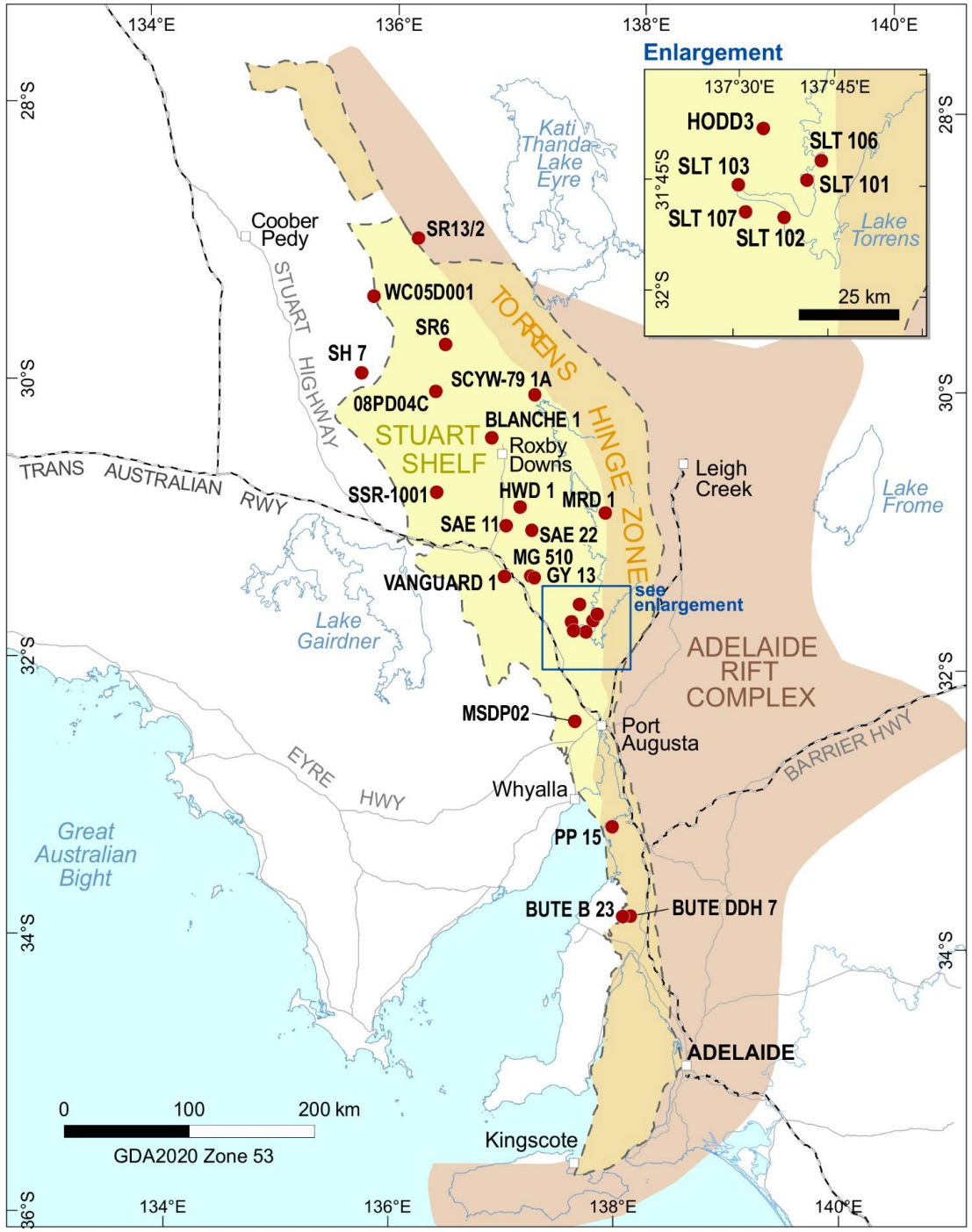


- drillholes with core (Neoprot.)



- drillholes with HyLogged™ core (Neoprot.)





New data collection included:

25 drillholes selected

→ 10570 m of core relogged in detail

→ 25 drillholes HyLogged™

→ 9245 gamma data, 4711 pXRF data (including standards)

→ 3450 detailed core photographs

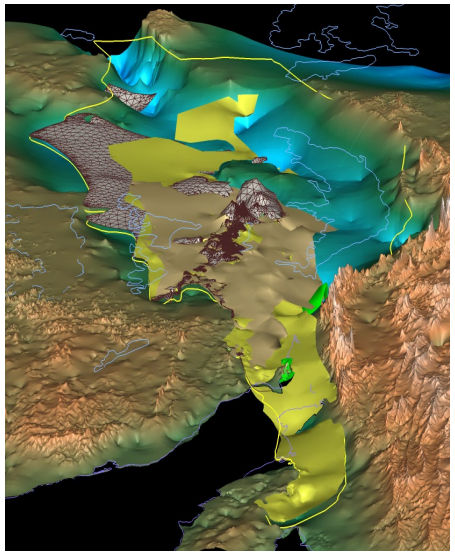
→ 120 samples for carbon isotope

→ 8 samples for Rb-Sr dating

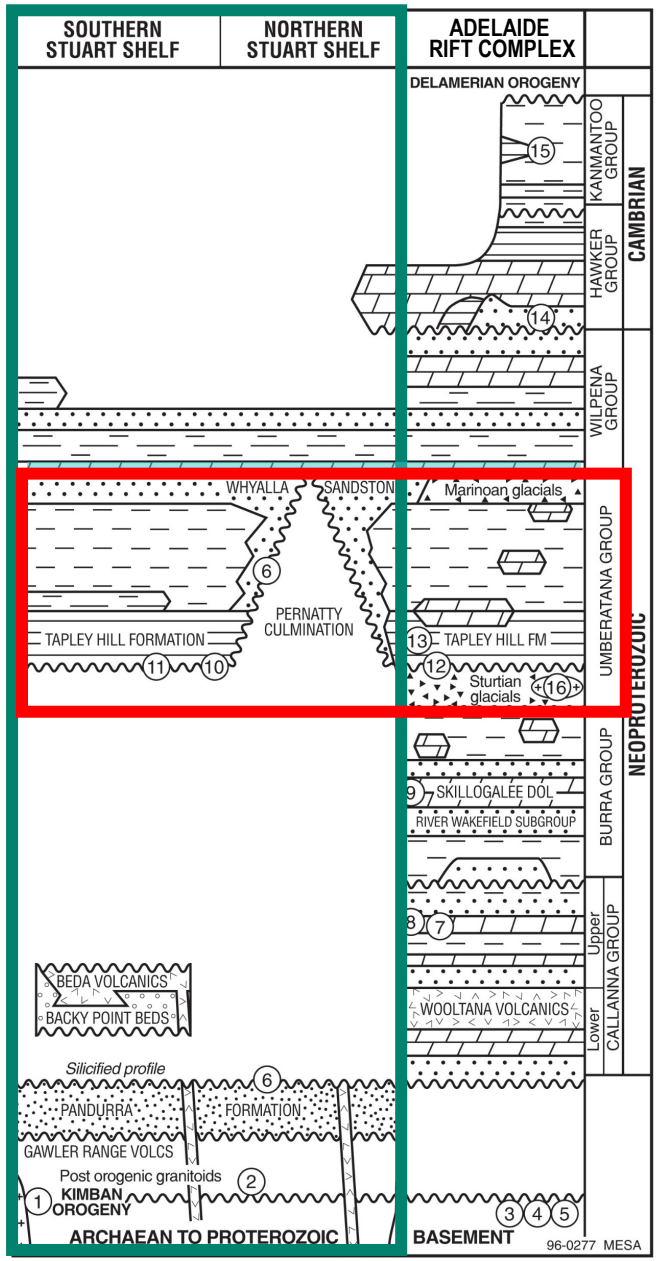
→ 20 thin sections for diagenesis study

→ ***18 lithofacies, 7 facies association***

→ ***3D surfaces***



Stuart Shelf stratigraphy – a historical challenge



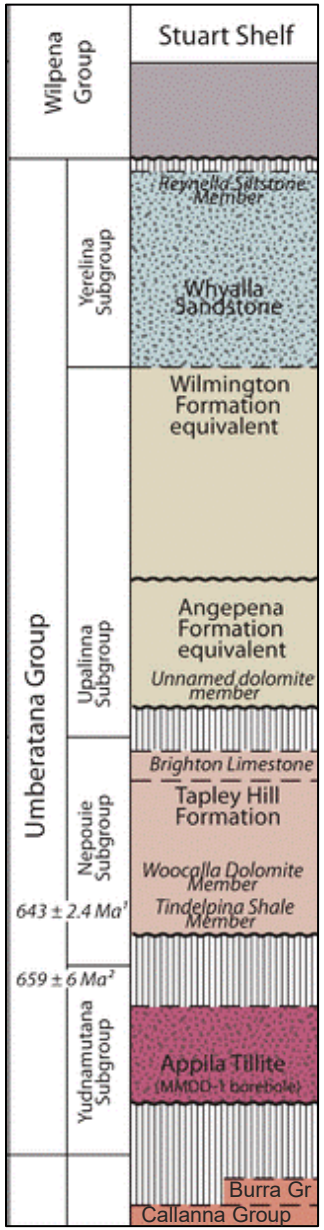
Umberatana Group

- mudstones, siltstones, sandstones and carbonates
- includes Sturtian and Marinoan glacials
- Tapley Hill Formation – reductant

Wainwright 1914	Dickinson 1942	Johns et al. 1964	Tonkin 1966	Thomson and Johnson 1968		Tonkin 1974a, b	Thomson c. 1974	Mason 1978		Preiss 1987
'Leaching sands'	'Upper white sandstone'	Pernatty Grit	'Lithic sandstone'	Tent Hill Formation	Whyalla Sandstone Member	Whyalla Sandstone	Whyalla Sandstone	'Cattle Grid Formation'	Whyalla Sandstone	Whyalla Sandstone
	'Upper red sandstones and grit'					'Yudnapinna beds'			'Yudnapinna beds'	? (=Wilmington Formation)
									'Augusta shale'	? (=Angepena Formation)
	'Dolomitic limestone'		Woocalla Dolomite Member	Pernatty Grit	Woocalla Dolomite Member	Woocalla Dolomite Member	Tapley Hill Formation	Tapley Hill Formation		Brighton Limestone Member
										Tapley Hill Formation
										Woocalla Dolomite Member
'Hard red quartzite'	'Lower red sandstone'		'Red quartzite'		Pandurra Formation	Pandurra Formation	Pandurra Formation		Pandurra Formation	Pandurra Formation

205135-015

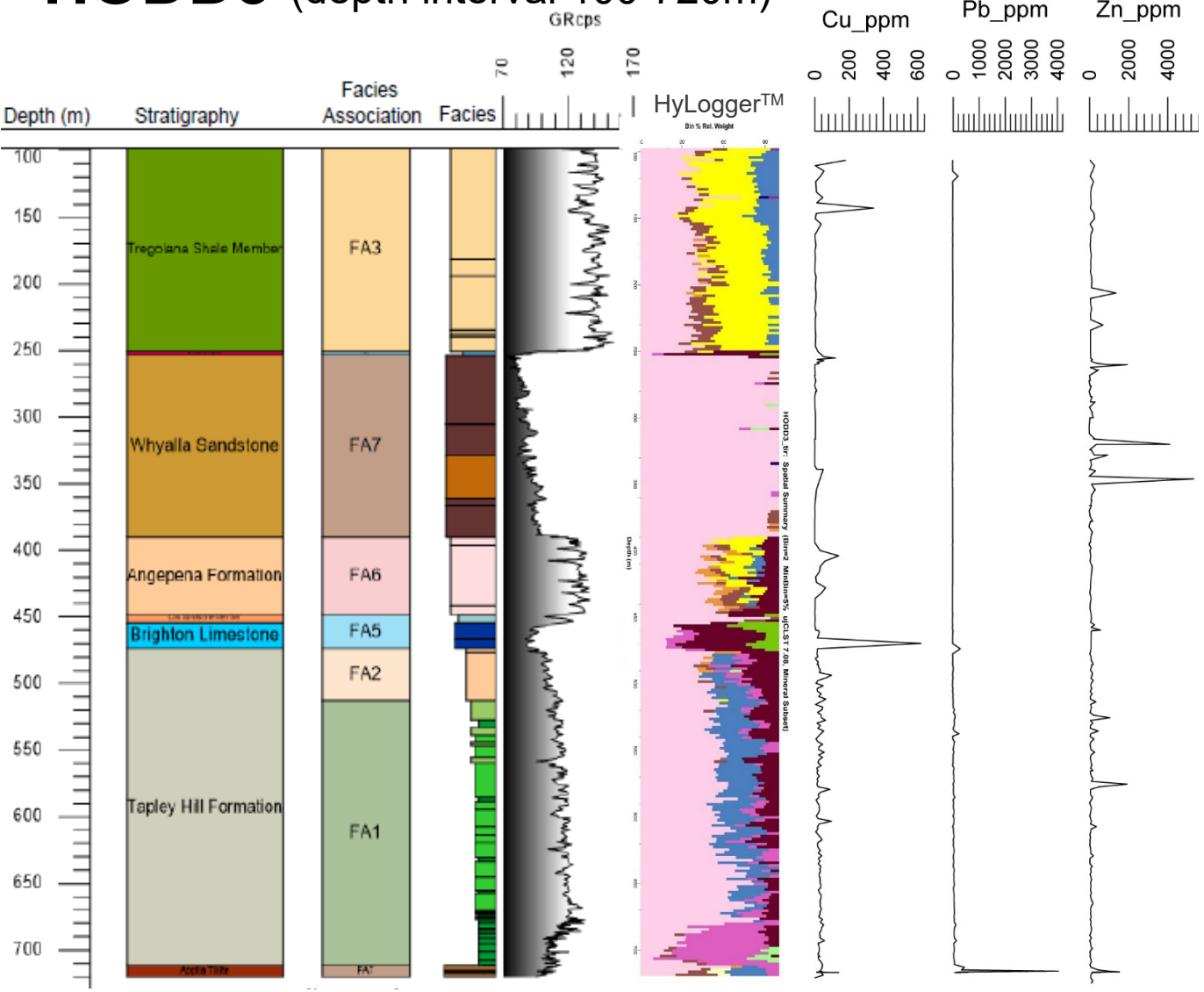
Stratigraphic correlation chart of the southern Stuart Shelf (from: Tonkin, 2019)

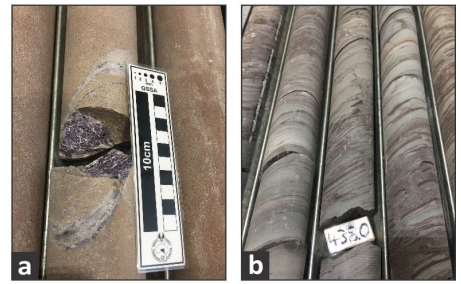


Busfield & LeHeron, 2014

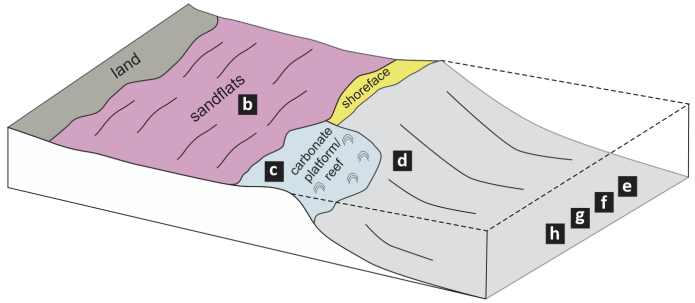
Drillhole review and data collection - example

HODD3 (depth interval 100-720m)





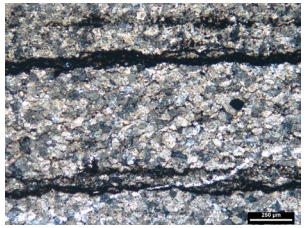
Depositional Environments

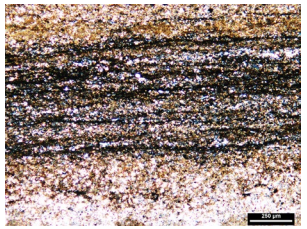


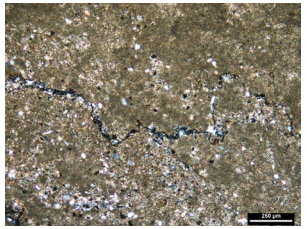
Facies Association (FA)

- FA1: offshore
- FA2: offshore transition
- FA3: lower shoreface - prodelta
- FA4: shoreface to delta front
- FA5: shallow subtidal to subtidal
- FA6: intertidal to supratidal
- FA7: glacial to fluvio-glacial

Thin sections







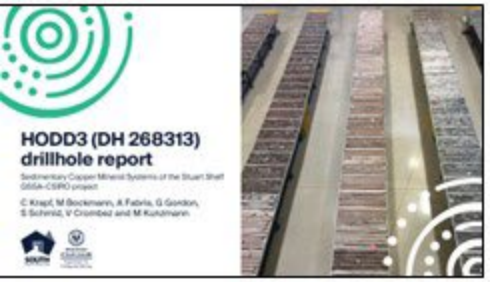

08PD04C (DH 237529)
drillhole report


BLANCHE 1 (DH 206086)
drillhole report


BUTE B 23 (DH 30054)
drillhole report


BUTE DDH 7 (DH 29752)
drillhole report


GY 13 (DH 184731)
drillhole report


HODD3 (DH 268313)
drillhole report


HWD 1 (DH 20770)
drillhole report


MG 510 (DH 139752)
drillhole report


MRD 1 (DH 25375)
drillhole report


MSDP02 (DH 287996)
drillhole report


PP 15 (DH 23935)
drillhole report

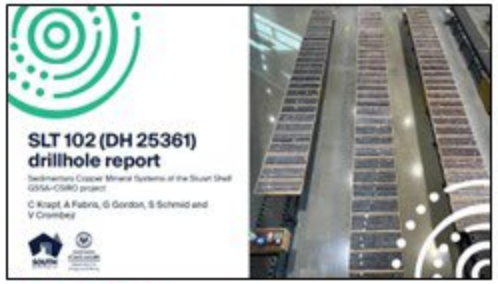

SAE 11 (DH 165125)
drillhole report


SAE 22 (DH 165530)
drillhole report


SCYW-79 1A (DH 20829)
drillhole report


SH7 (DH 227935)
drillhole report

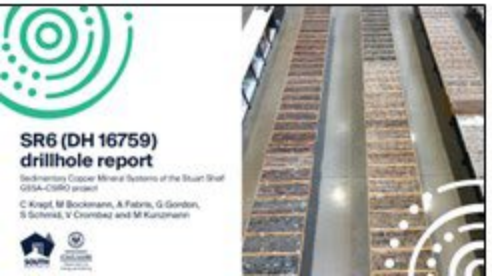

SLT 101 (DH 25360)
drillhole report

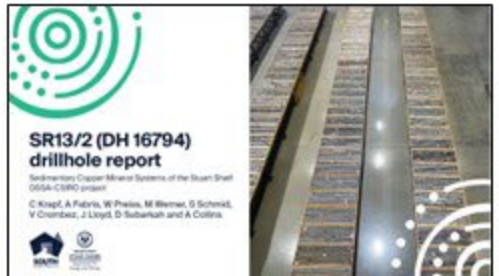

SLT 102 (DH 25361)
drillhole report


SLT 103 (DH 25362)
drillhole report


SLT 106 (DH 25363)
drillhole report


SLT 107 (DH 25357)
drillhole report


SR6 (DH 16759)
drillhole report


SR13/2 (DH 16794)
drillhole report


SSR-1001 (DH 16638)
drillhole report


VANGUARD 1 (DH 18092)
drillhole report


WC05D001 (DH 210004)
drillhole report

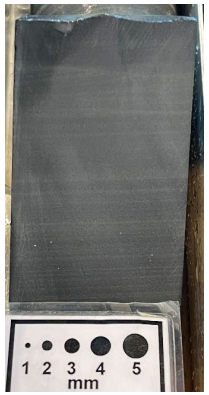
Facies analysis

UNOFFICIAL

18 lithofacies → 7 facies associations (FA)

distinguished based on compositional and textural properties, and the occurrence of distinct sedimentary structures

FA 1 offshore	FA 2 offshore transition	FA 3 lower shoreface - prodelta	FA 4 shoreface to delta front	FA 5 shallow subtidal to subtidal	FA 6 intertidal to supratidal	FA 7 glacial to fluvio-glacial


SKYW-79 1A


SLT 102


HODD3


PP 15


HODD3


08PD04C


SLT 106


HODD3


PP 15


PP 15


SAE 22

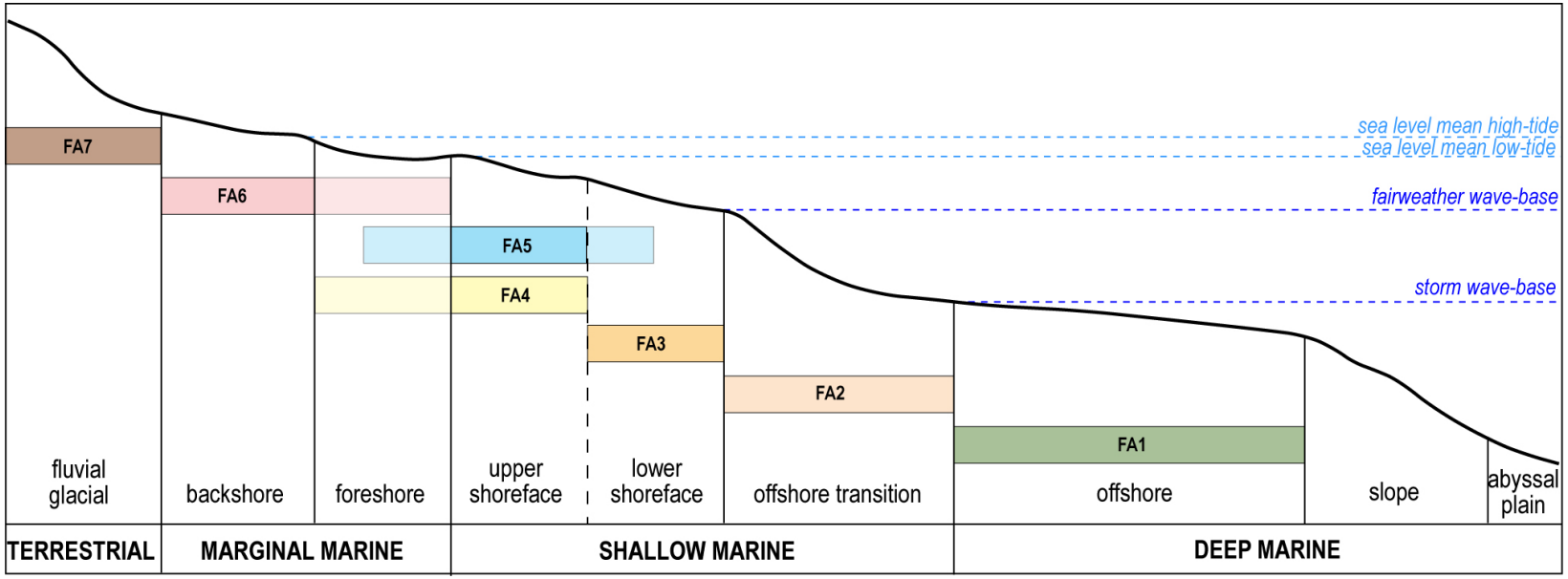
UNOFFICIAL

Facies analysis

18 lithofacies → 7 facies associations (FA)

in parts these are aligned closely with existing stratigraphic units

FA 1 offshore	FA 2 offshore transition	FA 3 lower shoreface - prodelta	FA 4 shoreface to delta front	FA 5 shallow subtidal to subtidal	FA 6 intertidal to supratidal	FA 7 glacial to fluvio-glacial
Tapley Hill Fm (basal)	Tapley Hill Fm (above BSFR)	Tregolana Shale Mbr	Corraberra Sst Mbr Simmens Qtz Mbr	Brighton Lst Nuccaleena Fm	Angepena Fm Cox Sandstone Mb	Whyalla Sandstone Appila Tillite Wilmington Fm

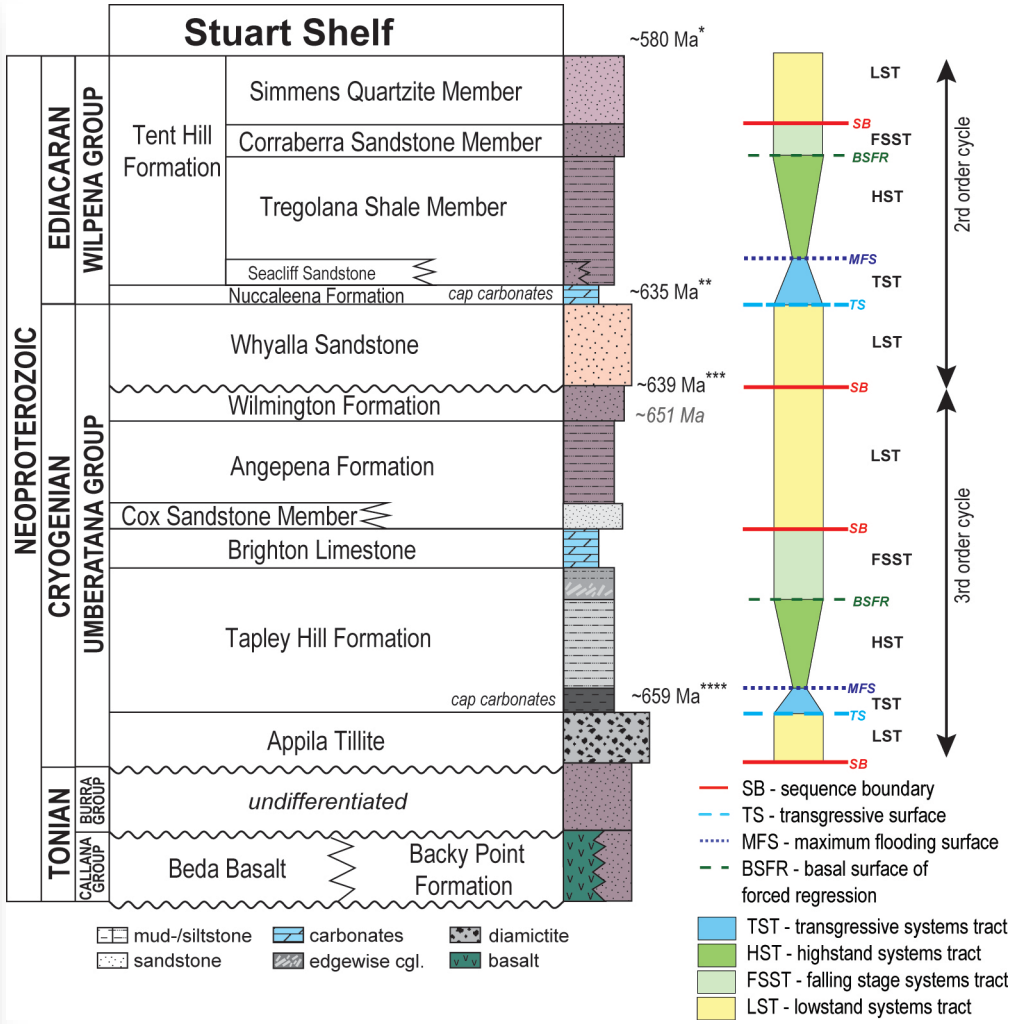


Correlative surfaces mapped from facies

black mudrock

maximum flooding surface

SLT 102

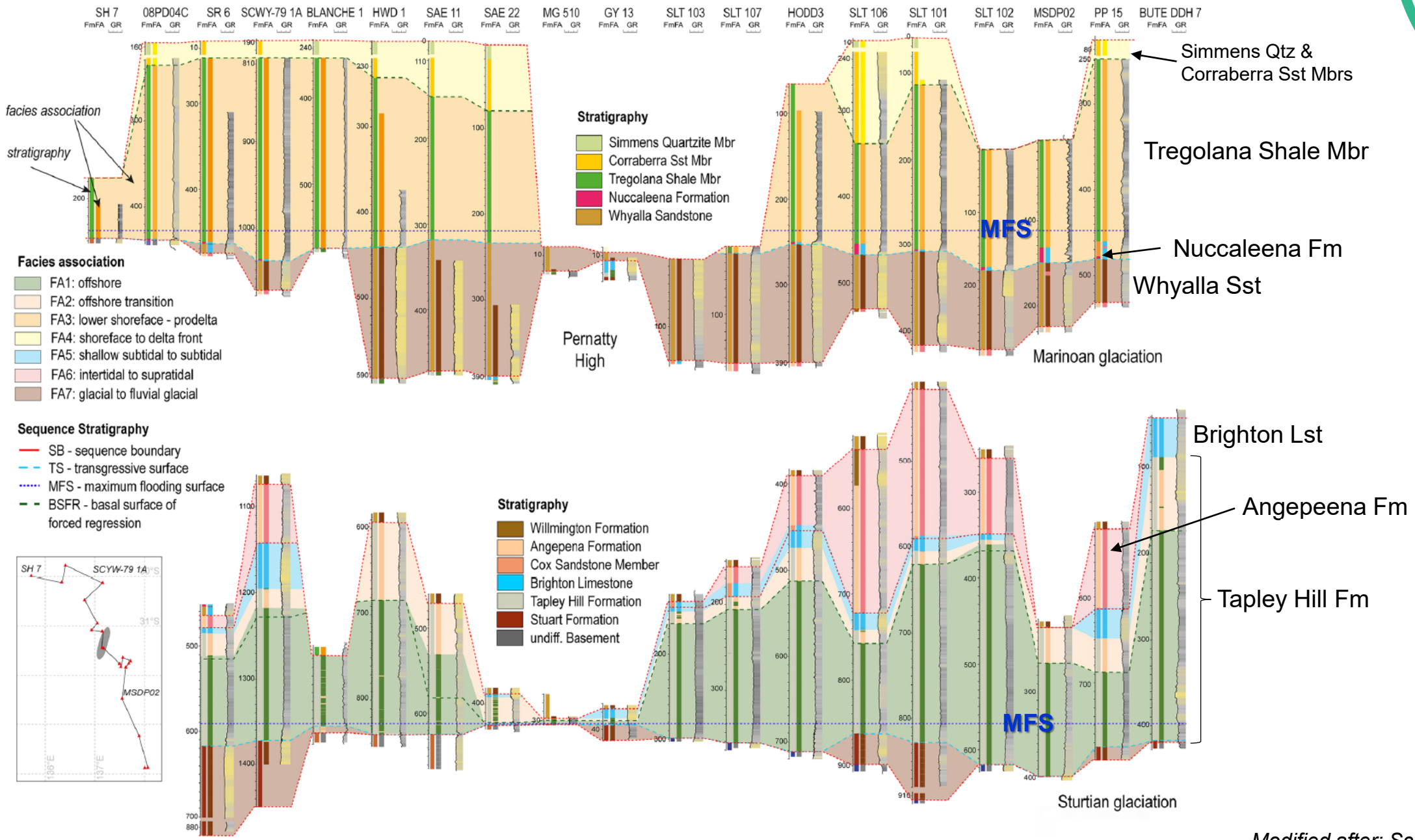


edgewise conglomerate

basal surface of forced regression (BSFR)

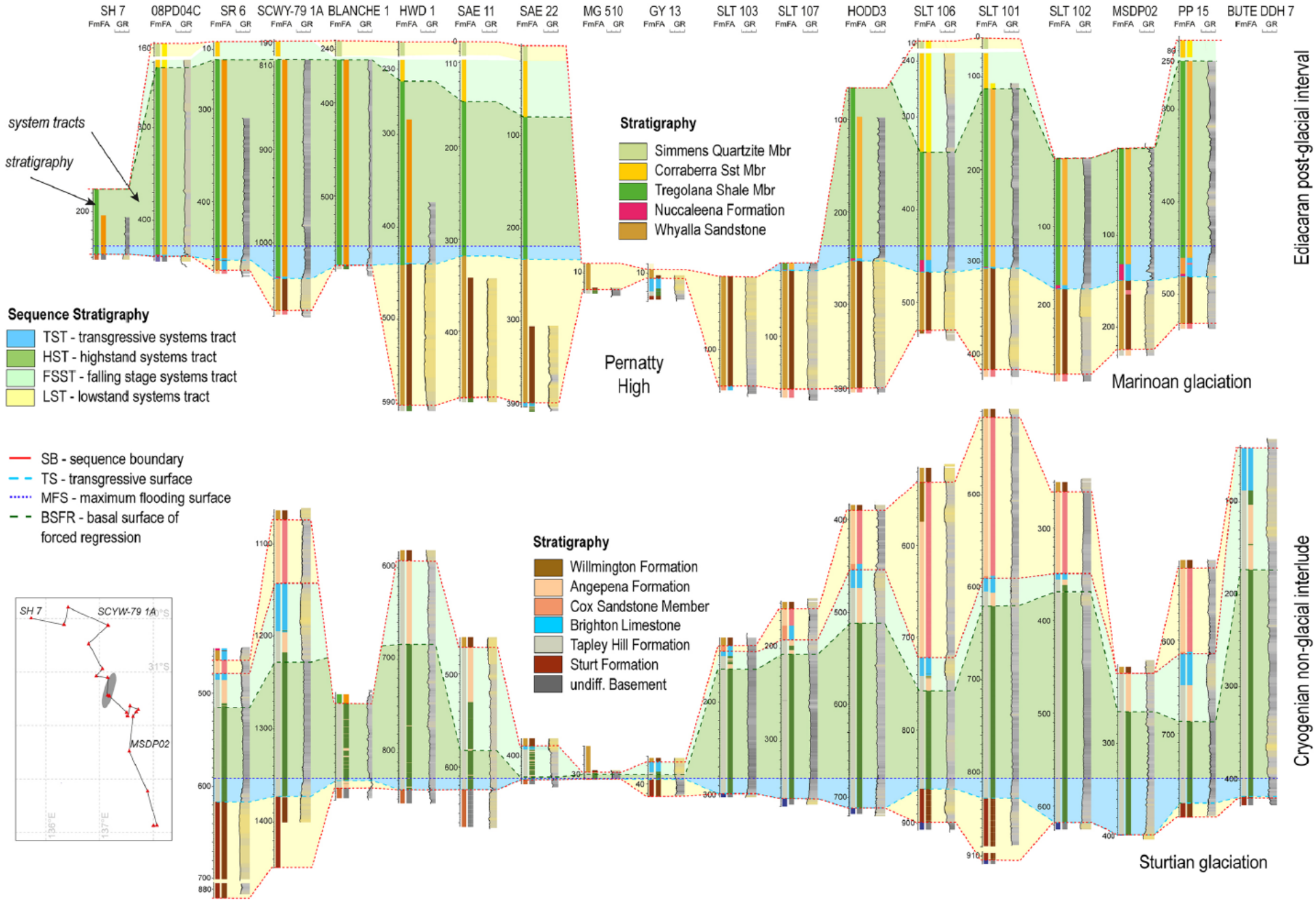
HODD 3

Correlating stratigraphic units across Stuart Shelf



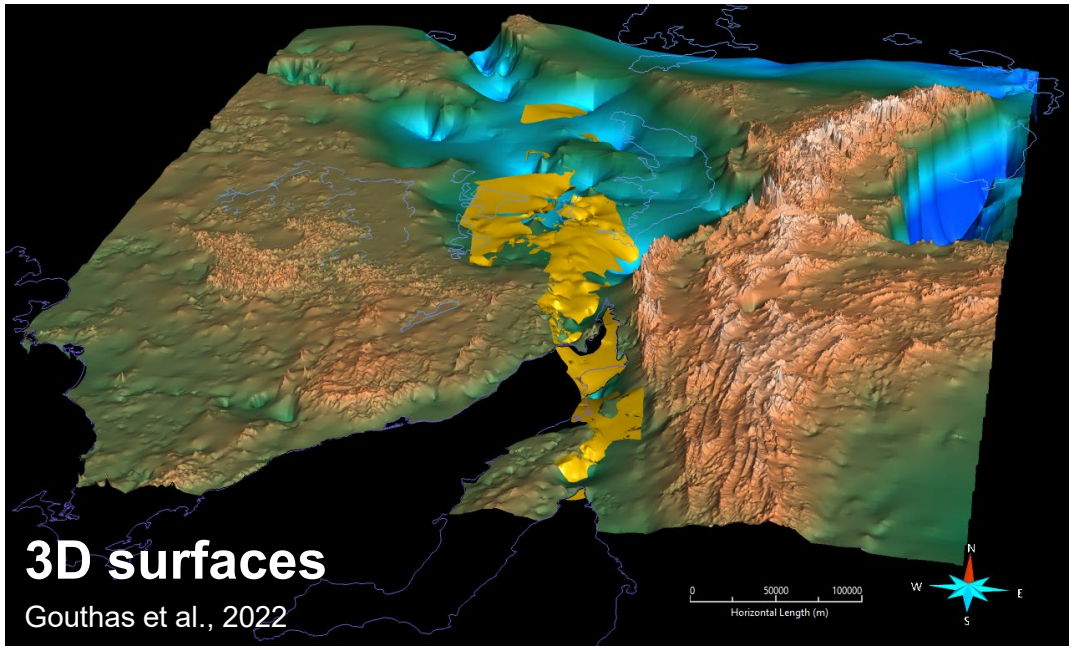
Modified after: Schmid et al. (2024)

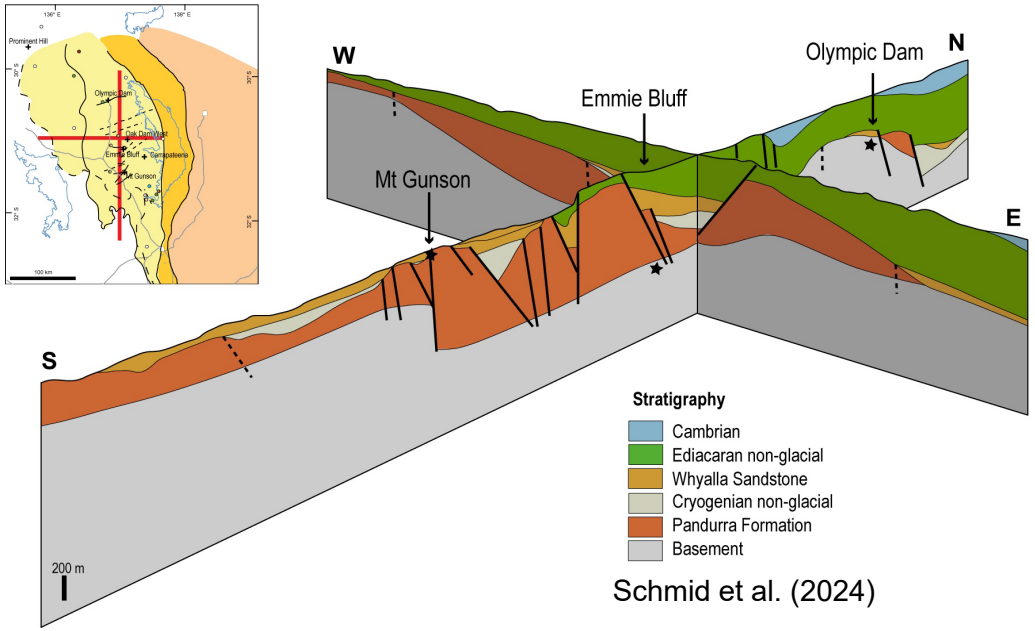
Sequence Stratigraphic framework Stuart Shelf



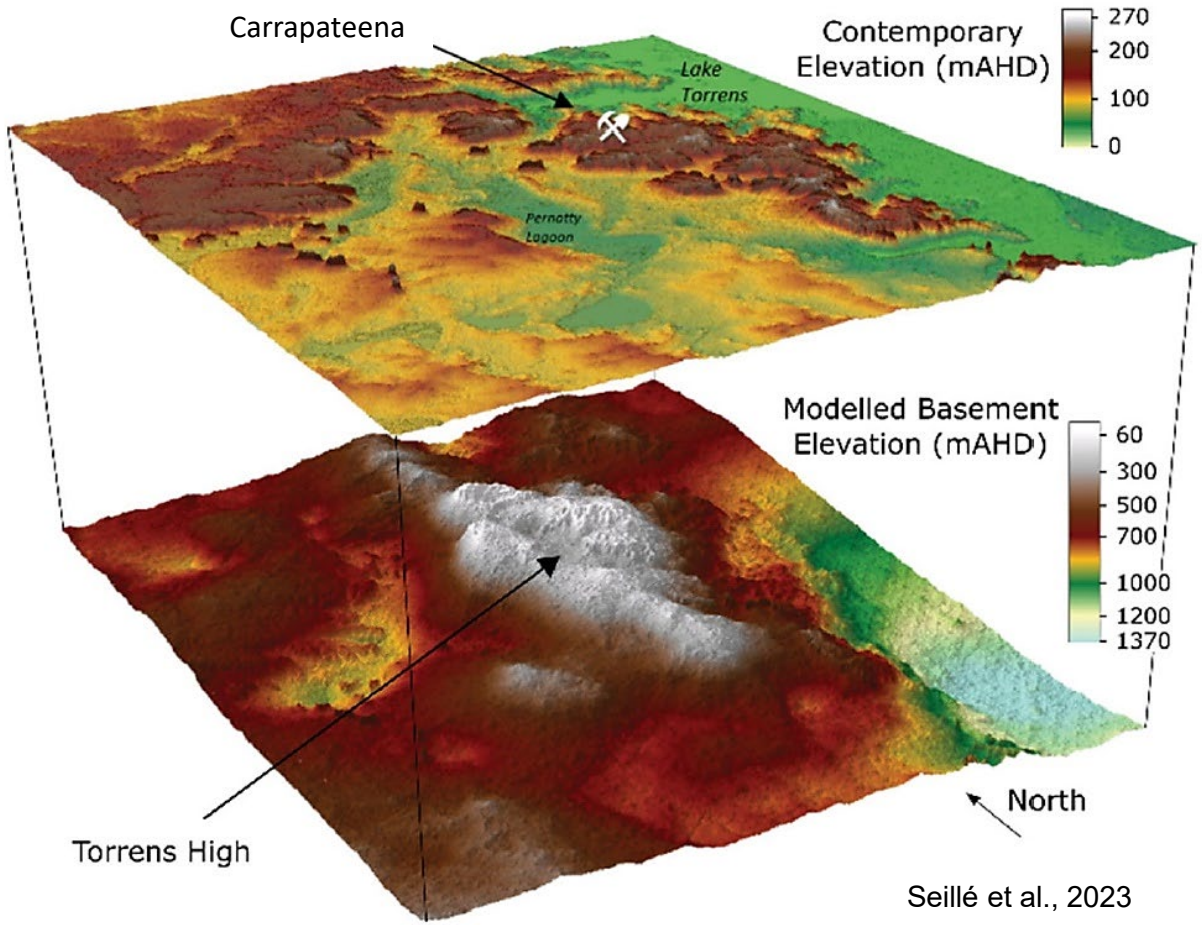
Schmid et al. (2024)

Basin architecture framework of the Stuart Shelf





Schmid et al. (2024)



Seillé et al., 2023

Summary

Applying an energy systems approach to the Neoproterozoic succession of the Stuart Shelf in South Australia resulted in:

- updated stratigraphy and recognition of basin-wide correlatable units
- basin-wide sequence stratigraphic framework
- modelling of multiple 3D surfaces and unit thickness
- construction of 2D cross section across known basement highs
- uncover of the ‘Torrens High’ basement high

→ facilitates the re-evaluation of sediment-hosted copper potential across Stuart Shelf
→ new search space and revisiting of brownfield areas with a better understanding

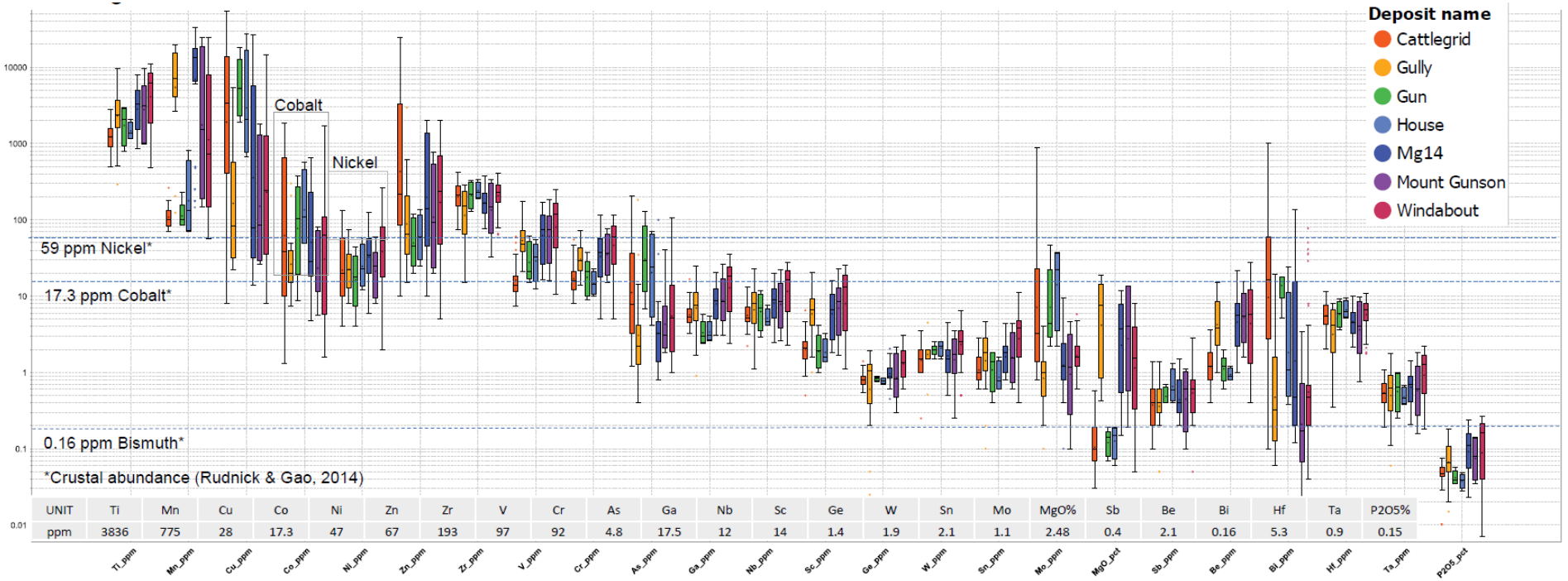
→ **?role of underlying IOCG deposits vs. classical basin-hosted stratabound model?**

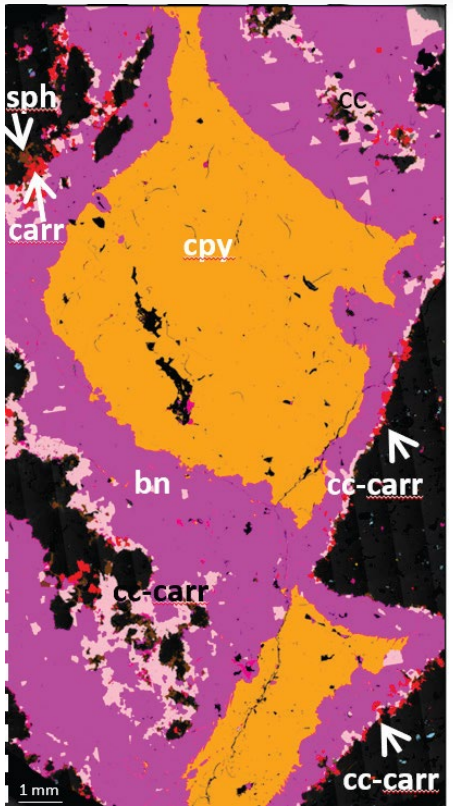
Resampling for Critical Minerals

- 167 samples from 21 historic drillholes from seven known deposits within the Mount Gunson District
- focus on the mineralised zone
- analysed full suite of major and trace element geochemistry

→ ***in addition to copper high values of cobalt, bismuth, molybdenum, silver, zinc, lead, manganese and arsenic***

→ ***cobalt and bismuth were found to be hosted by carrollite and emplectite***





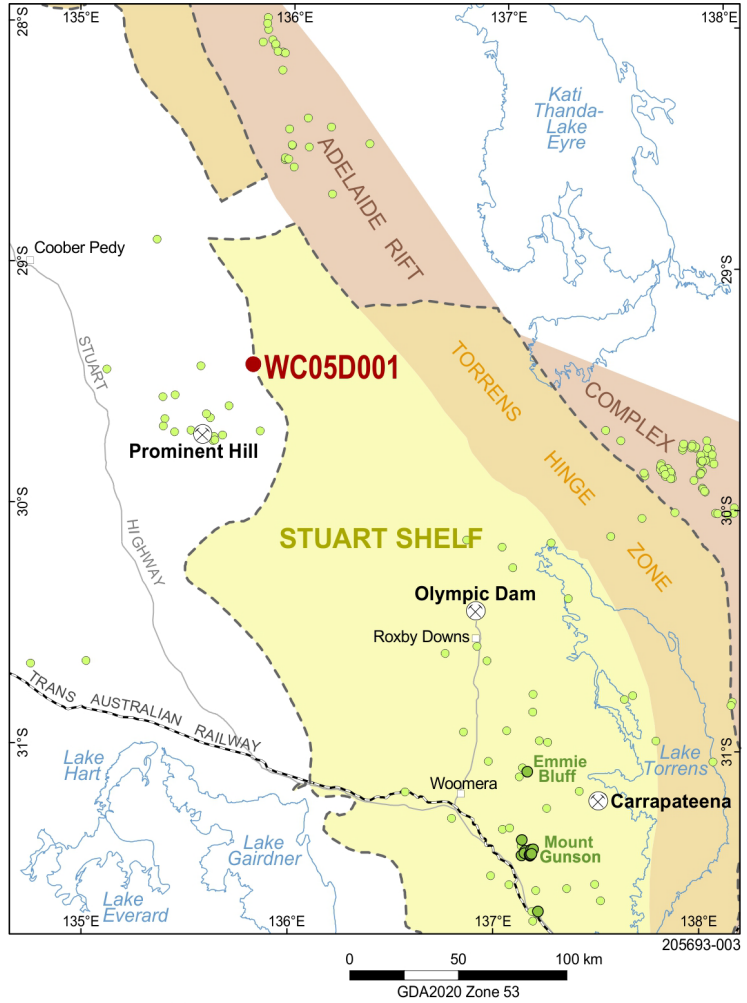
Dating for Stratigraphy

THE UNIVERSITY of ADELAIDE

- **new in-situ laser Rb–Sr geochronological technique** by University of Adelaide to constrain ages of altered volcanic rocks and Proterozoic sedimentary rocks
- sampled succession of sedimentary and mafic volcanic rocks (drillhole WC05D001) in northern Stuart Shelf
- constrained to being of Tonian age by a minimum age for overlying volcanics of 766 ± 26 Ma and a maximum age for deposition of lower sedimentary rocks of 904 ± 46 Ma
- correlates with Arkaroola Subgroup of Callanna Group

→ implications for sedimentary-hosted copper exploration

Callanna Group contains known copper-cobalt mineralisation and is age-equivalent to highly prospective Roan Group in the Central African Copperbelt (Cailteux et al. 2005).



Collins et al. 2024: New developments in laser Rb–Sr dating and their application in exploring Proterozoic sedimentary basins — an example from the northern Stuart Shelf, South Australia. MESA research article

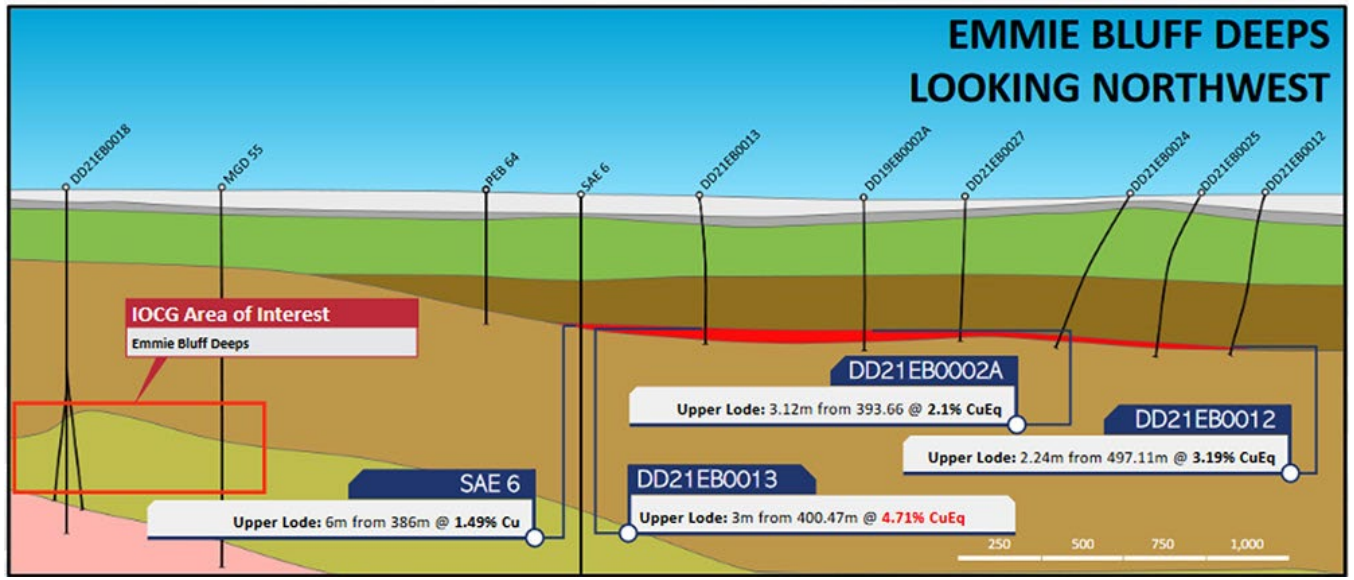
Timing of mineralisation

THE UNIVERSITY of ADELAIDE

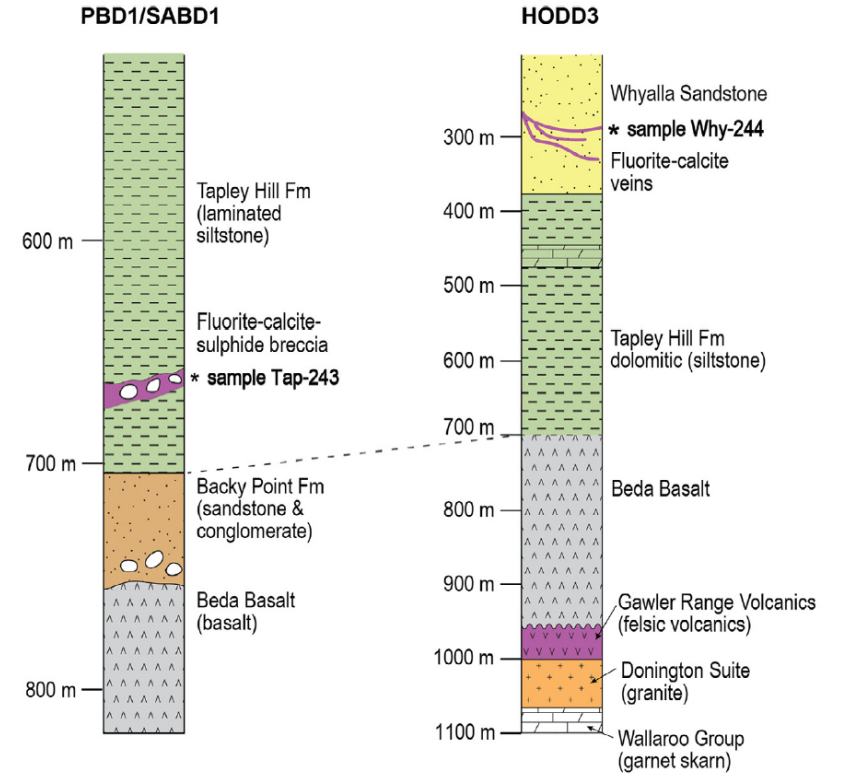
- using **new Lu-Hf method** developed by University of Adelaide to date fluorite and calcite veins

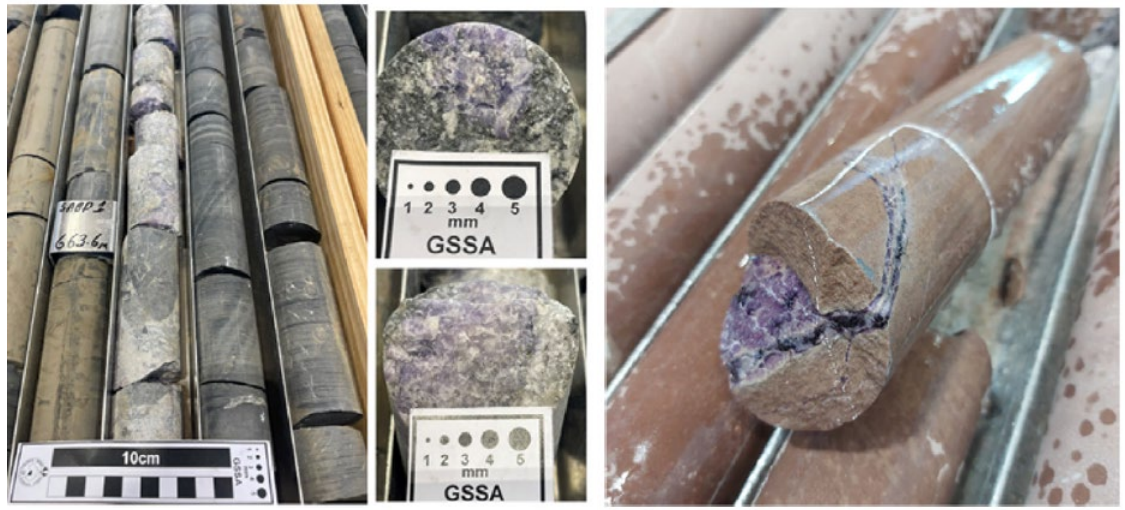
- 502 ± 14 Ma, which is consistent with the timing of the Delamerian Orogeny and an upgrading event in the Olympic Dam deposit

→ fluorine-rich fluids remobilised metals from fertile Olympic Cu-Au Province to Neoproterozoic cover during the Delamerian Orogeny, which may have led to development of sedimentary-hosted Cu-Co deposits such as those at Mount Gunson



https://stockhead.com.au/wp-content/uploads/2021/12/Picture-9.jpg



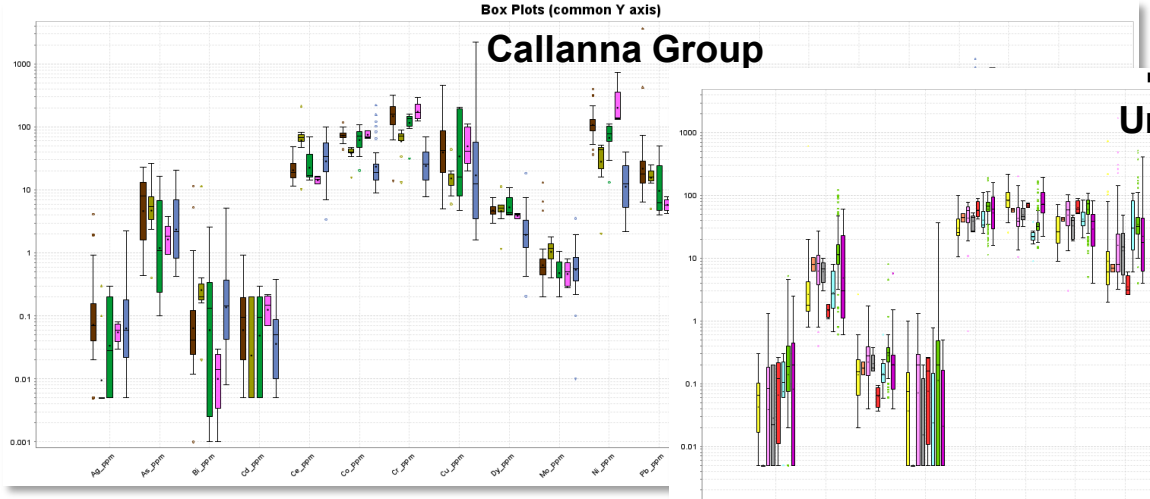


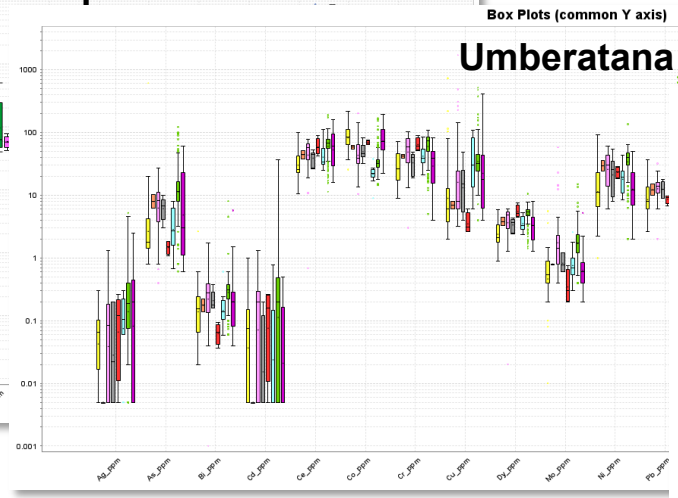
Glorie et al., 2023: *Laser ablation (in situ) Lu-Hf dating of magmatic fluorite and hydrothermal fluorite-bearing veins* (in: Geoscience Frontiers)

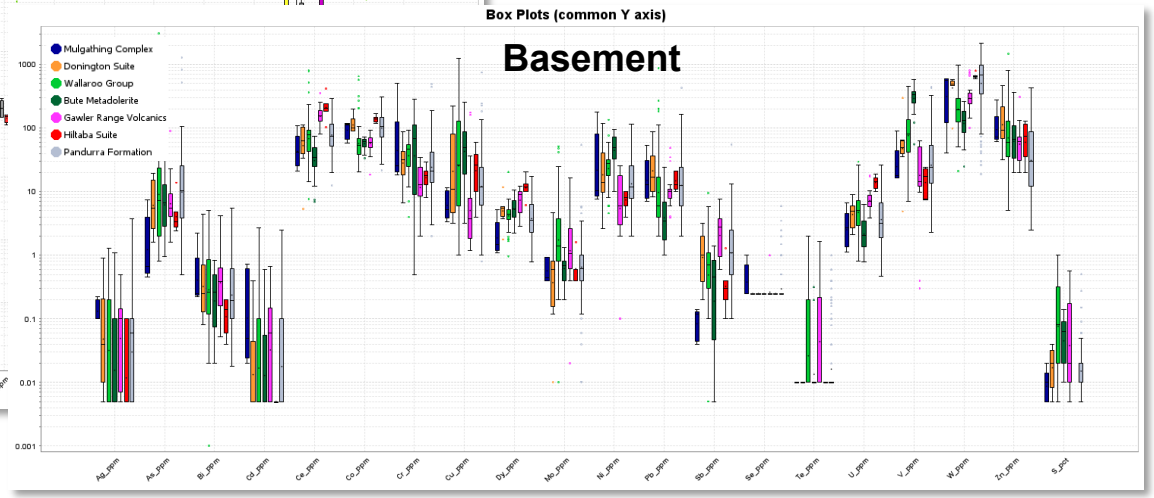
Geochemistry of drill core samples from the Stuart Shelf region

Australian Government
Geoscience Australia

- sampling program to investigate background geochemical values for common stratigraphic units in the Stuart Shelf and Torrens Hinge Zone (Champion et al., 2023)
- focussed on representative sections of core rather than mineralised intervals
  → *provides a useful measure of background values and their source potential*
- **best source rock potential (Cu):** Wallaroo Group, Bute Metadolerite, Doninton Suite, Beda Basalt, Wooltana Volcanics, Tapley Hill Formation and Brighton Limestone
- **best source rock potential (Co):** Donington Suite, Hiltaba Suite, Pandurra Formation, Callanna Group (Beda Basalt), Whyalla Sandstone and Appila Tillite (now Sturt Fm)



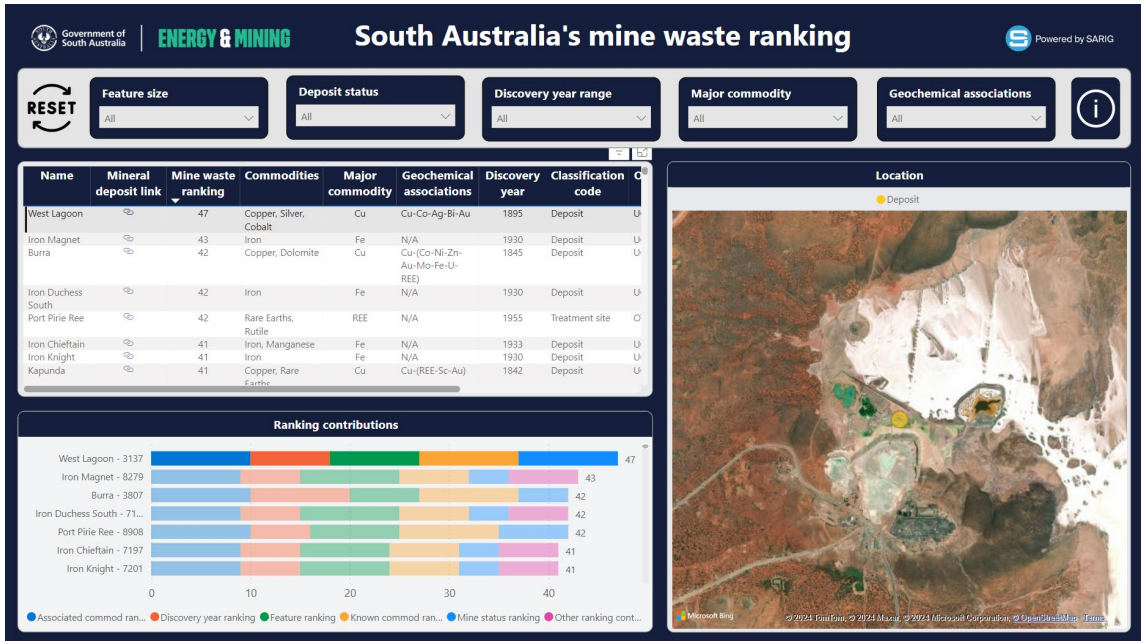




Champion, D.C., Huston, D.L., Bastrakov, E., Fabris, A., Krapf, C., Ashley, P., Gilmore, S., Byass, J. and S. Webber, S. 2023. *Geochemistry of drill core samples from the Stuart Shelf region, South Australia. Exploring for the Future – Baseline whole rock geochemistry data release*. Record 2023/39. Geoscience Australia, Canberra. http://dx.doi.org/10.26186/148538

Opportunities - Minewaste

- examining potential of tailings, stockpiles and waste dumps from historic mining operations to host critical minerals content in partnership with MIWATCH team *(Sustainable Minerals Institute, Univ. Queensland)* and Geoscience Australia
- identifying and ranking potential of SA's historical mine waste based on publicly accessible data
- active sampling of selected mine waste sites to provide assessment of their critical metal endowment and mineralogy



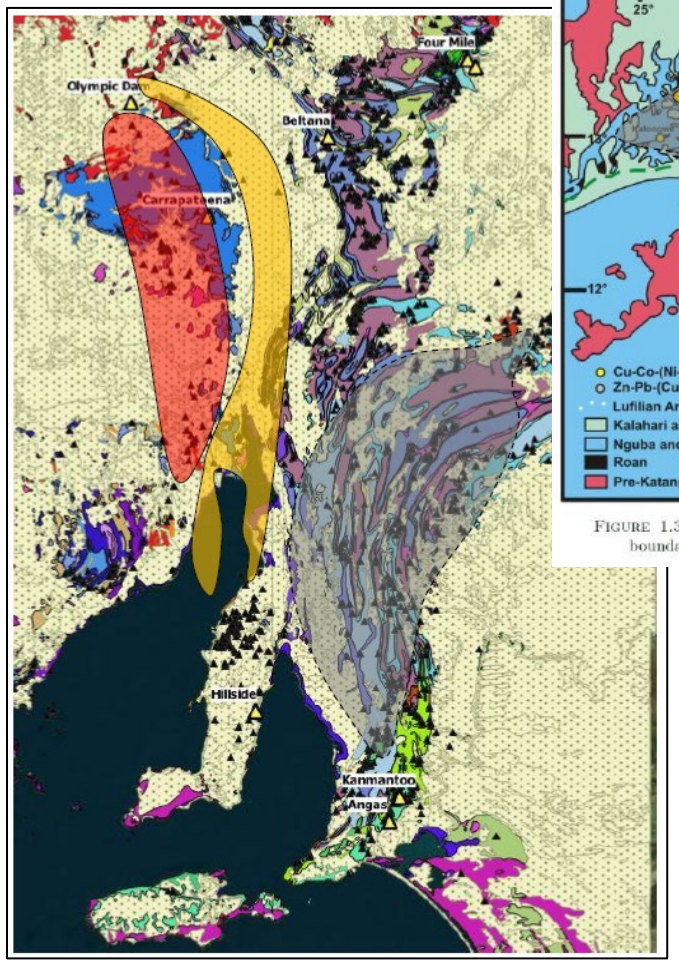
https://www.energymining.sa.gov.au/industry/geological-survey/gssa-projects/critical-minerals-south-australia/south-australias-critical-minerals-dashboards

Mt Gunson tailings sampling

SedCu opportunities beyond the Stuart Shelf

Torrens Hinge Zone

- Does THZ contain significant deposits at explorable depths?



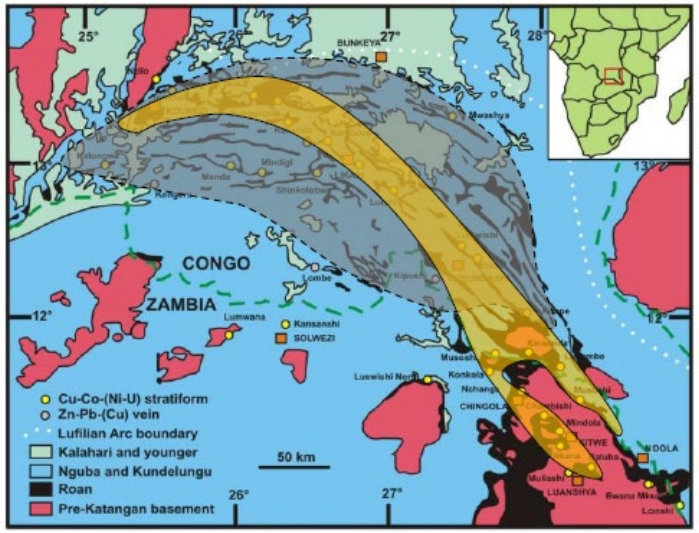


FIGURE 1.3: Geological map of the Central African Copperbelt, with geographic boundaries and ore deposits marked. (Adapted from Cailteux et al., 2005a).

"You could hide the main mineralised segment of the CACB in the Torrens Hinge Zone"

Stuart Bull, 2020 Mwale Symposium

Adelaide Rift Complex (ARC)

- With <1% of Dh's in ARC drilled to >100m, could some of those small occurrences at surface be pointing to something bigger at depth?

- Diapirs – REE potential
  (e.g., Taruga's Mount Craig project)

Worrumba Anticline, Flinders Ranges

Contacts

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Department for Energy and Mining

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SOUTH AUSTRALIA

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