Using Permian glacials and Paleocene-Eocene Thermal Maximum regolith as time markers to constrain the uplift history and landscape evolution of Victoria, and implications for mineral explorers

Ross Cayley

(on behalf of the GSV MinEx Phase 3 research crew)

Geological Survey of Victoria.

AIG Victorian Minerals Roundup 18 June, 2026

RESOURCES VICTORIA

We acknowledge and respect Victorian Traditional Owners as the original custodians of Victoria's land and waters, their unique ability to care for Country and deep spiritual connection to it.

We honour Elders past and present whose knowledge and wisdom has ensured the continuation of culture and traditional practices.

Resources Victoria is committed to genuinely partnering with Victorian Traditional Owners and Victoria's Aboriginal community to progress their aspirations.

Talk Outline

- **Why did we look into this? The quest for Critical Minerals understanding!**
- The PETM – what is it? Why do we consider it so important for landscape history mapping?
- PETM regolith – where is it preserved? What does it look like?
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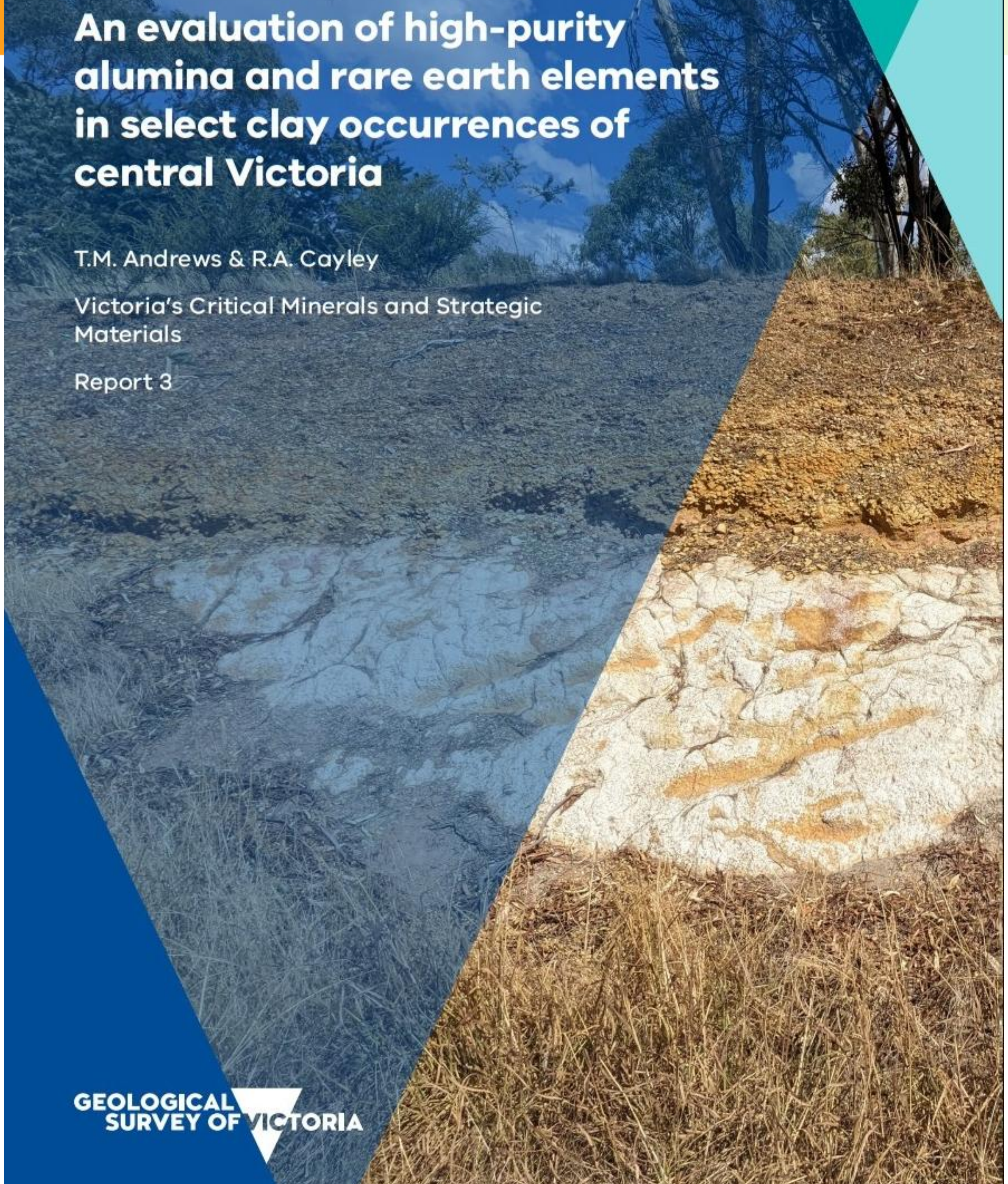
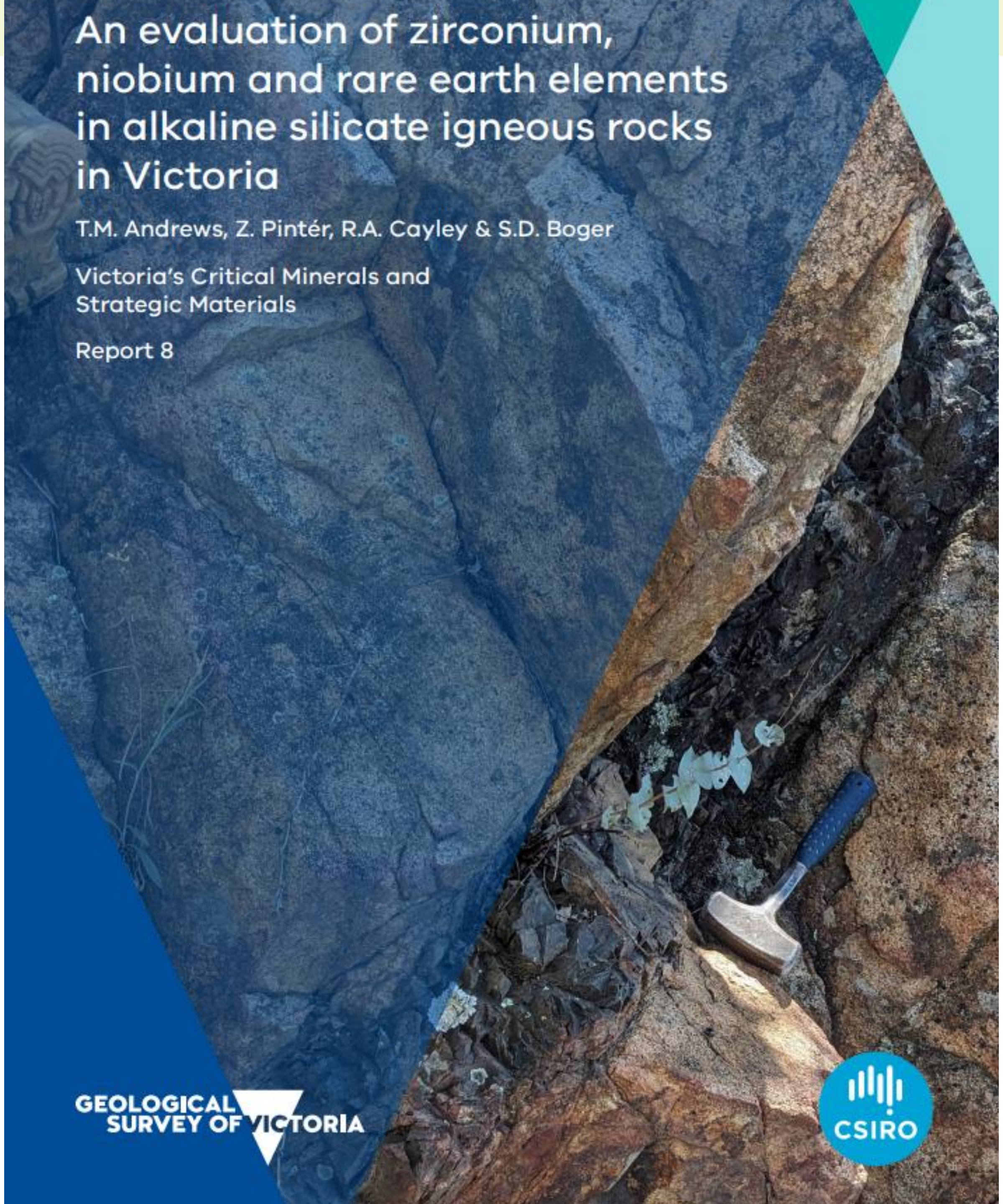

An evaluation of high-purity alumina and rare earth elements in select clay occurrences of central Victoria

T.M. Andrews & R.A. Cayley

Victoria's Critical Minerals and Strategic Materials

Report 3

GEOLOGICAL SURVEY OF VICTORIA


An evaluation of zirconium, niobium and rare earth elements in alkaline silicate igneous rocks in Victoria

T.M. Andrews, Z. Pintér, R.A. Cayley & S.D. Boger

Victoria's Critical Minerals and Strategic Materials

Report 8

GEOLOGICAL SURVEY OF VICTORIA

CSIRO

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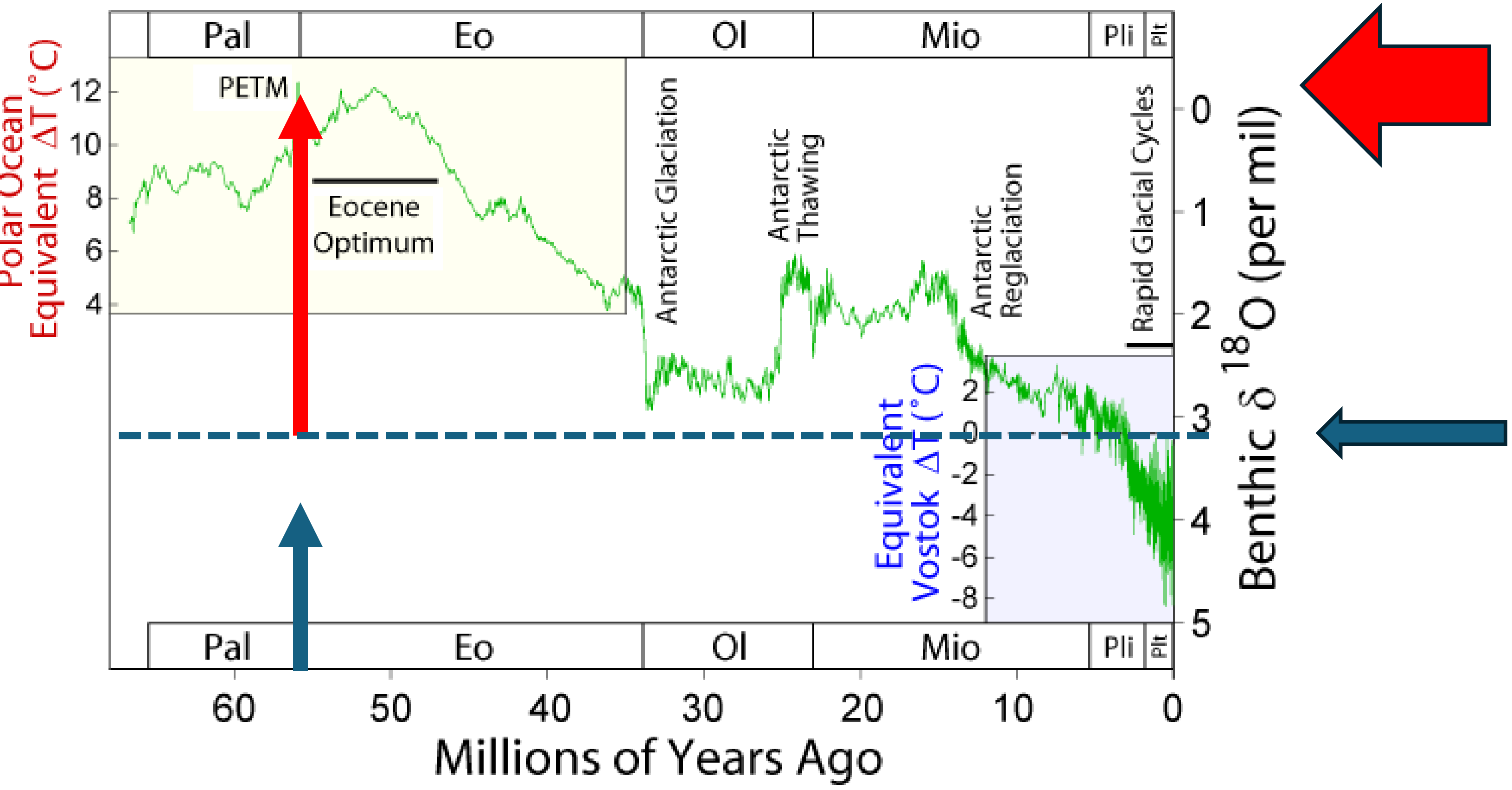
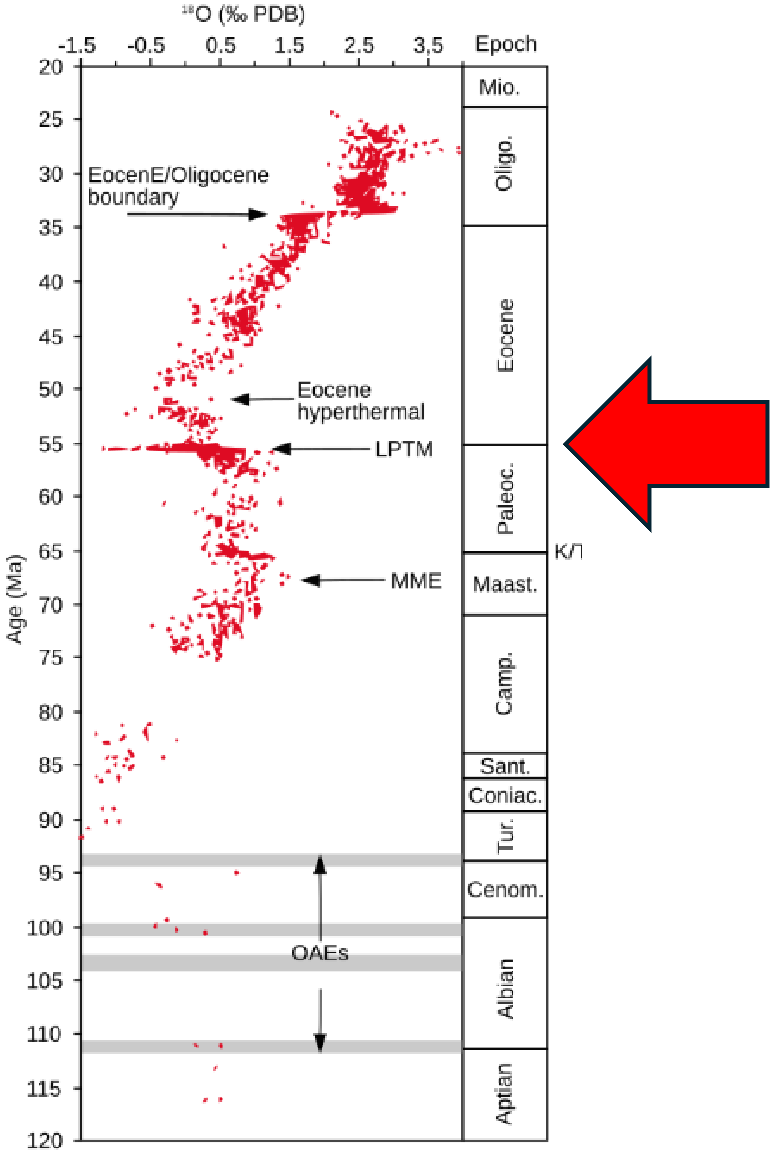
The Paleocene – Eocene Thermal Maximum. What is it?



By Robert A. Rohde - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=466265



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Global mean surface temperature at peak PETM: 27.2-34.5° C. (Inglis et al., 2020)

Sea surface temperatures in the East Tasman Plateau (located ~65° S at ~57 Ma) were **33° C**! (estimated from sediment core samples; Sluijs et al., 2011)

For ~200 thousand years Victoria was both subpolar and rampantly ‘tropical’, with a sustained semi-tropical climate persisting for the next ~10 million years!

PETM significance for constraining Victoria's landscape evolution history:

We can assign thick, tropical-style paleo-regolith profiles in Victoria to the PETM with confidence because:

- the preceding +ve temperature excursion of similar magnitude (Cretaceous Thermal Maximum at ~90 mya) is too old to explain thick in-situ tropical-style regolith profiles developed upon Paleocene fluvial units.

- Eocene strata in Victoria are weathered with slightly less intensity (consistent with the sustained 'Eocene Optimum' that followed the PETM).

- Olicocene and younger strata in Victoria preserve no evidence of tropical-style weathering (but locally incorporate reworked PETM remnants -kaolinitic clays / lateritic clasts – but intermixed with unweathered materials)

- there has been no comparable global +ve thermal excursion since the Eocene – so no younger 'tropical' regolith.

We consider the **PETM is a fantastic time-marker**.

- PETM regolith: indiscriminate and thick (uneroded PETM regolith profiles extend to ~80m deep in Palaeozoic bedrock).
- Super easy and unambiguous to recognise
- Given the global context and Statewide remnant distribution of PETM in Victoria,
  we expect this event affected every rock exposed in Victoria at that time.

Therefore:

- Where PETM regolith and / or coeval stratigraphy is substantially or even intermittently preserved:
  local land-surface is Late Paleocene (at a minimum).
- Where PETM regolith and / or coeval stratigraphy is entirely absent: local land-surface
  is younger than the PETM (ie: has been subjected to a significant (~50m +) denudation post-Eocene)

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PETM clay localities (commercial)

PETM regolith best preserved in river valley flanks and floors (minor younger exceptions)

PETM regolith only preserved on high plateau surface remnants (where locally protected).
PETM entirely absent from river valley flanks and floors (very minor exceptions)

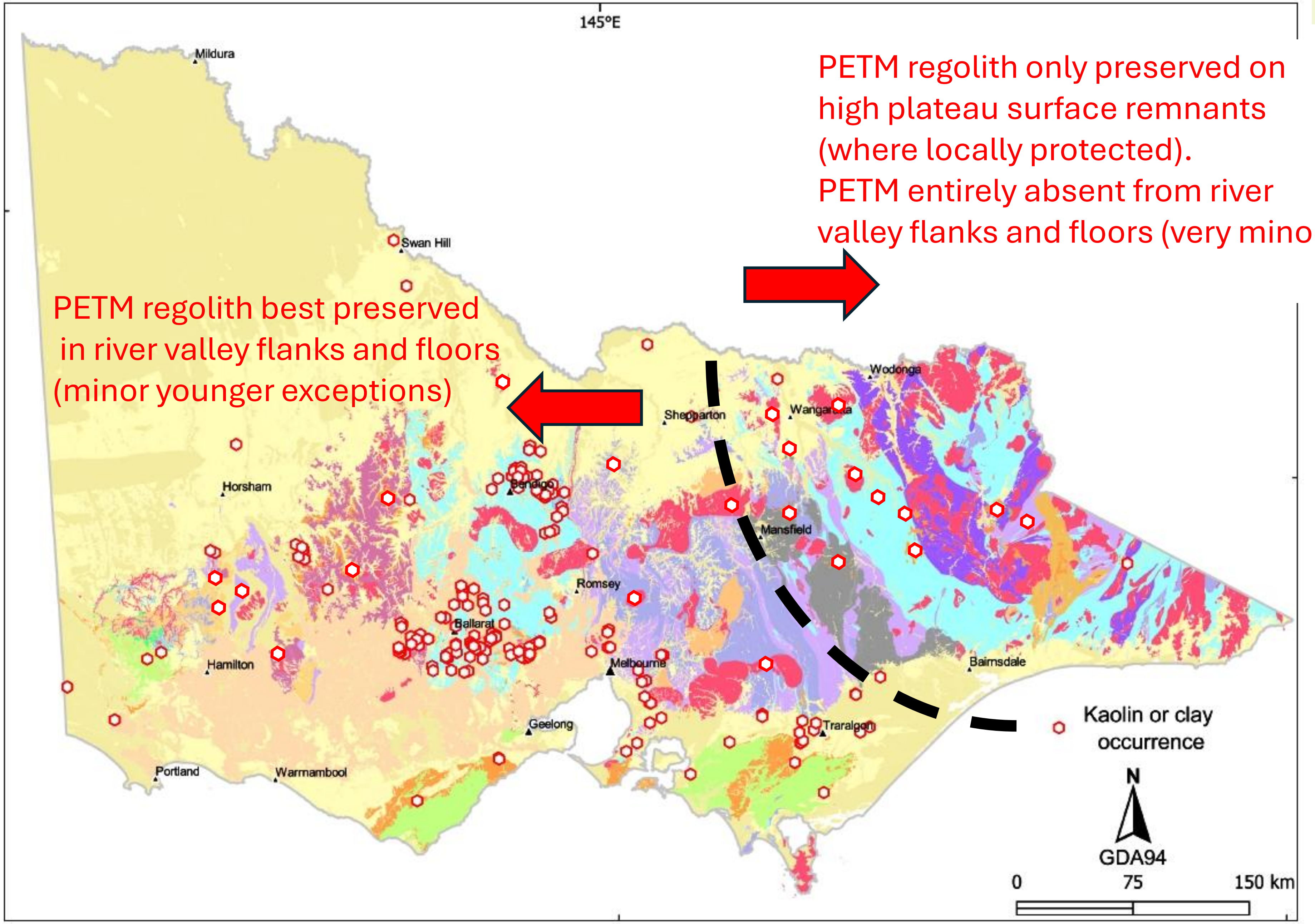
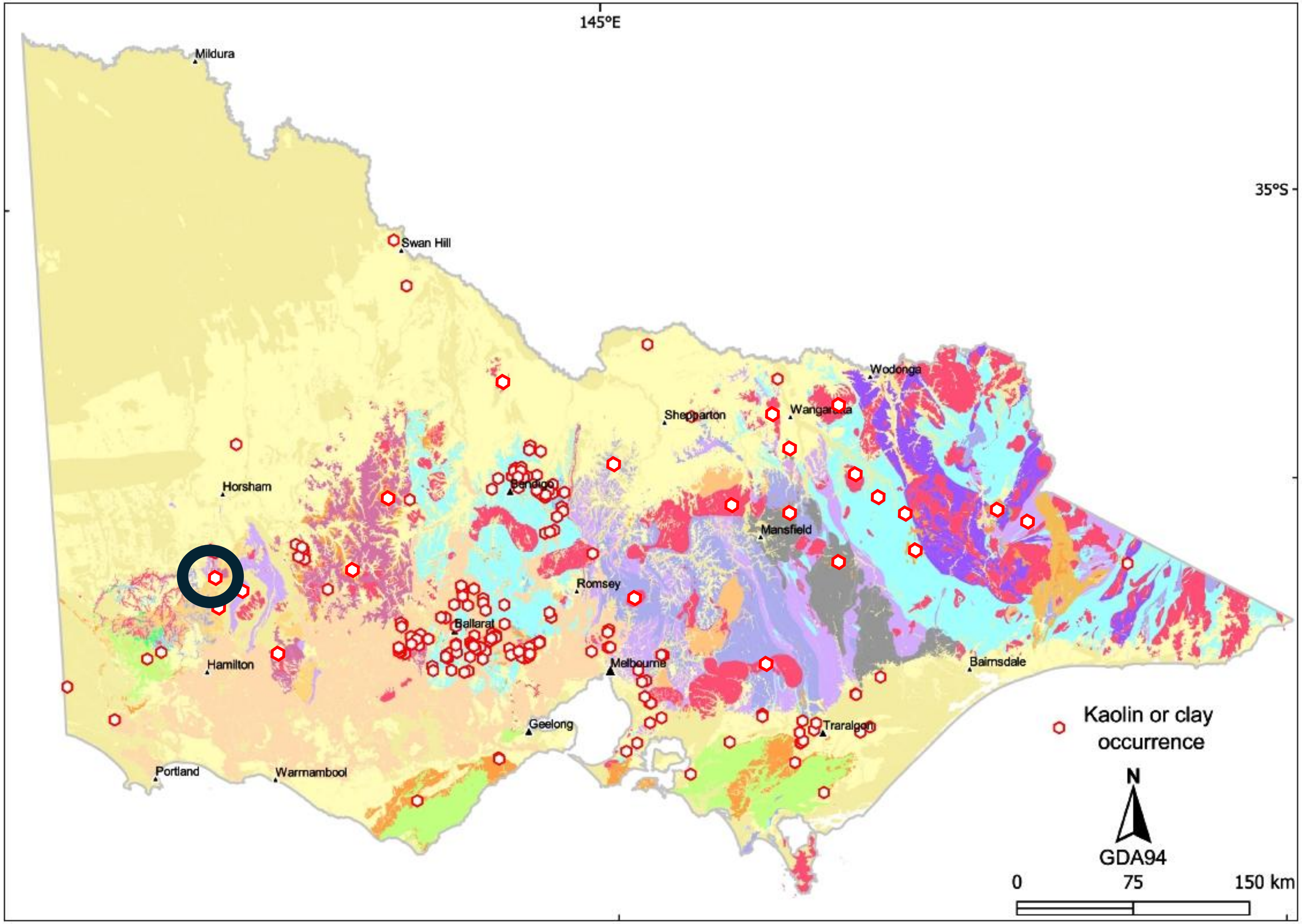


Figure 2.2 Mineral occurrences listing kaolin and clay as the primary production commodity on Victoria's Seamless Geology (simplified after Welch et al., 2011).



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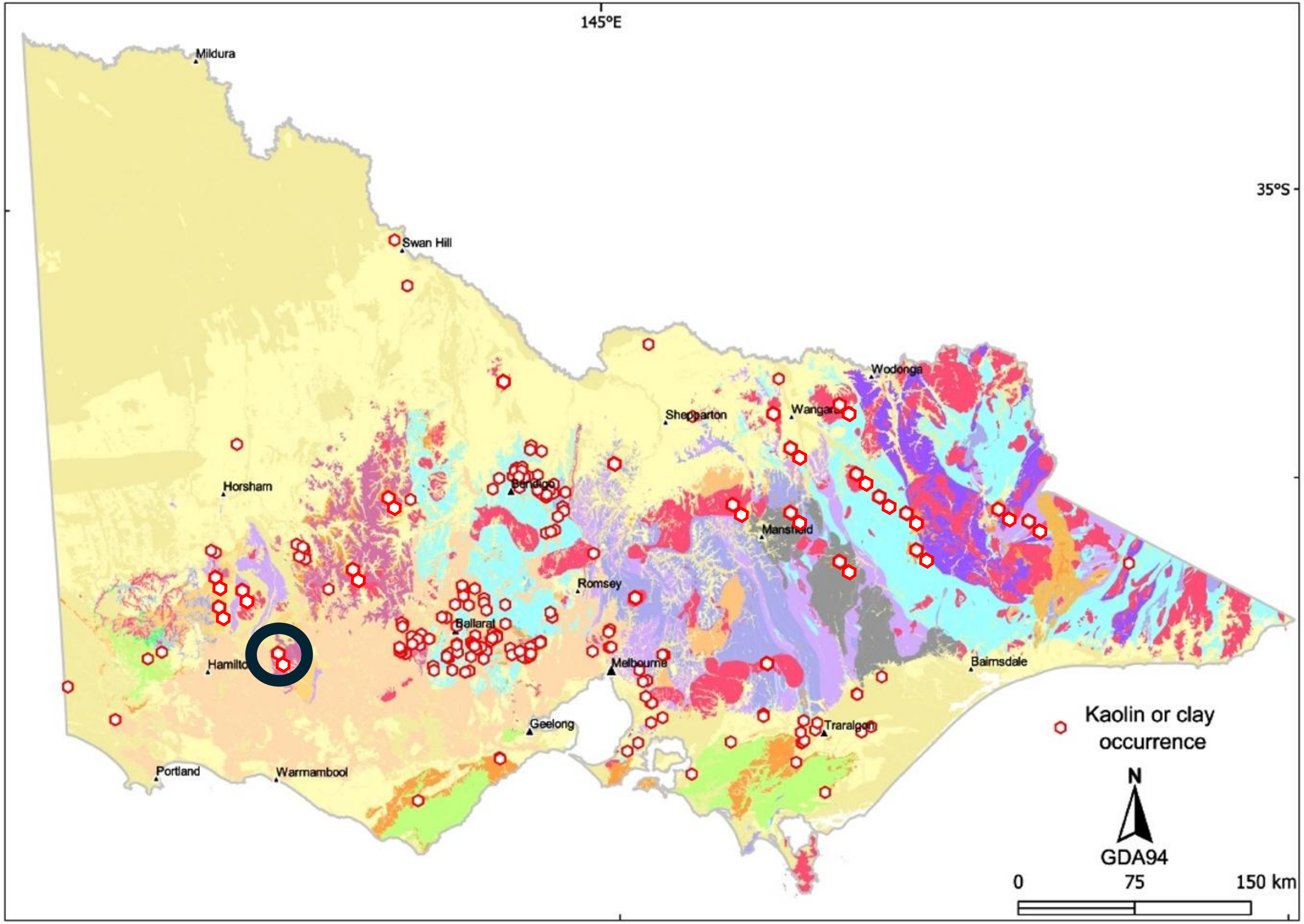
Black Range / Rocklands Reservoir



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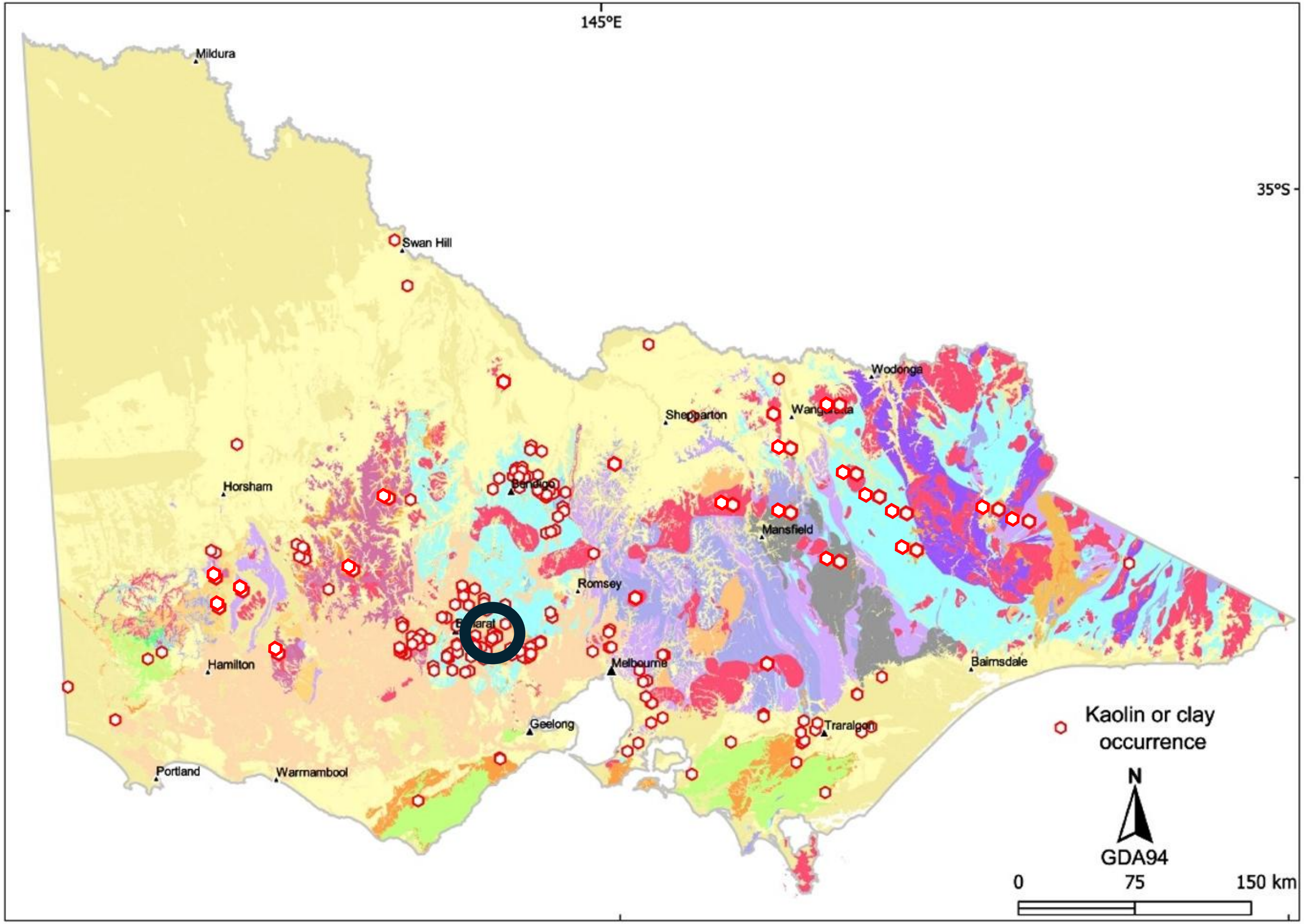
Glenthompson



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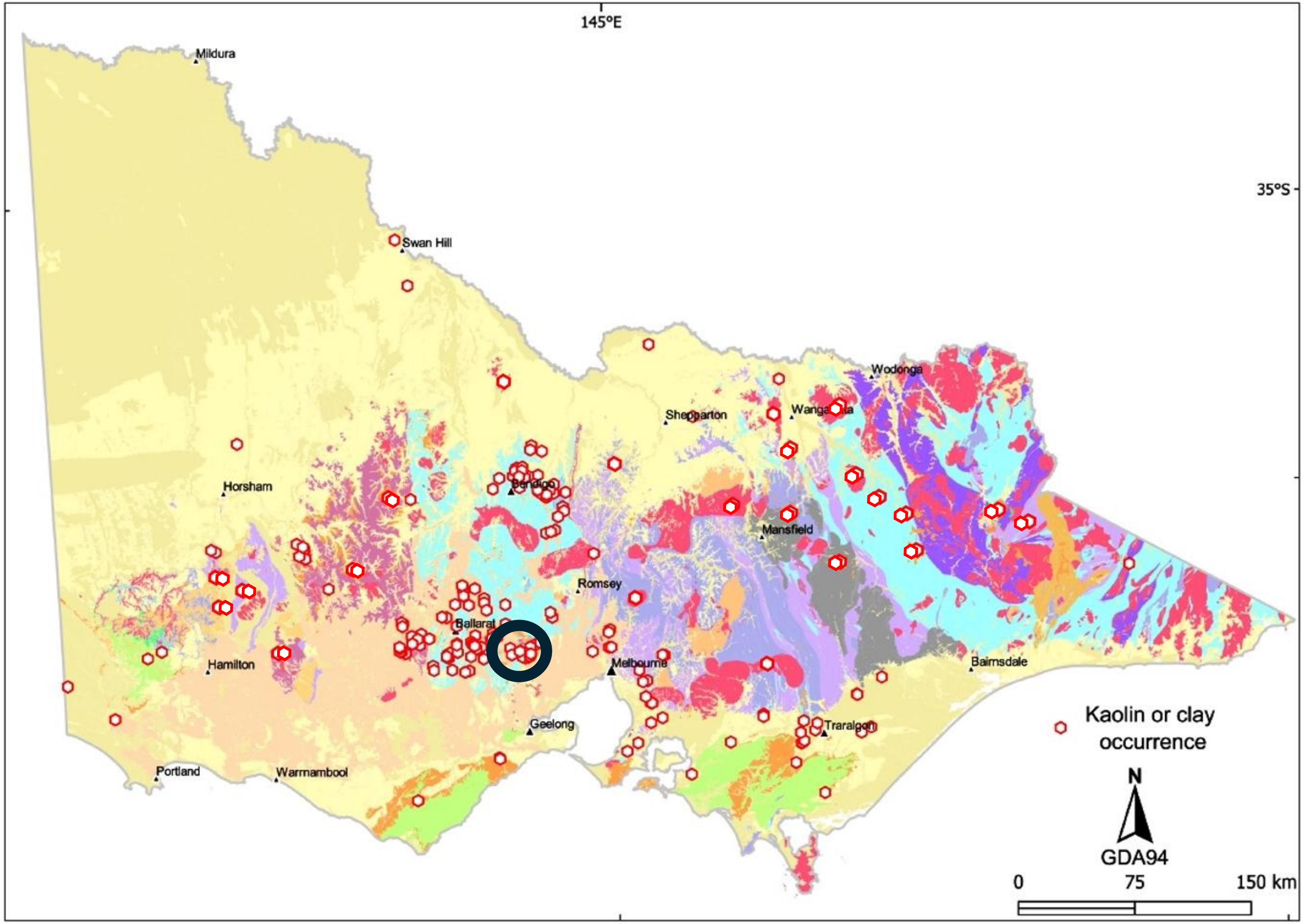
Egerton / Lal Lal
PETM regolith, particularly in granitic rocks – high HPA resource potential



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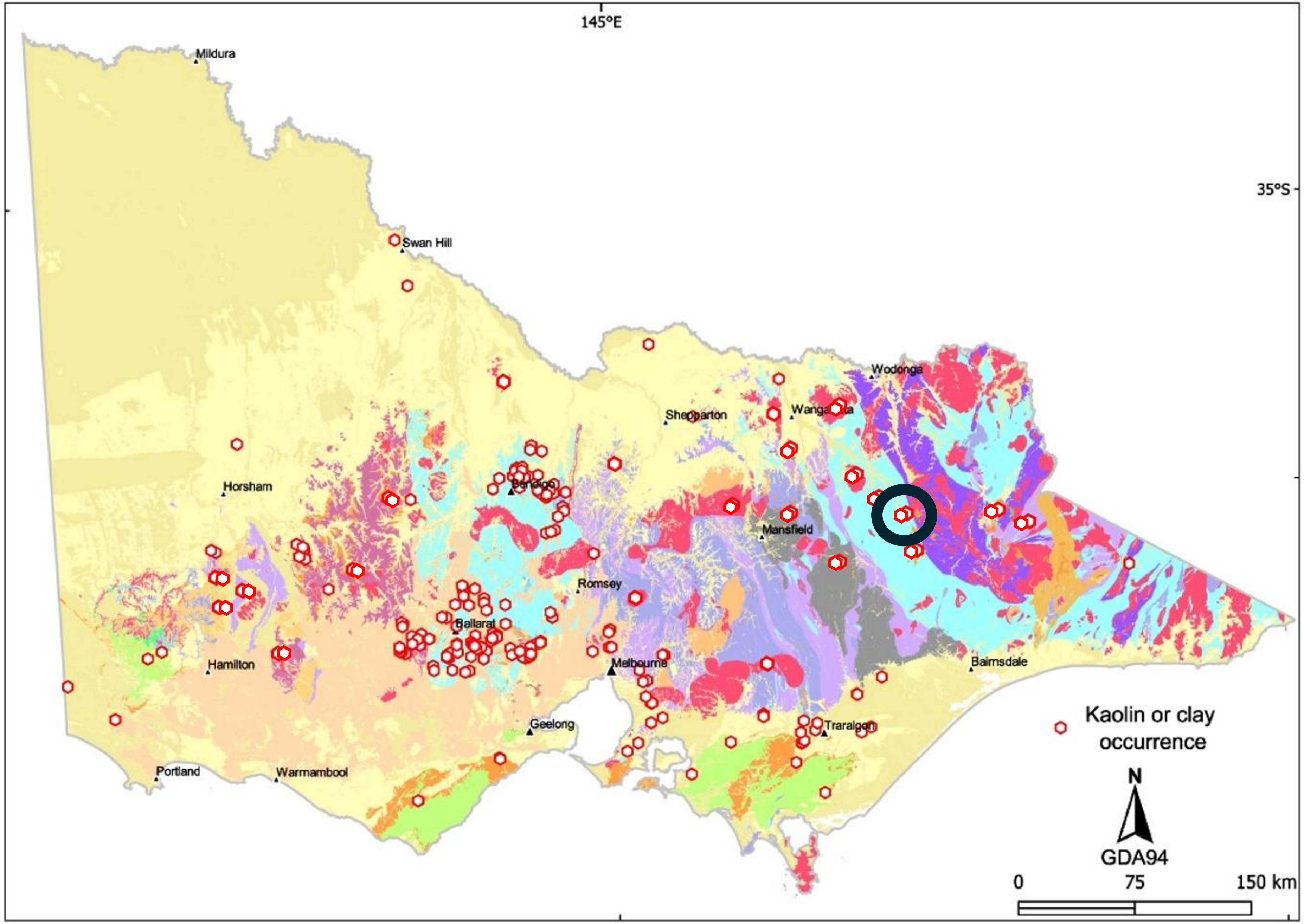
Ingliston Gorge, Bacchus Marsh
(Werribee Formation)



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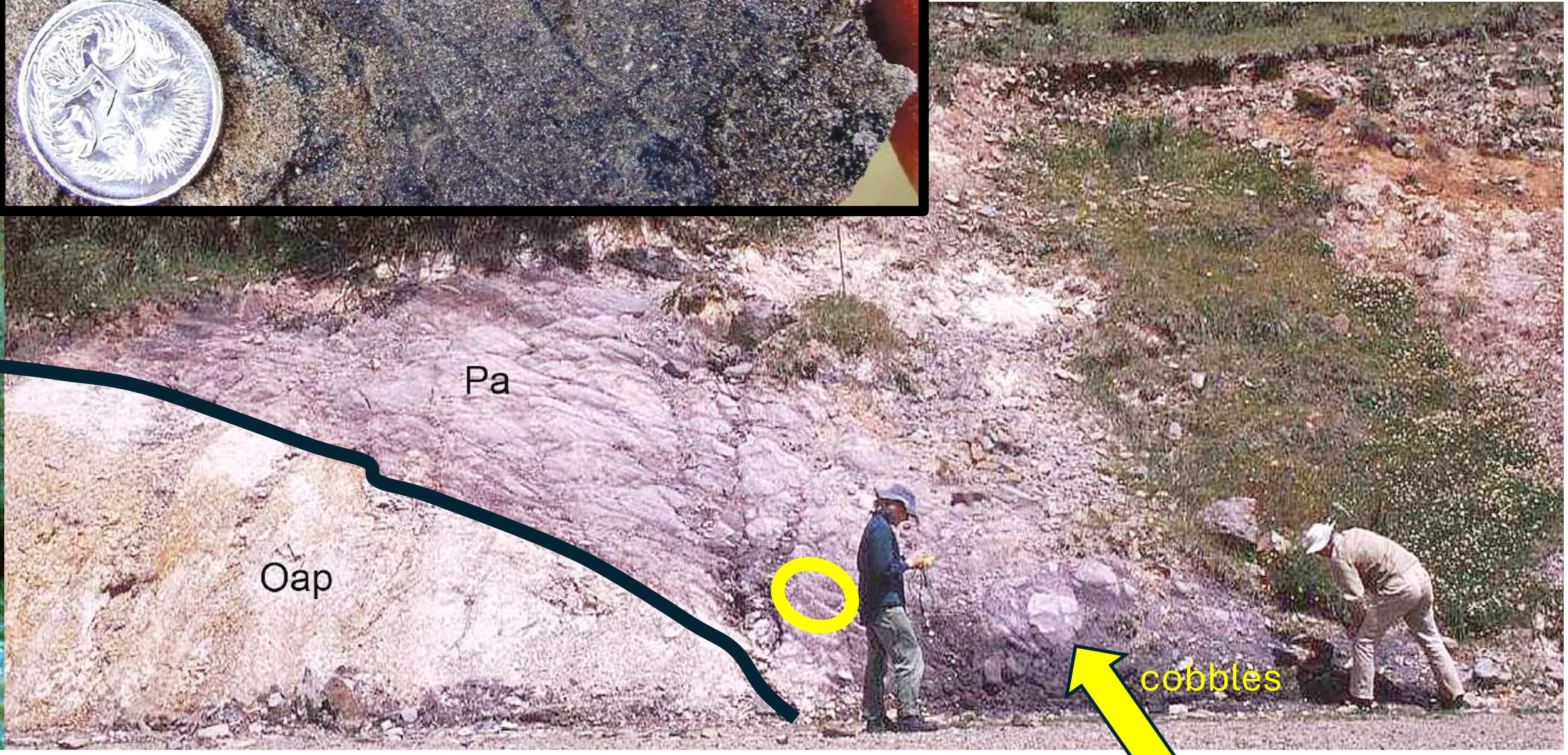
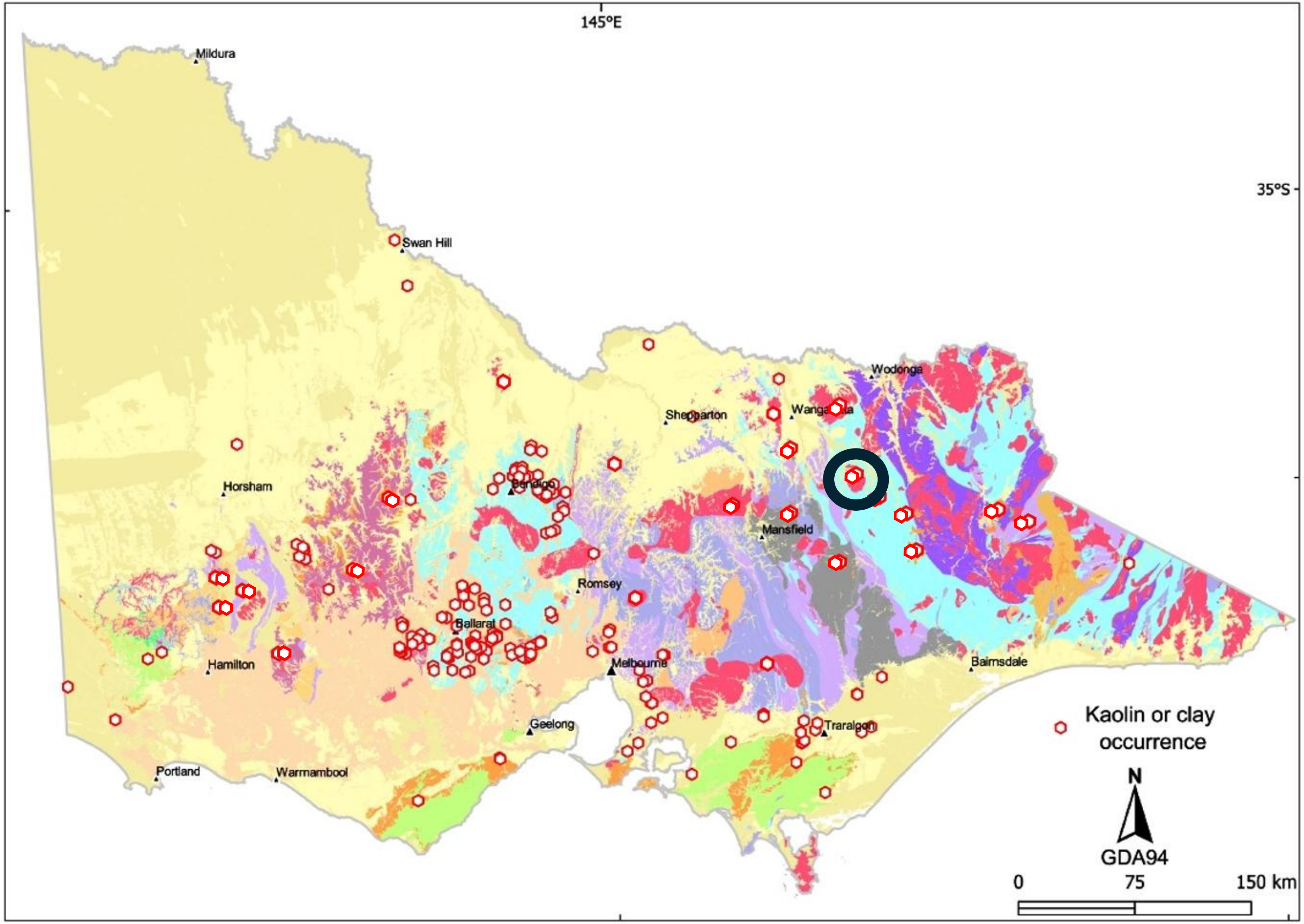
Mount Fainter summit

Alpine vegetation
(e.g. Greenwood et al., 2017)
implication: plateau uplift
preceded the Paleocene.

Mount Little Higginbotham summit
(Mt Hotham; Morand et al., 2005)





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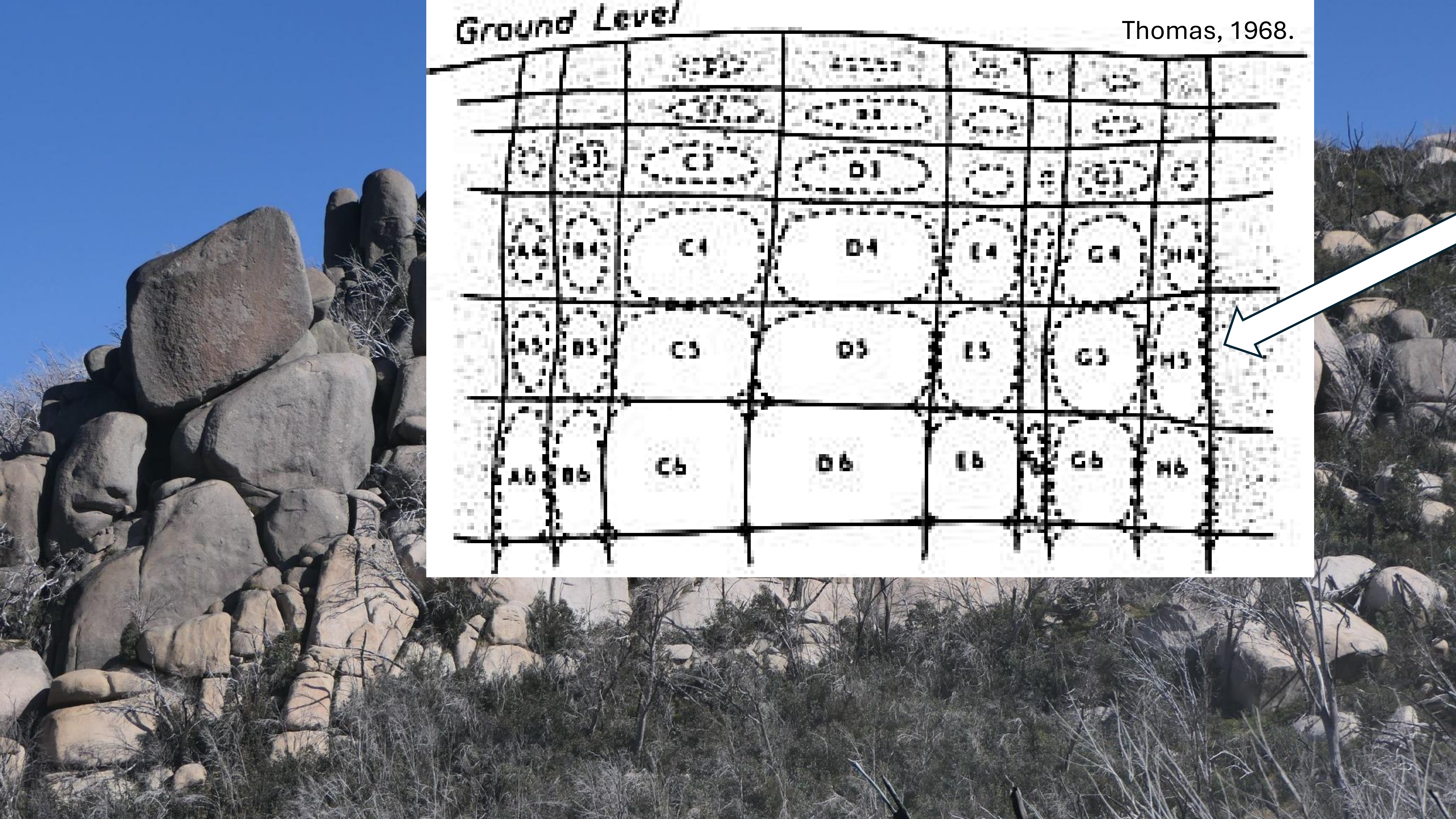
Mount Buffalo inselberg – uplifted plateau remnant


toppled tors


Ground Level
C3
D3
A4
B4
C4
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E4
G4
H4
A5
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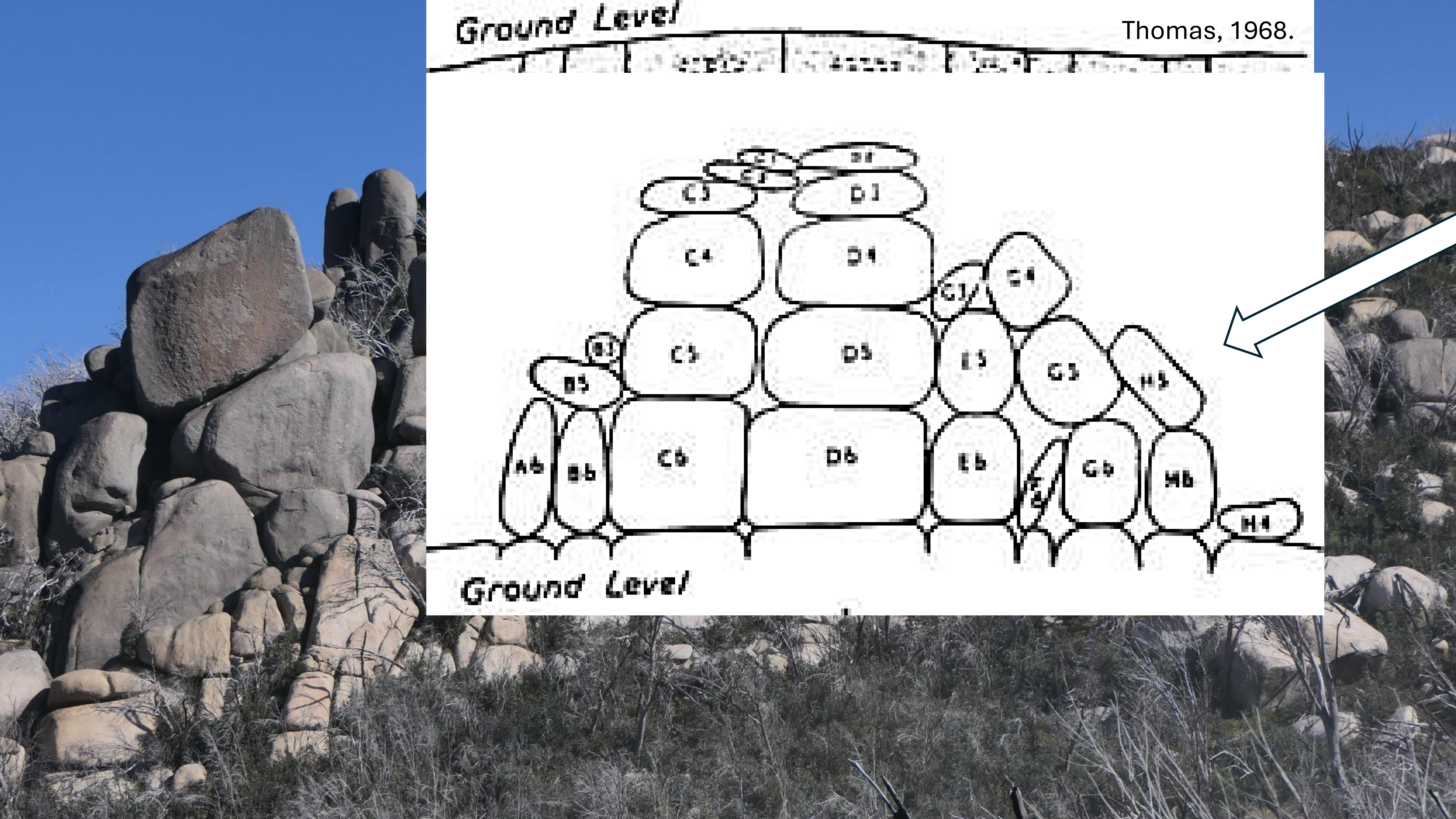
H6
Thomas, 1968.


Ground Level
C3
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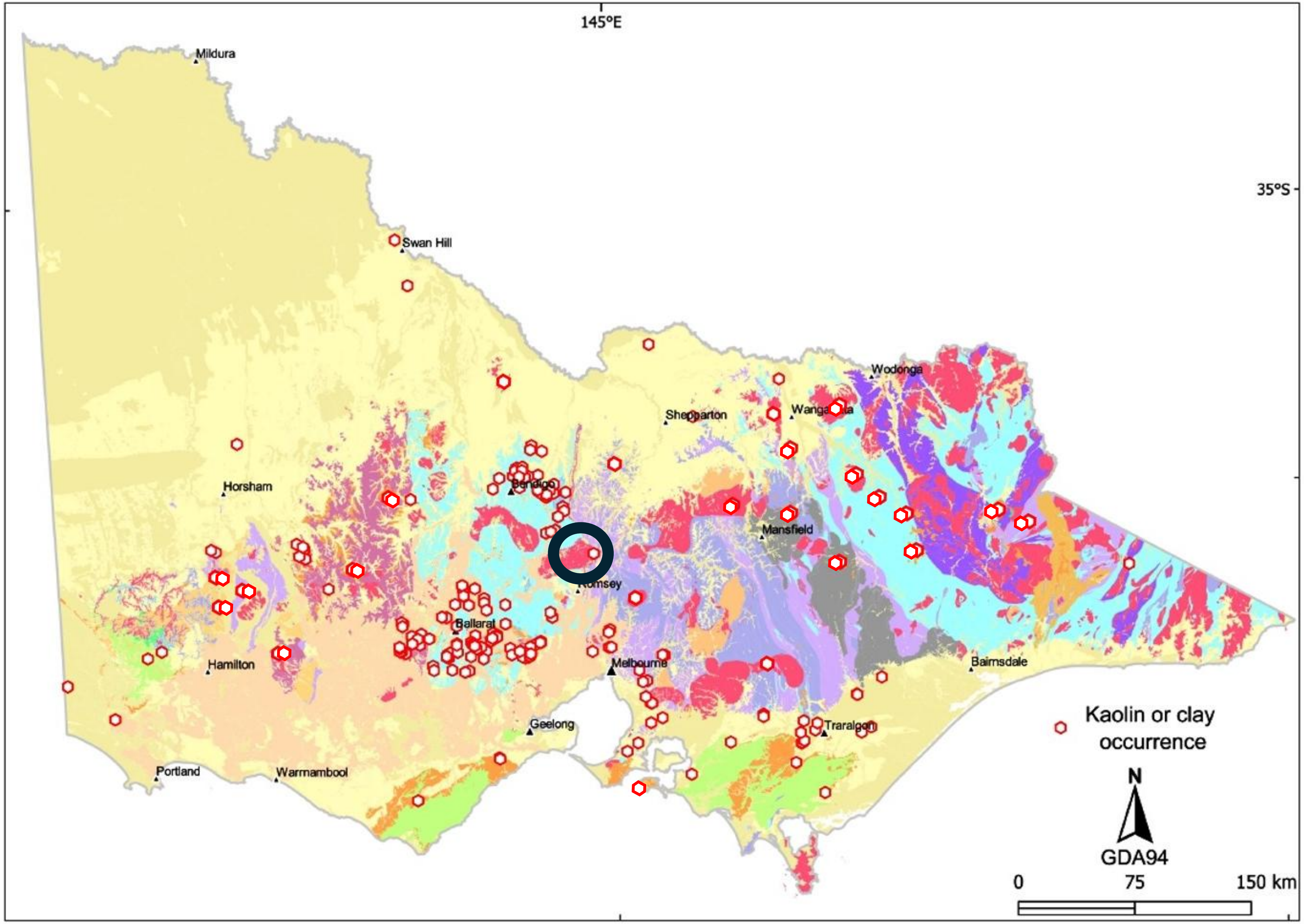
H6
H4
Ground Level

Thomas, 1968.


Thomas, 1968.
PETM land surface



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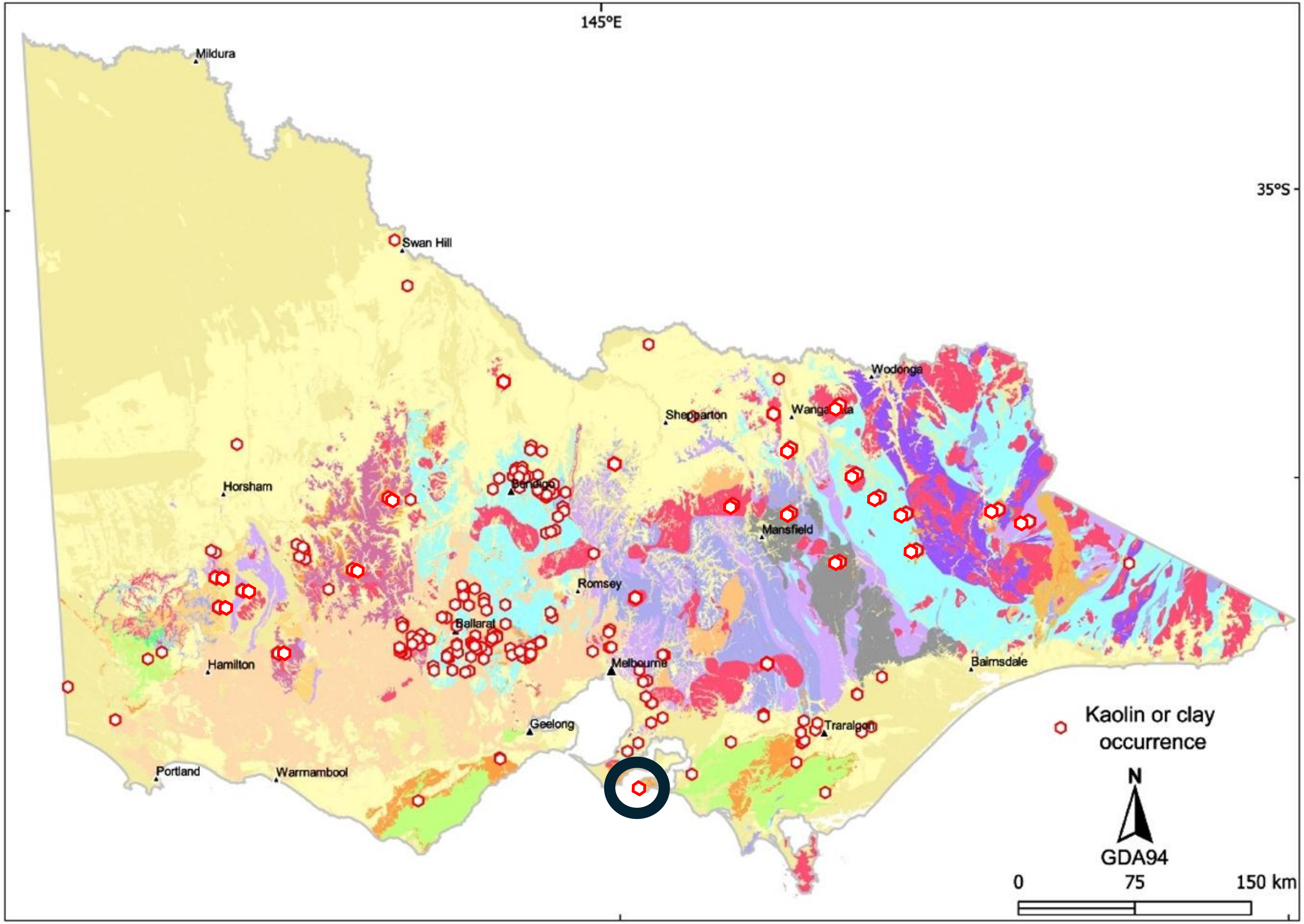

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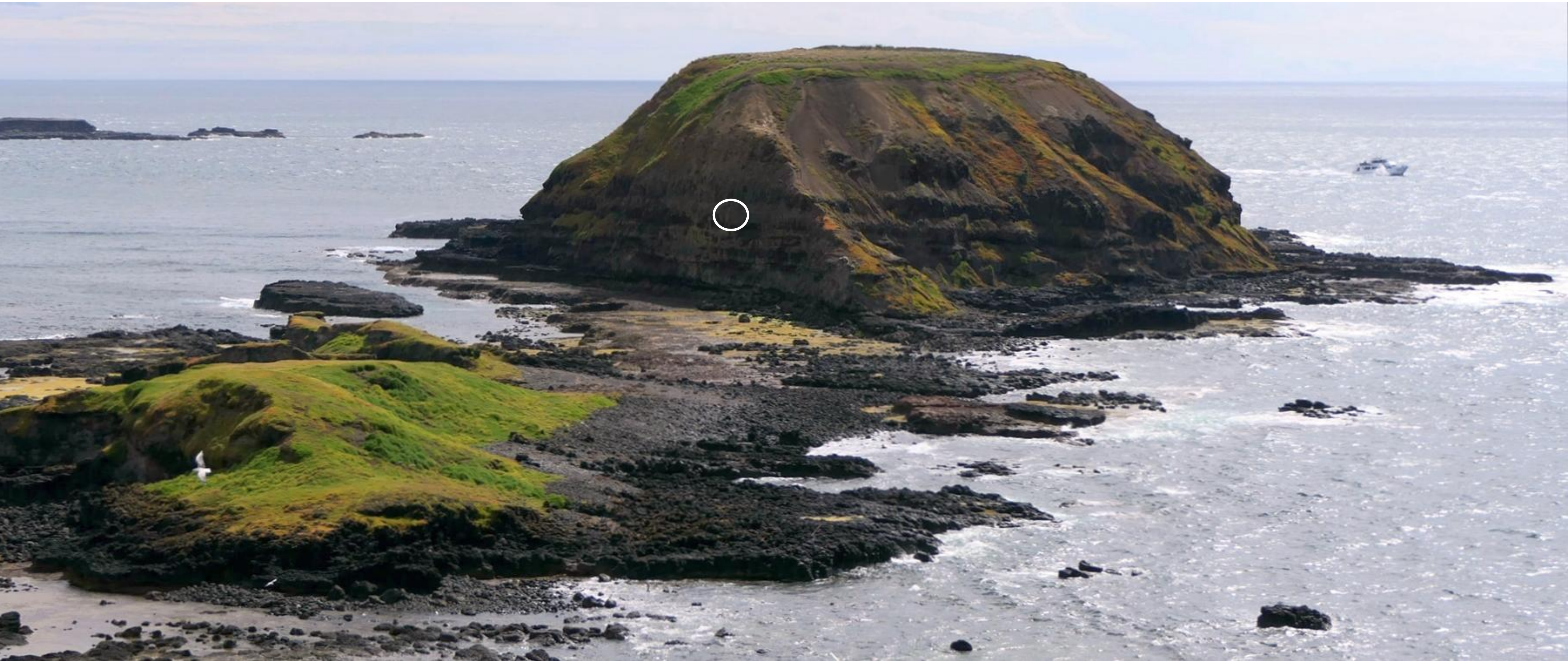
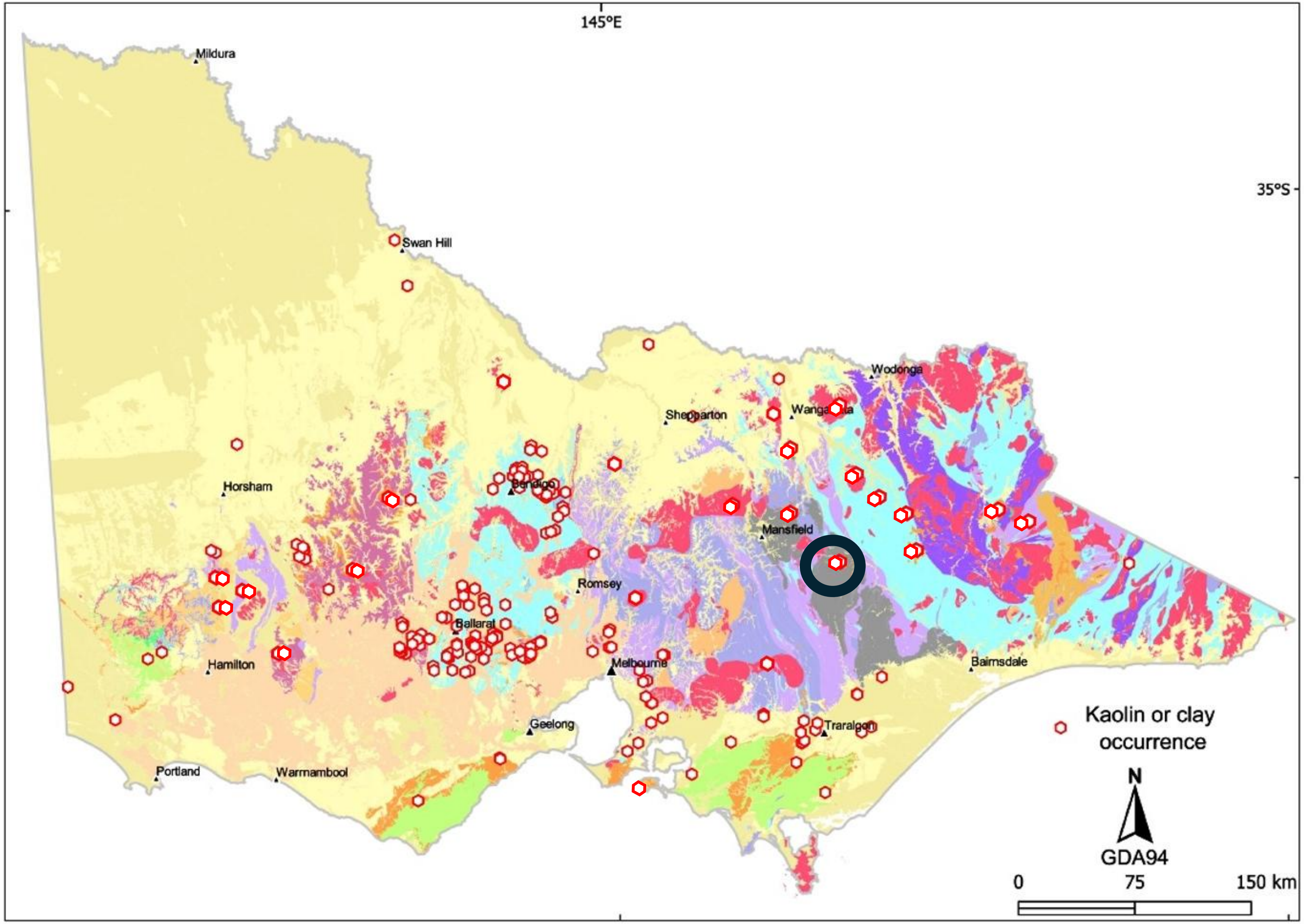
‘The Nobbies’
Phillip Island

Older Volcanics PETM regolith
mined for bauxite at Mirboo



Zeolite amygdales



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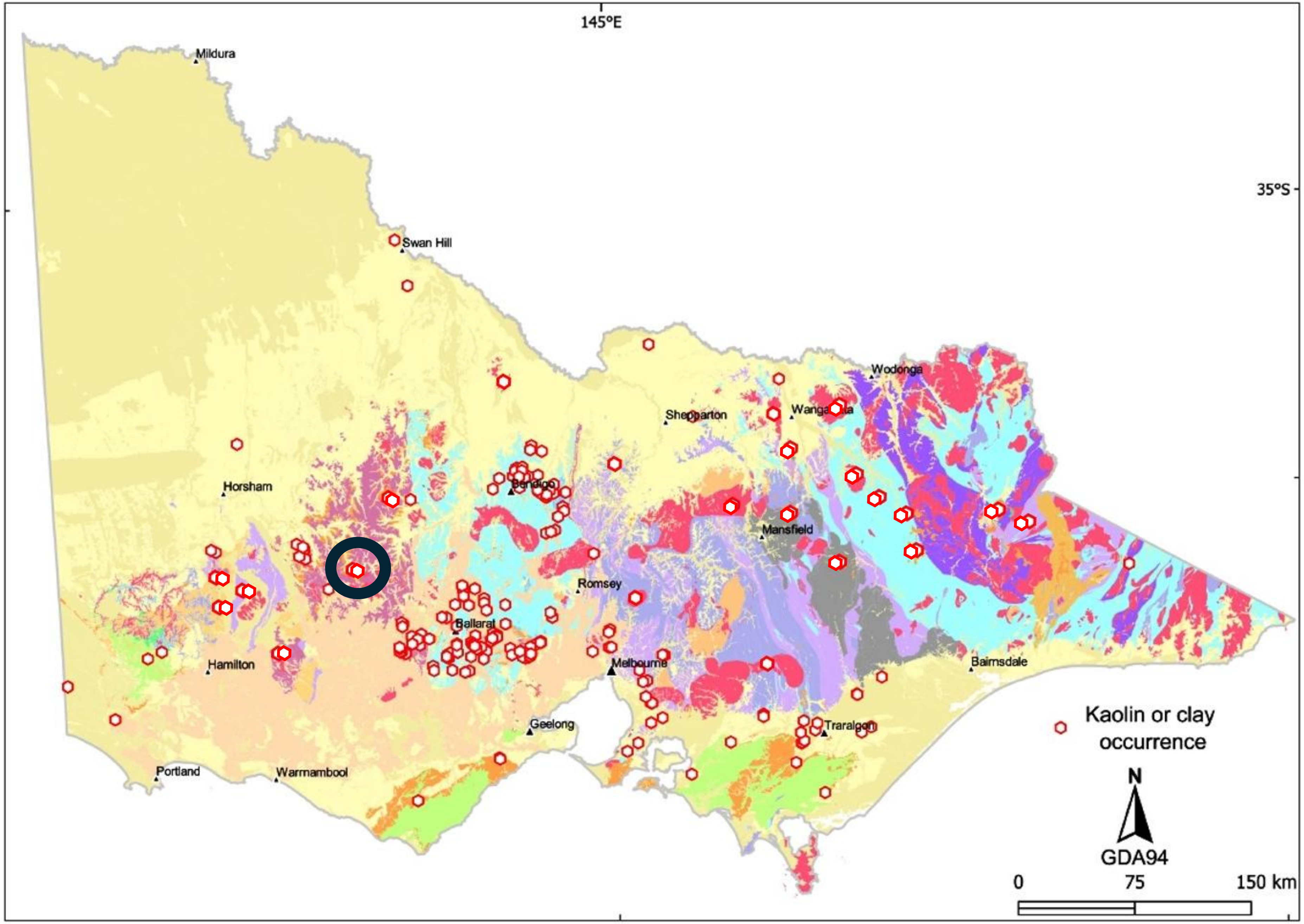
Mount Clear (King Billy in the distance)


Zeolite amygdales
('Eocene Optimum' regolith trace)



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PETM regolith, particularly in granitic rocks – high HPA resource potential

Quartz cobbles in Palaeocene gravels subjected to PETM deep weathering – potential HPQ resource

(GSV collaboration with Geoscience Australia currently testing this opportunity)

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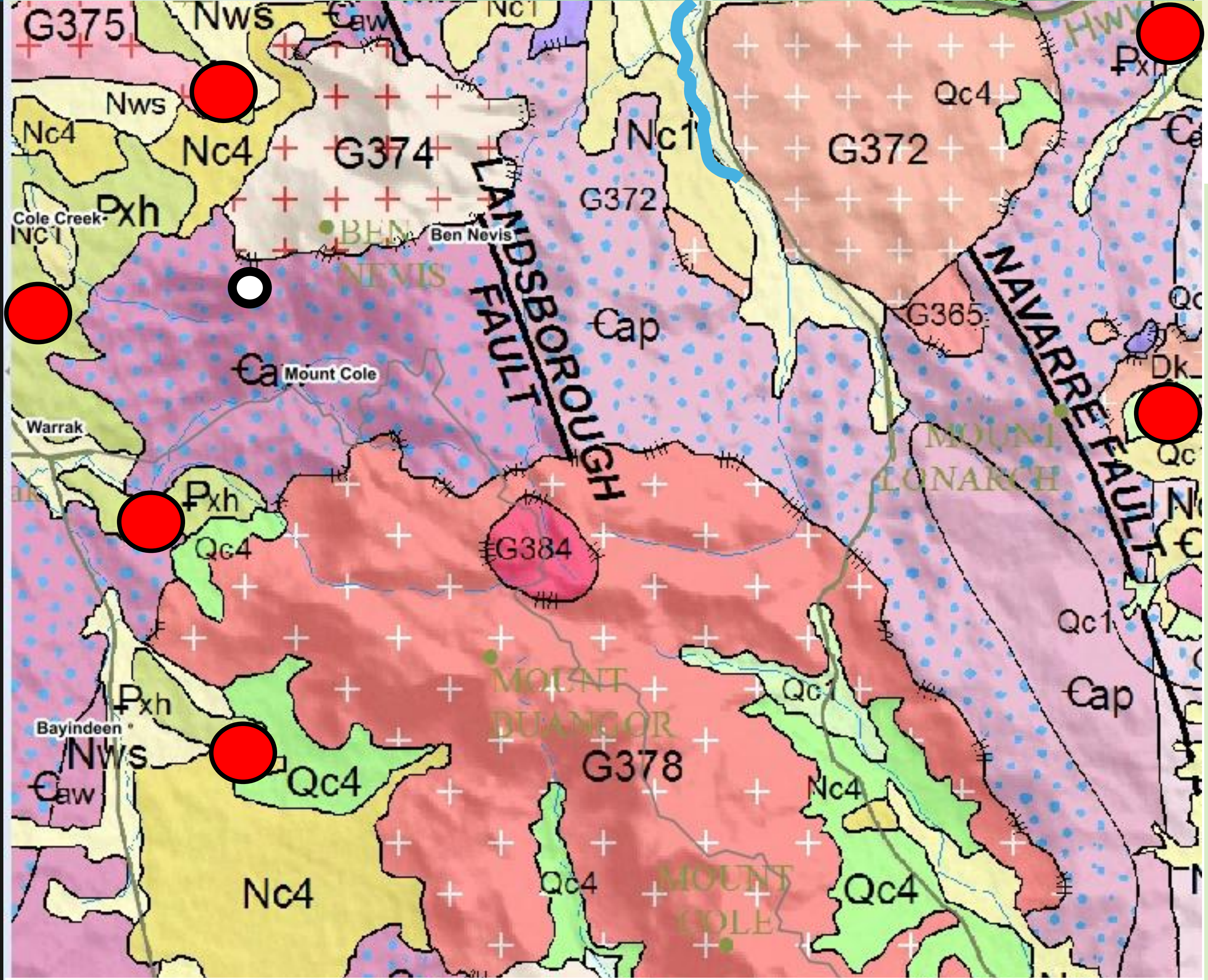
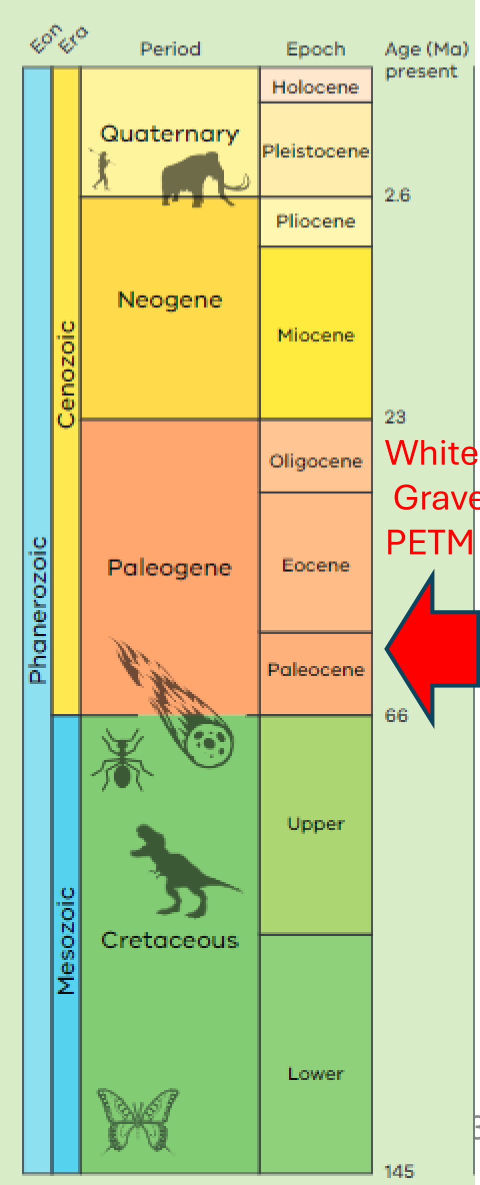
Mount Cole / Ben Nevis / Pyrenees Range

remnants of the same ancient, uplifted alpine land surface, but in Western Victoria





White Hills Gravel PETM regolith

THIS CONSTRAINS THE MINIMUM POSSIBLE AGE OF LOCAL DEEP PLATEAU DISSECTION TO THE LATE CRETACEOUS-PALEOCENE!

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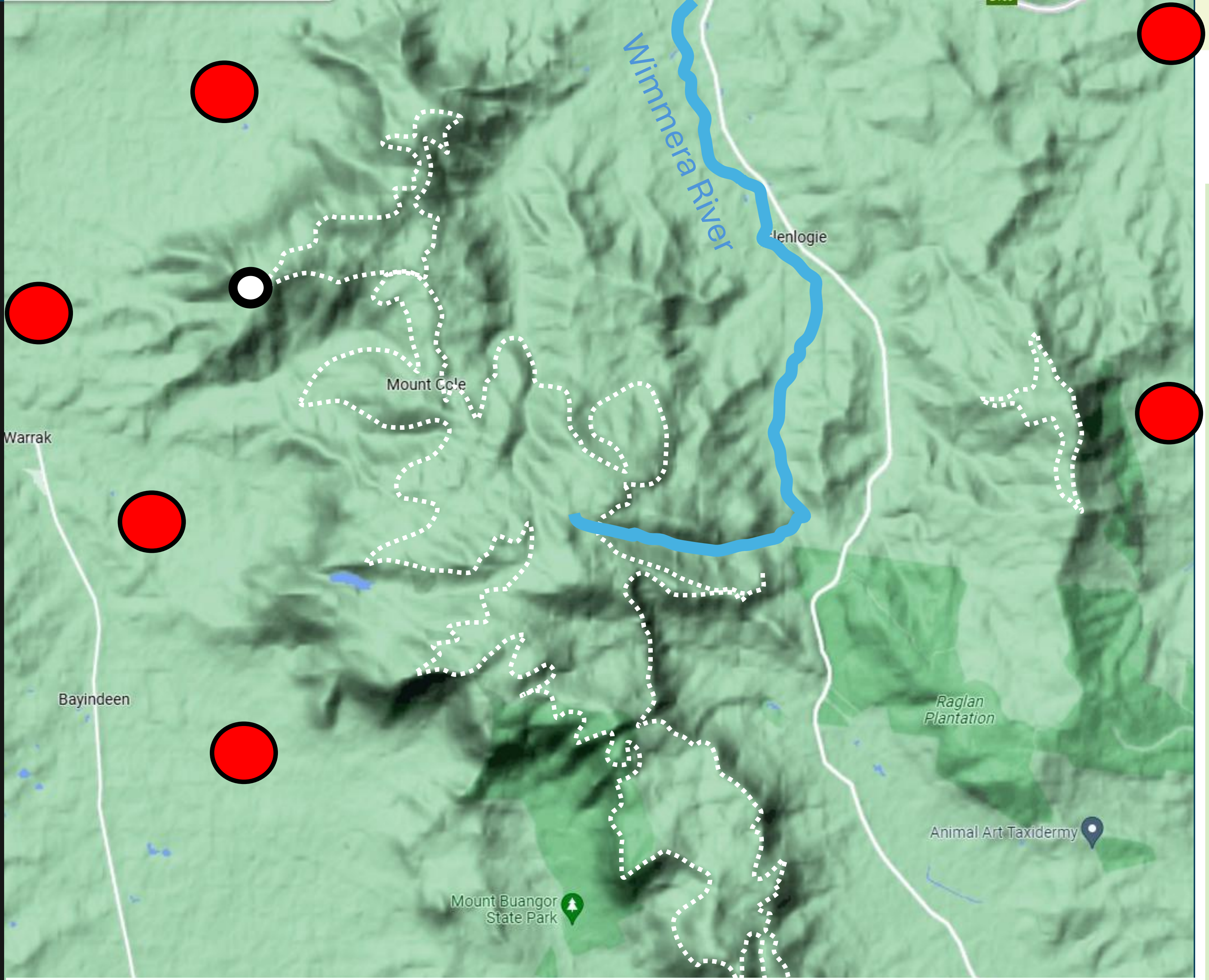
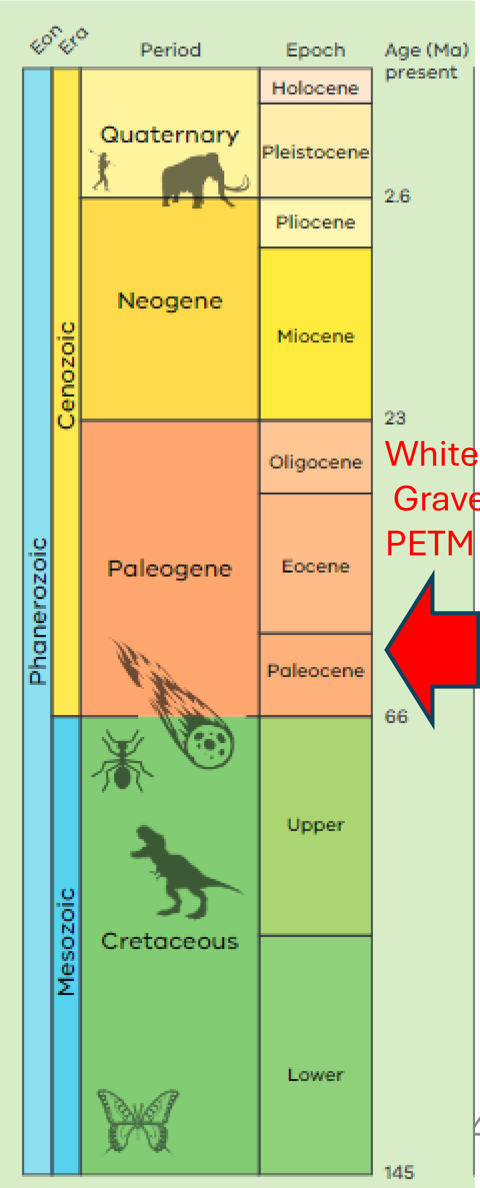
remnants of the same ancient, uplifted alpine land surface, but in Western Victoria





White Hills Gravel
PETM regolith

THIS CONSTRAINS THE MINIMUM POSSIBLE AGE OF LOCAL DEEP PLATEAU DISSECTION TO THE LATE CRETACEOUS-PALEOCENE!


Ben Nevis
~ 900m ASL
~ 300m ASL

A maximum age constraint for high plateau uplift in western Victoria

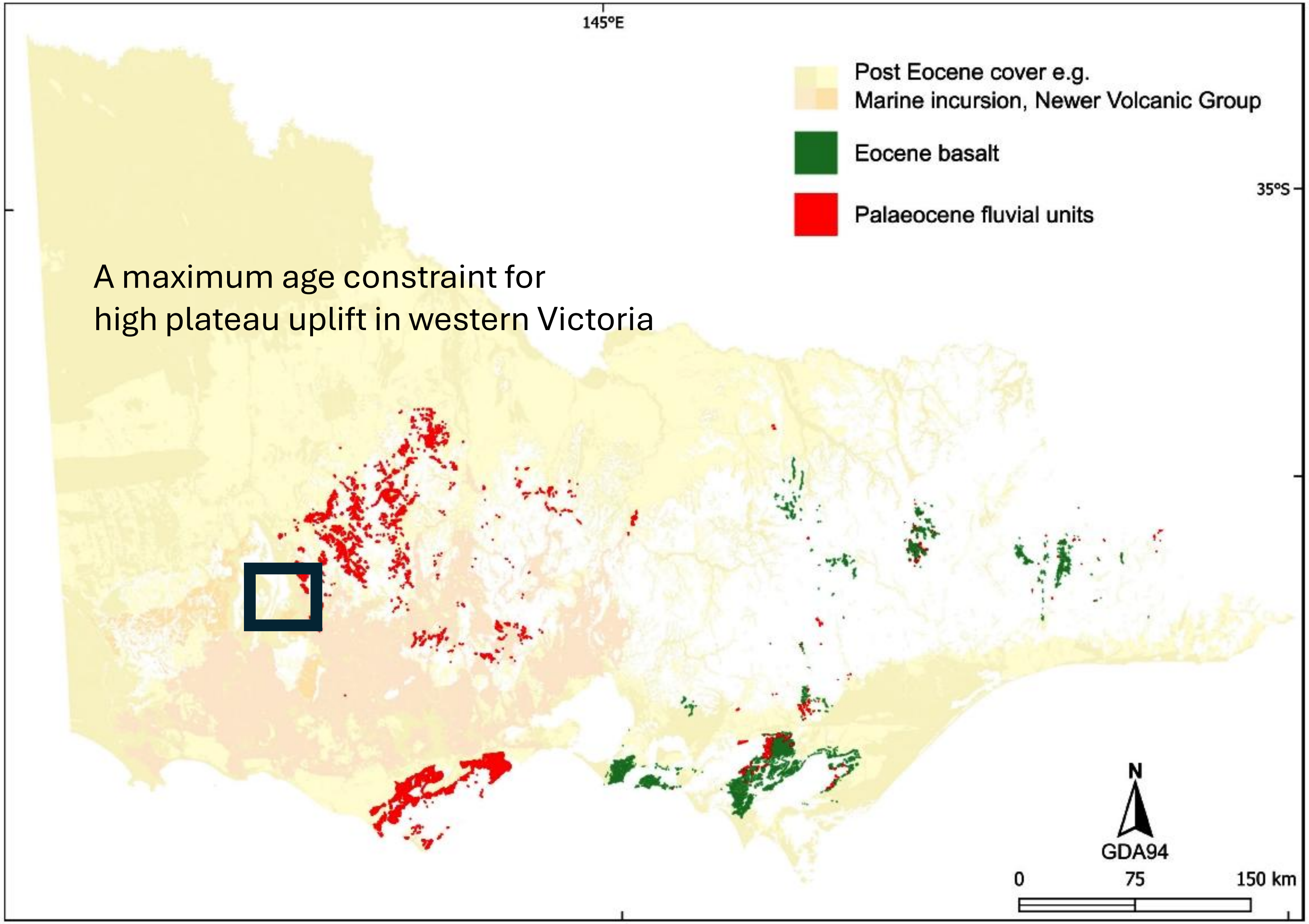
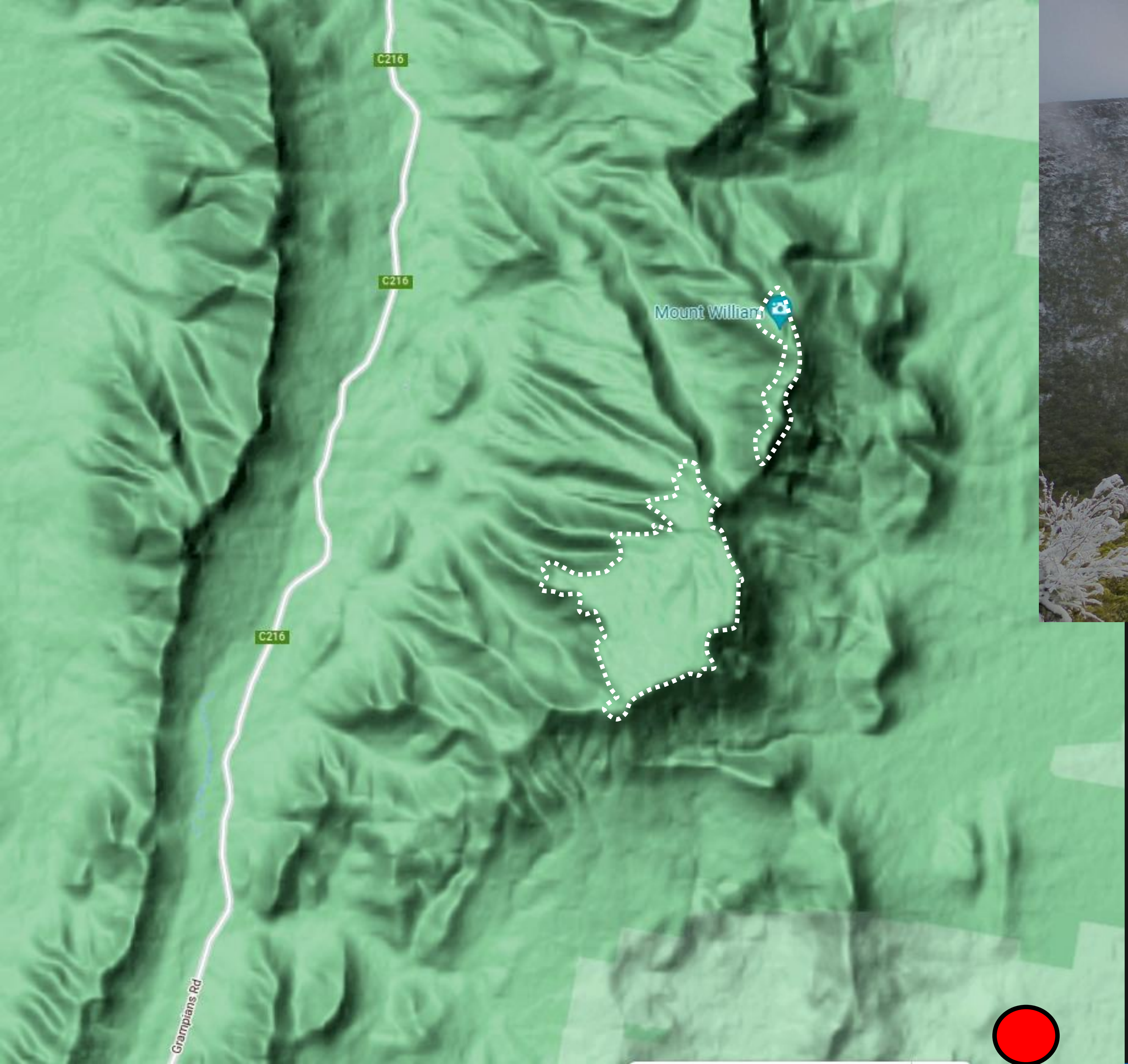


Figure 3.5 Distribution of Palaeocene fluvial, Eocene basalt, and post Eocene units. The Palaeocene fluvial and Eocene basalt deposits are proxies for local preservation of Palaeocene – Eocene thermal maximum regolith, and therefore increased critical minerals in clay prospectivity. Post Eocene units either destroy or overlie Palaeocene – Eocene regolith.

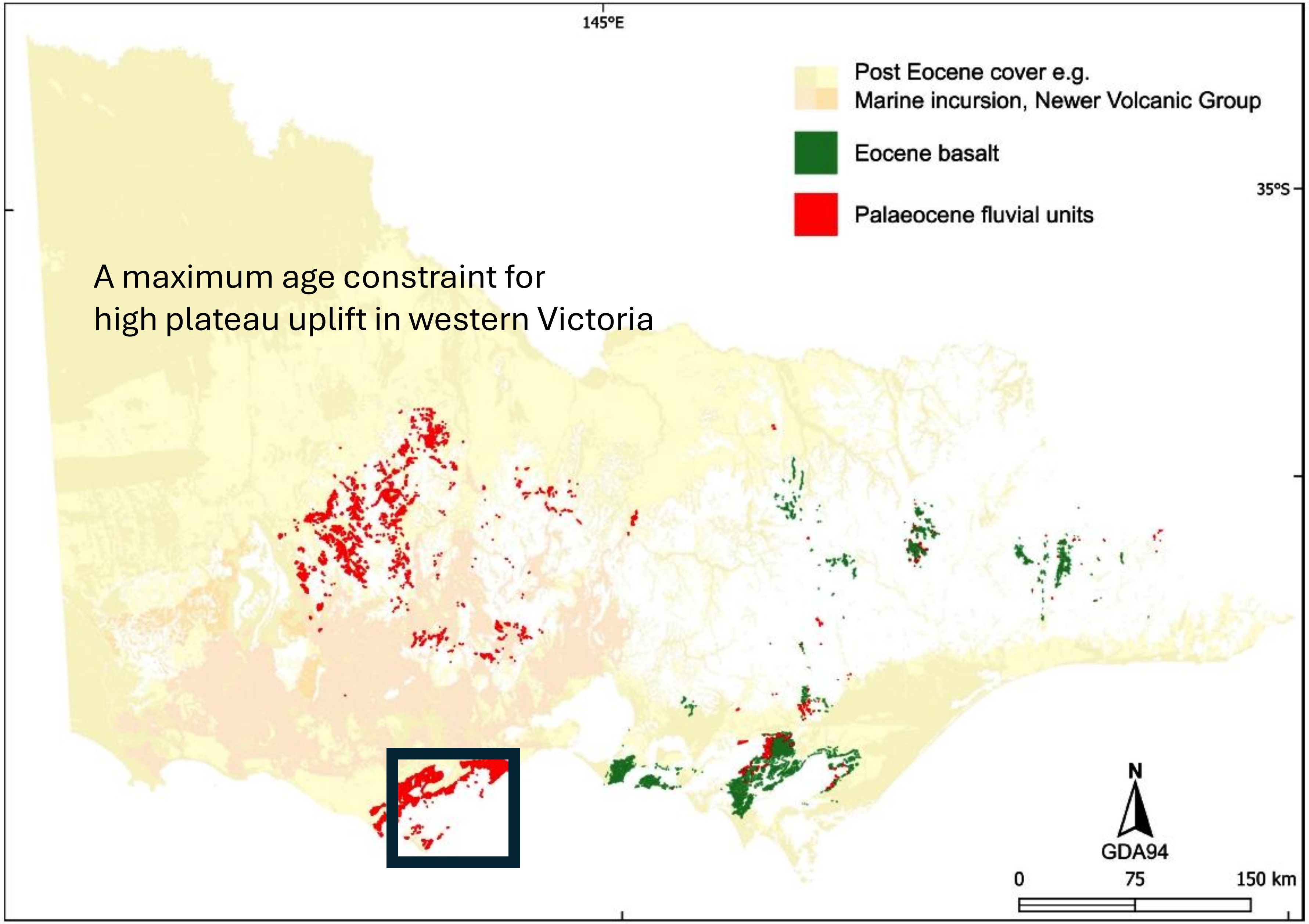


Gariwerd - Major Mitchell Plateau – one of several remnants of the old uplifted land surface deeply dissected prior to the Paleocene and PETM

White Hills Gravel and thick PETM regolith

Deep dissection of the uplifted Mount Cole / Pyrenees / Gariwerd landform is pre- to syn-PETM.

Is there a maximum age constraint for the preceding palaeo-land surface uplift?



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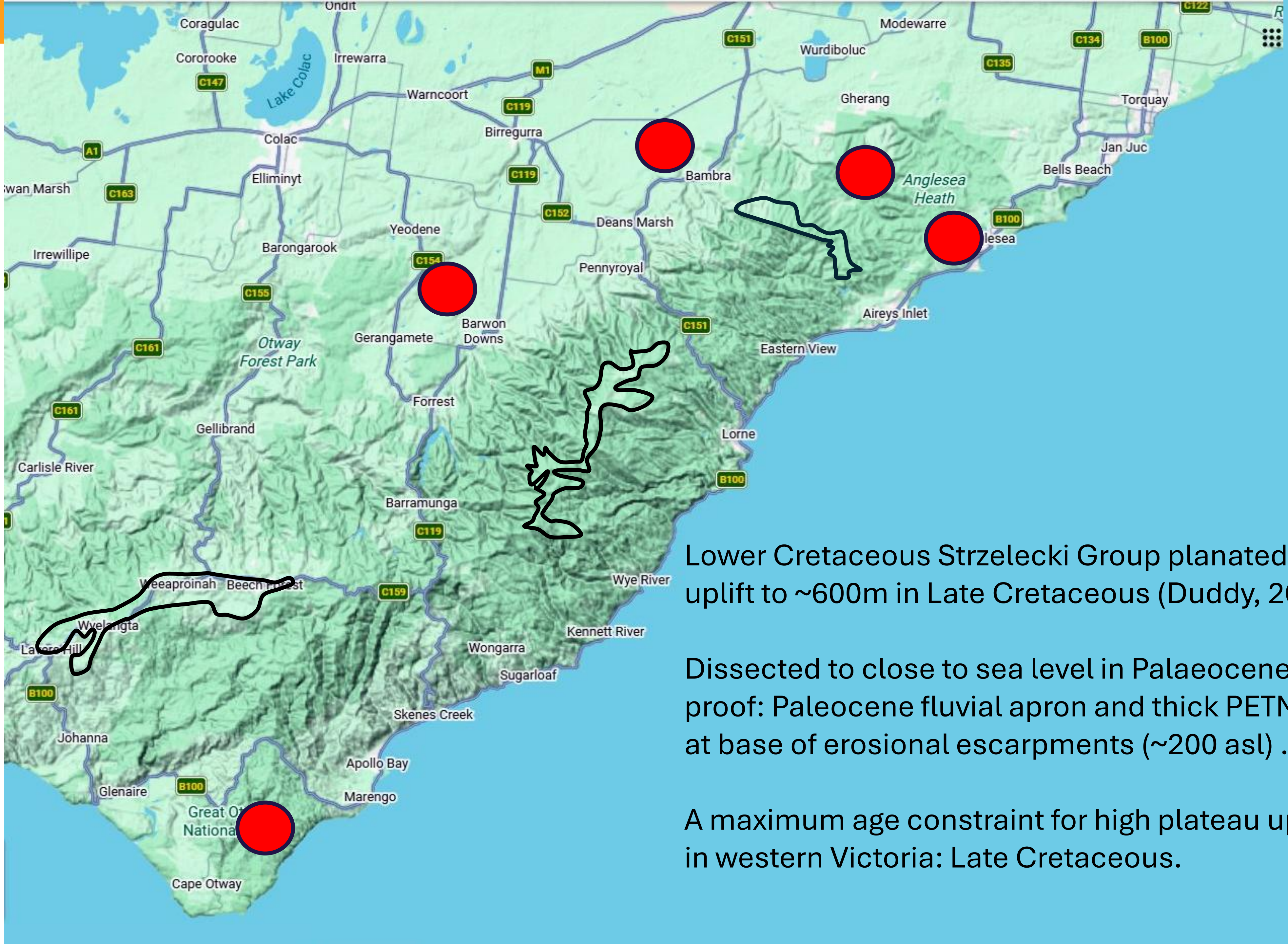
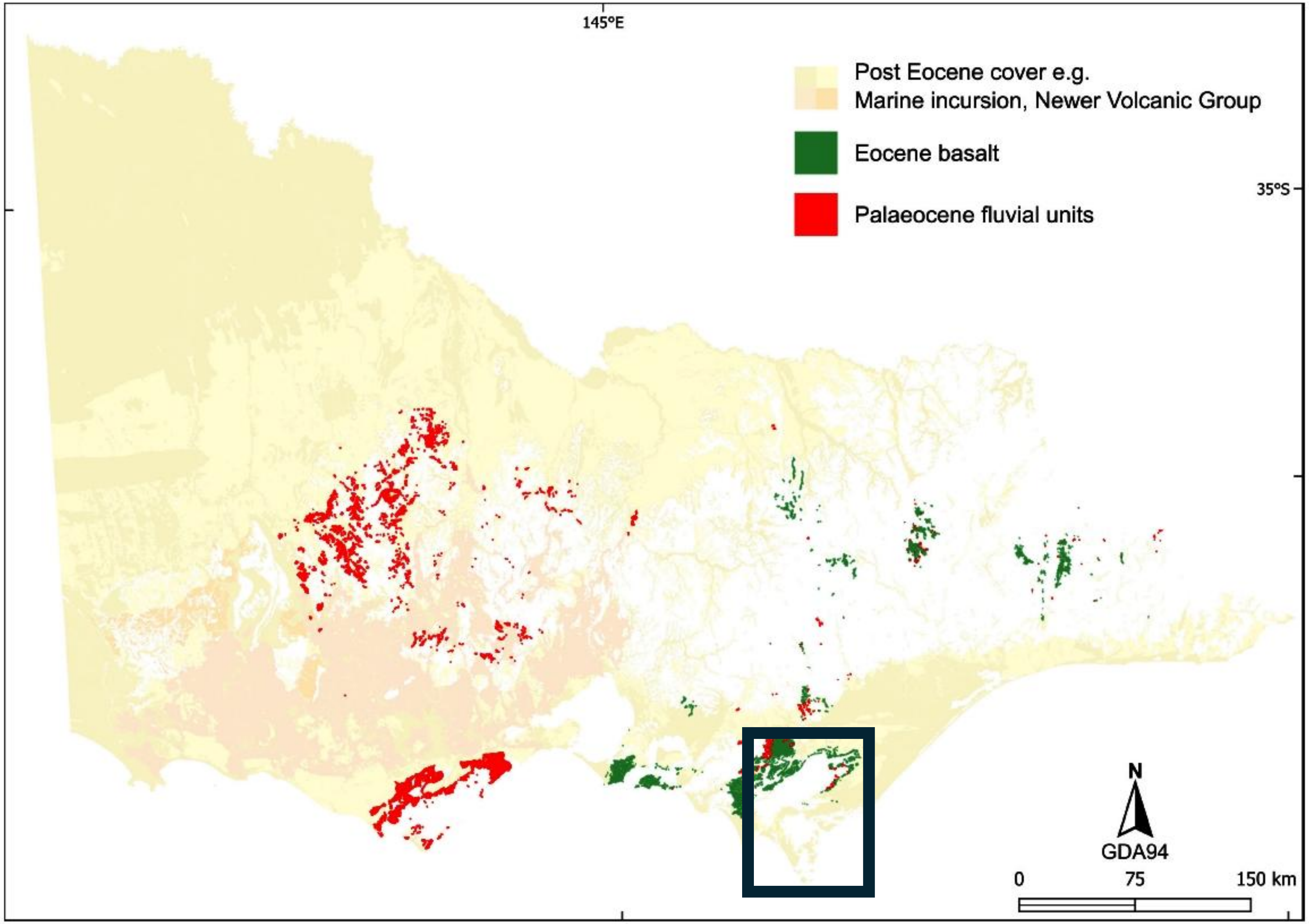


Lower Cretaceous Strzelecki Group planated prior to uplift to ~600m in Late Cretaceous (Duddy, 2003)

Dissected to close to sea level in Palaeocene – proof: Paleocene fluvial apron and thick PETM profiles at base of erosional escarpments (~200 asl) .

A maximum age constraint for high plateau uplift in western Victoria: Late Cretaceous.



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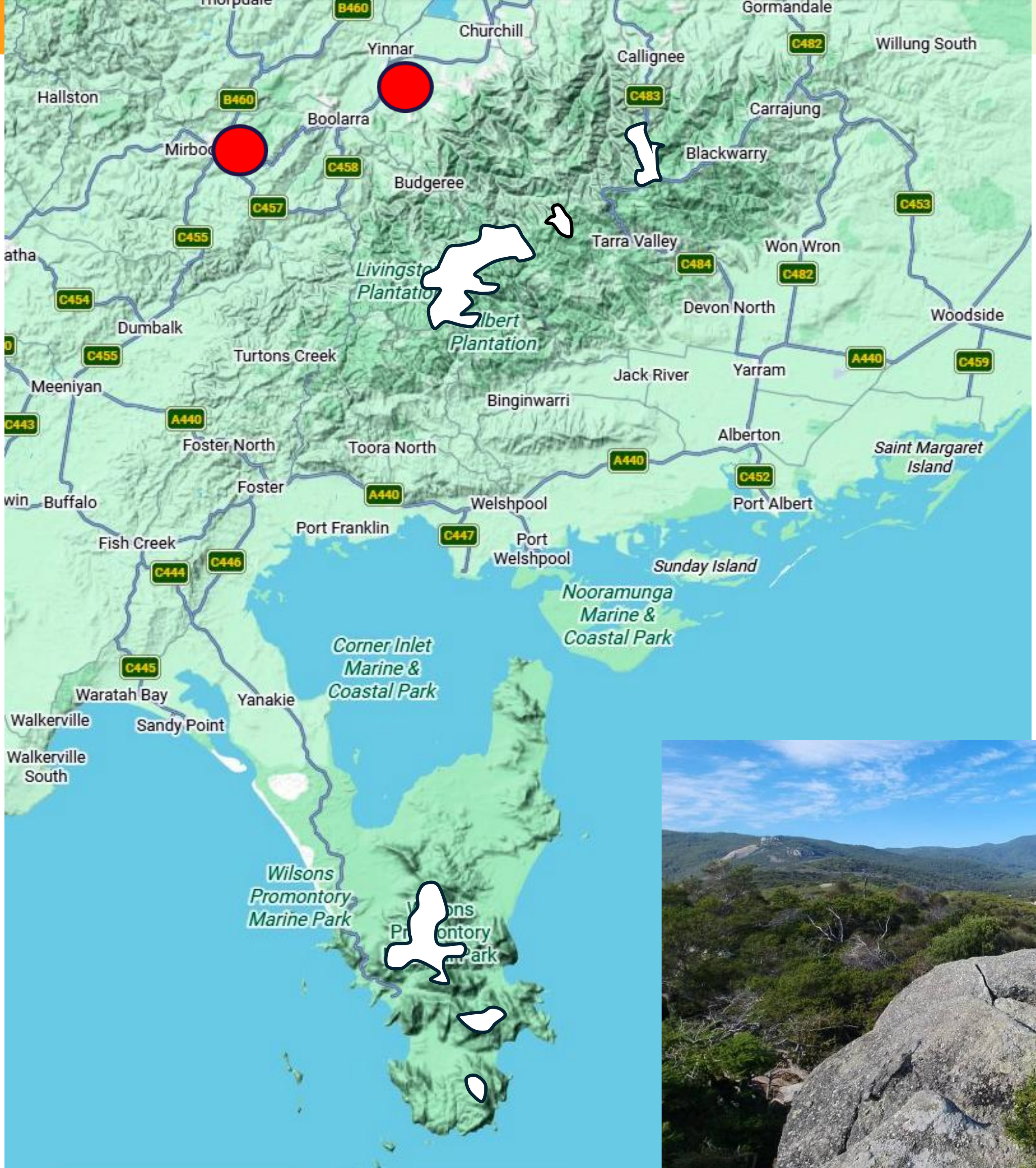

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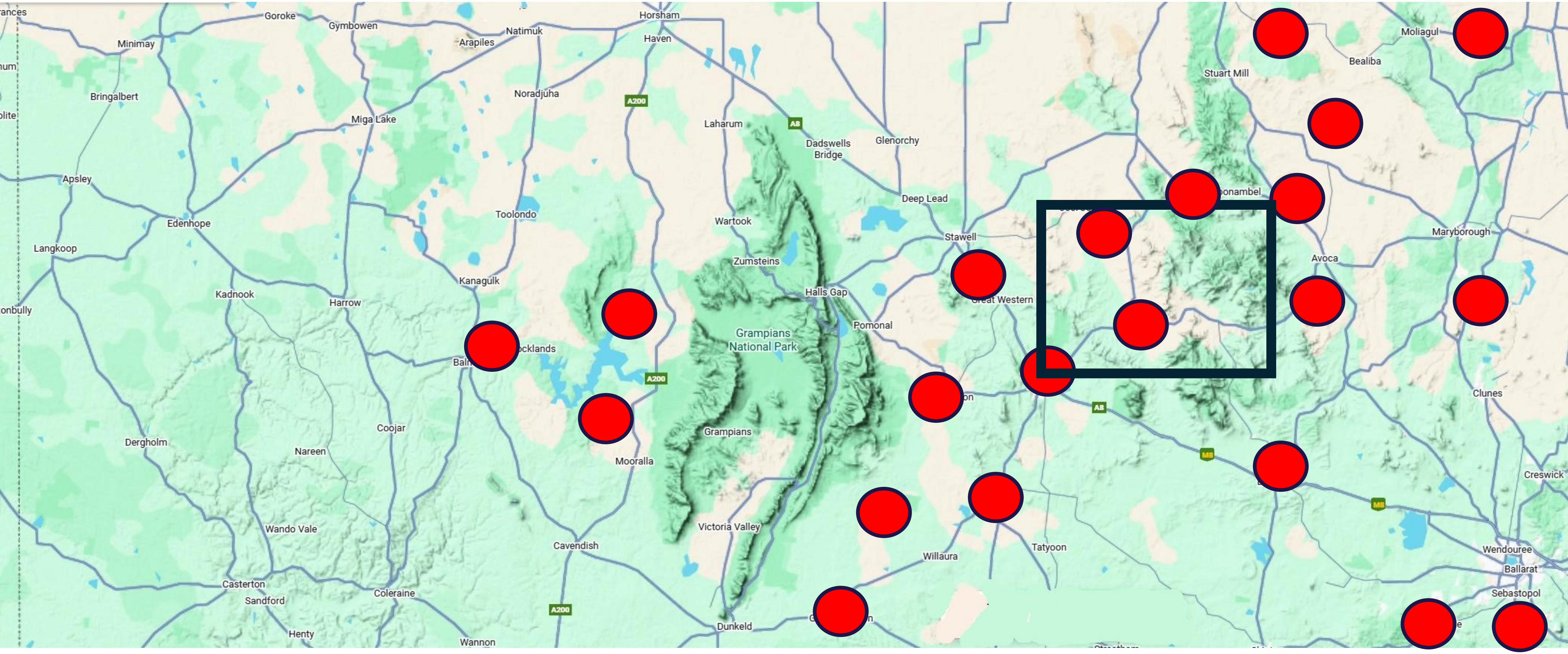
Dissected to close to sea level in Palaeocene – proof: Paleocene fluvial apron and thick PETM profiles at base of erosional escarpments (now at ~200 asl) .

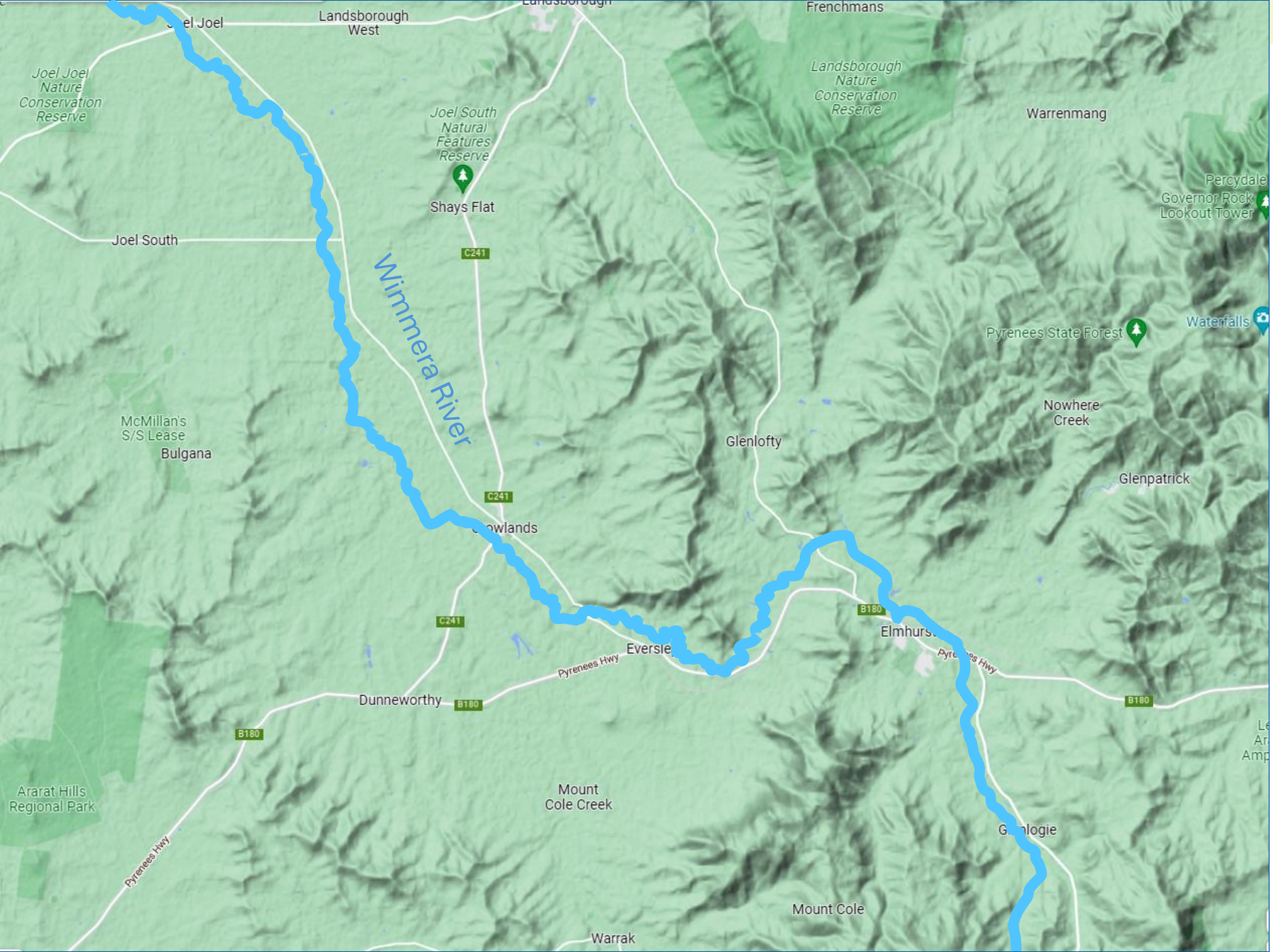
A maximum age constraint for high plateau uplift in southeastern Victoria: Late Cretaceous.

A minimum age constraint for high plateau uplift and deep dissection in southeastern Victoria: Palaeocene (pre-PETM).

SAME AS WESTERN VICTORIA



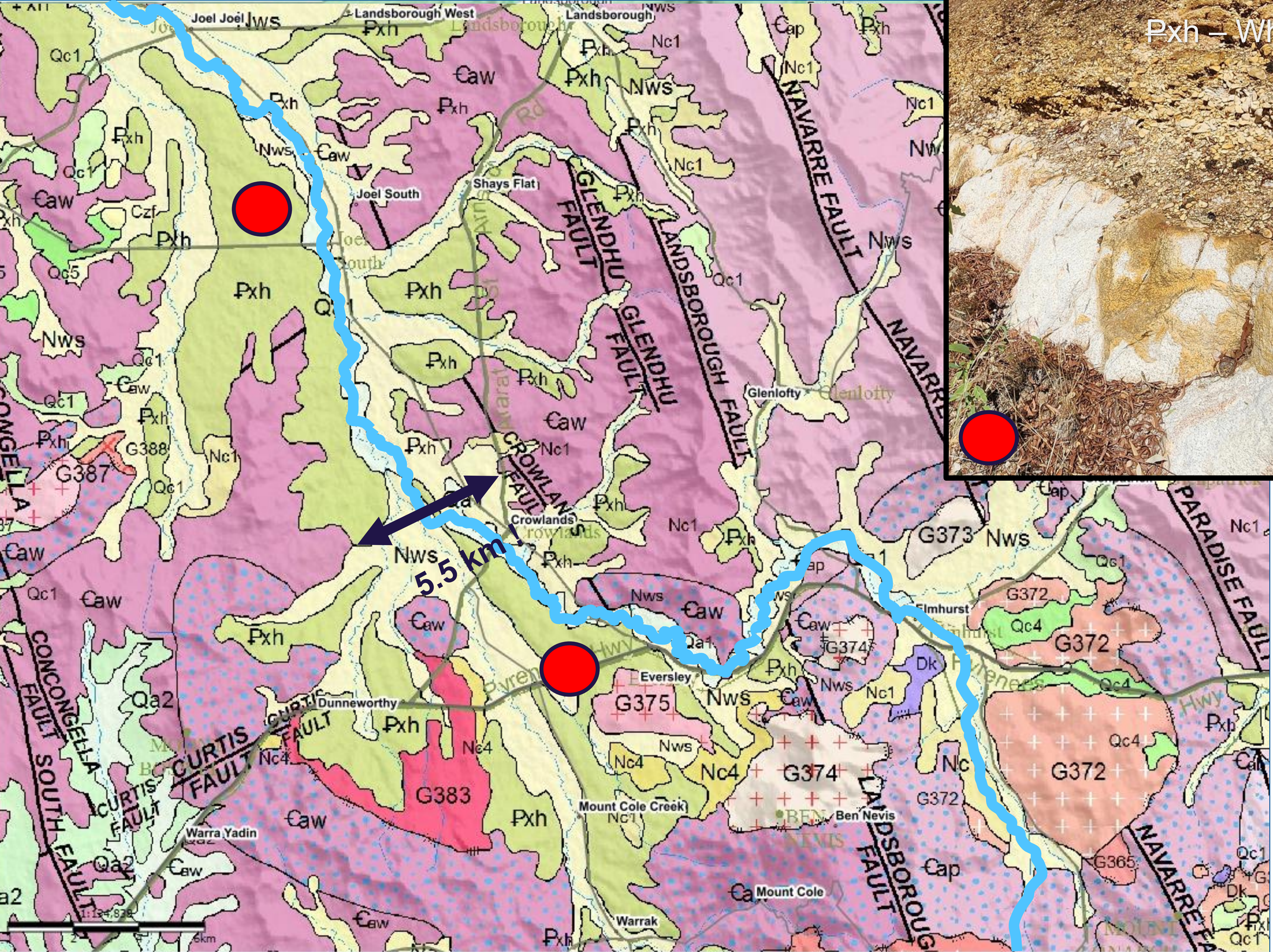
Paleocene fluvial 'White Hills Gravel' overprinted in-situ by deep PETM regolith



Modern Wimmera River:

tiny, ephemeral.

massively underfit in its valley



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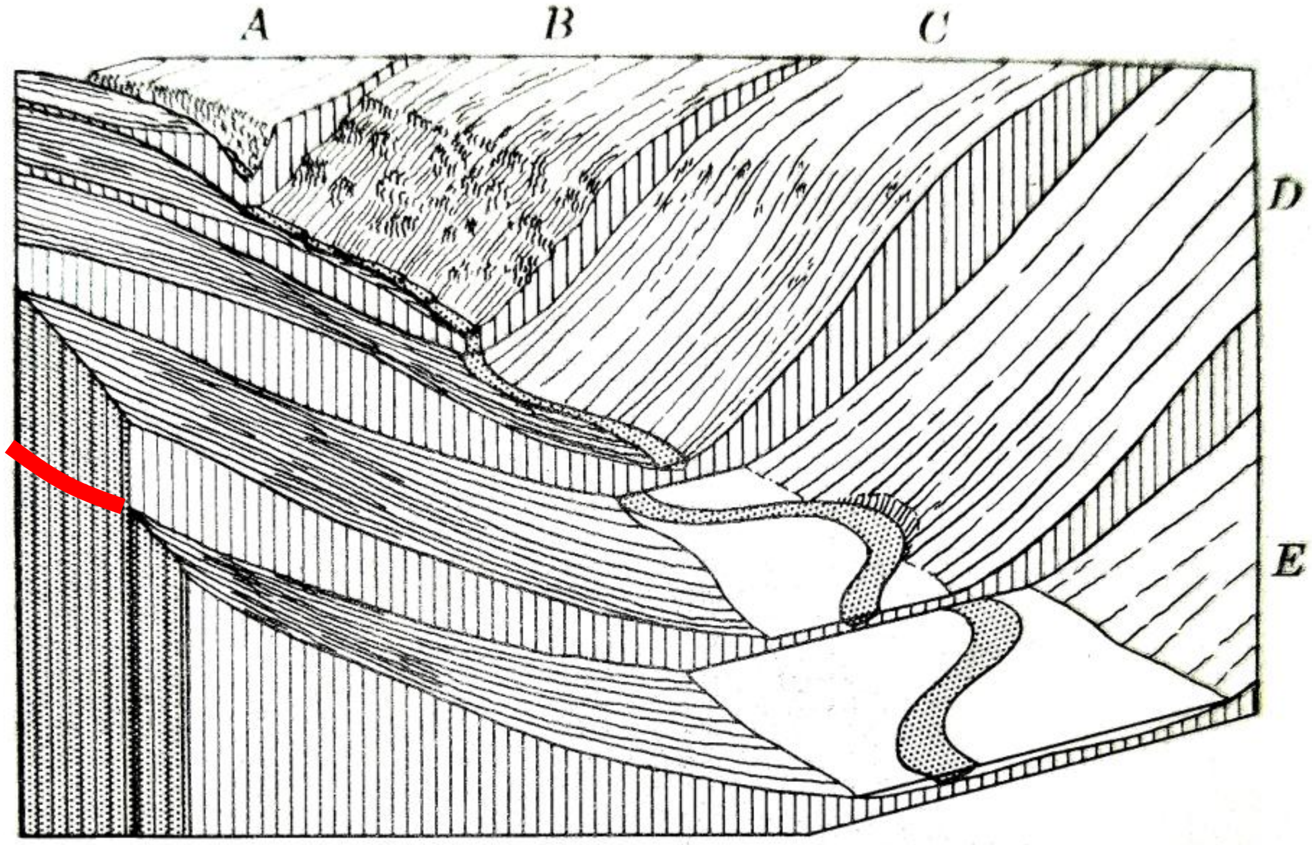
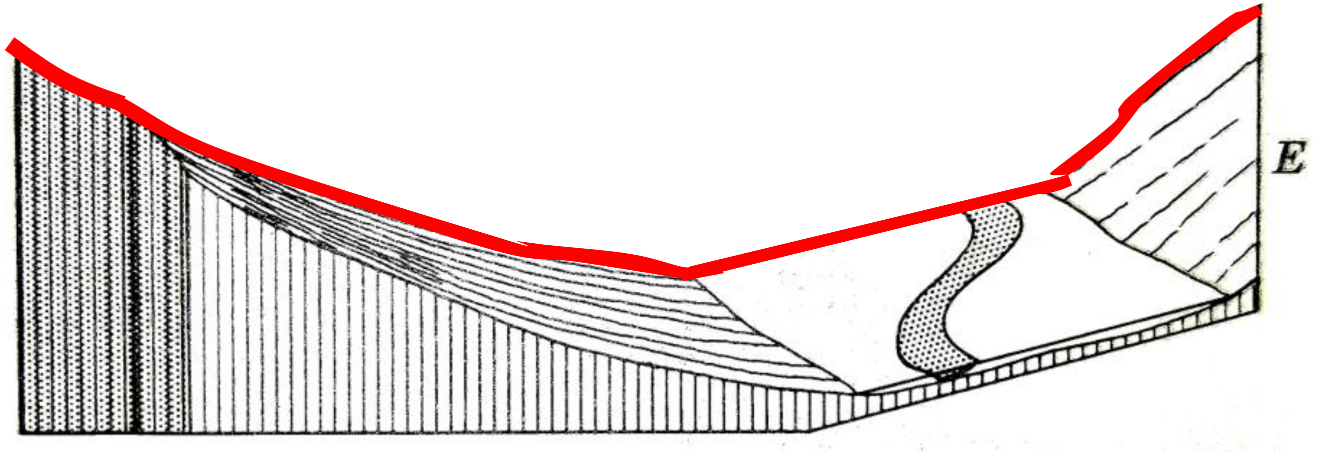
Strahler, 1951: Degrees of alluvial valley maturity:



Strahler, 1951: Degrees of alluvial valley maturity:

Western Victoria Paleocene valley systems: super-mature –
Broad, multi-kilometre-scale, braid-plain valley floors, separating wide inselberg-type mountain remnants



Waimakariri River, South Island, New Zealand

Conclusions:

western Victoria was WET in the Paleocene!

Erosion of the uplifted high plateau was rapid and aggressive.

Paleocene rivers were wide and highly energetic and eroded broad, mature braidplain valleys.

The modern rivers are all underfit.

Plateau erosion has barely advanced since the Eocene.

Why and how did this change?

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The Victorian Alps are different: pre-Palaeocene uplift, but little Paleocene erosion

‘Lateral stream’ Formation:

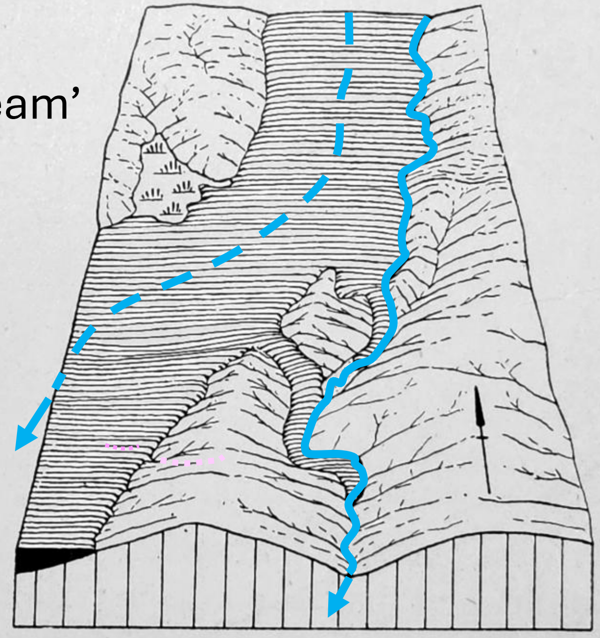
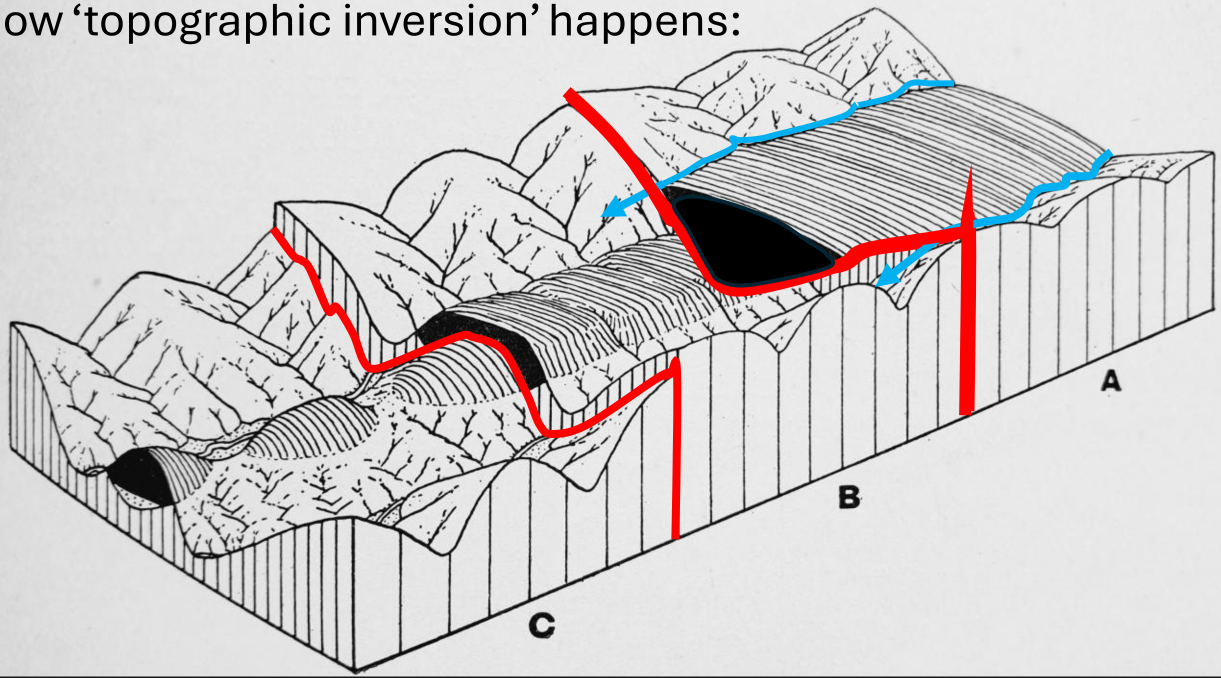
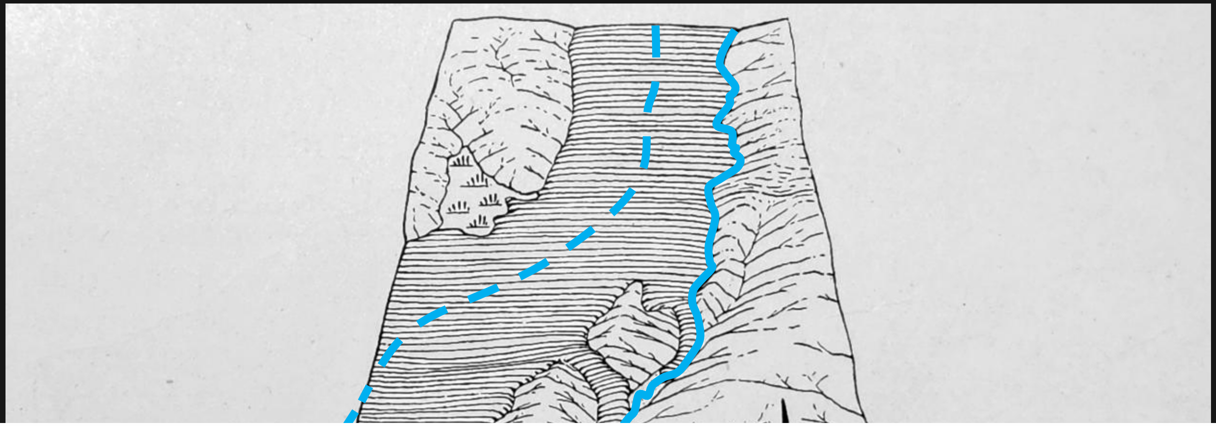
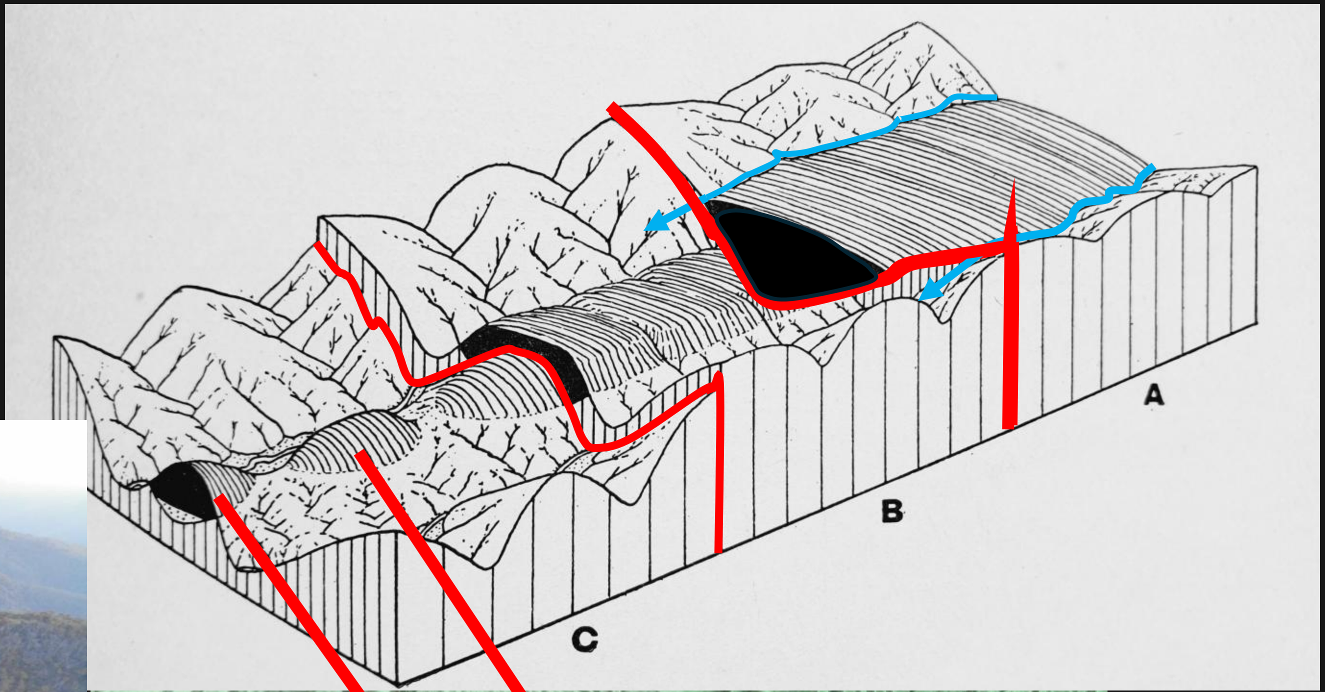


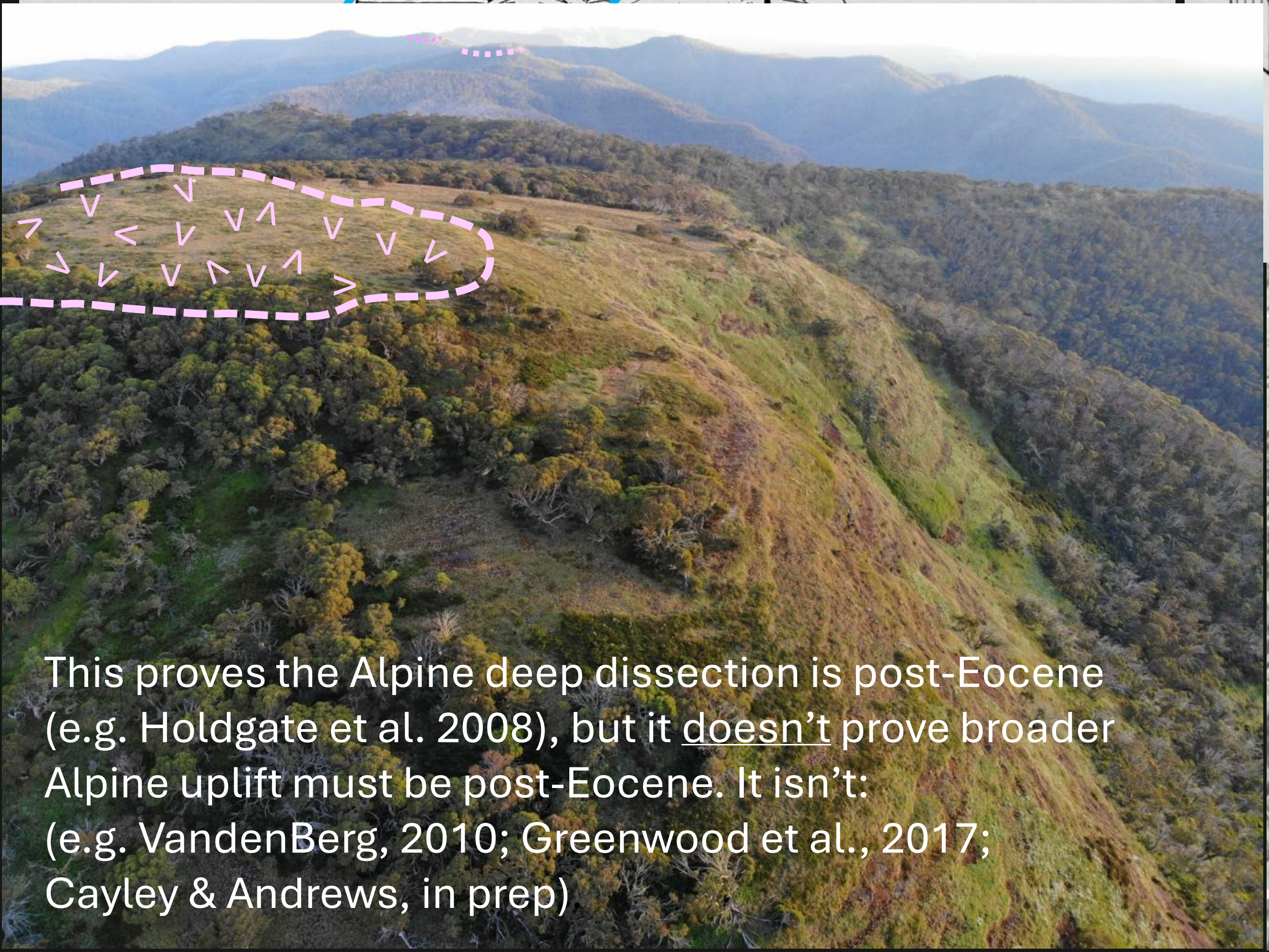
Fig. 259—Block diagram showing the diversion of the Plenty River from its lava-filled valley, at South Morang. [*After Jutson*

How ‘topographic inversion’ happens:

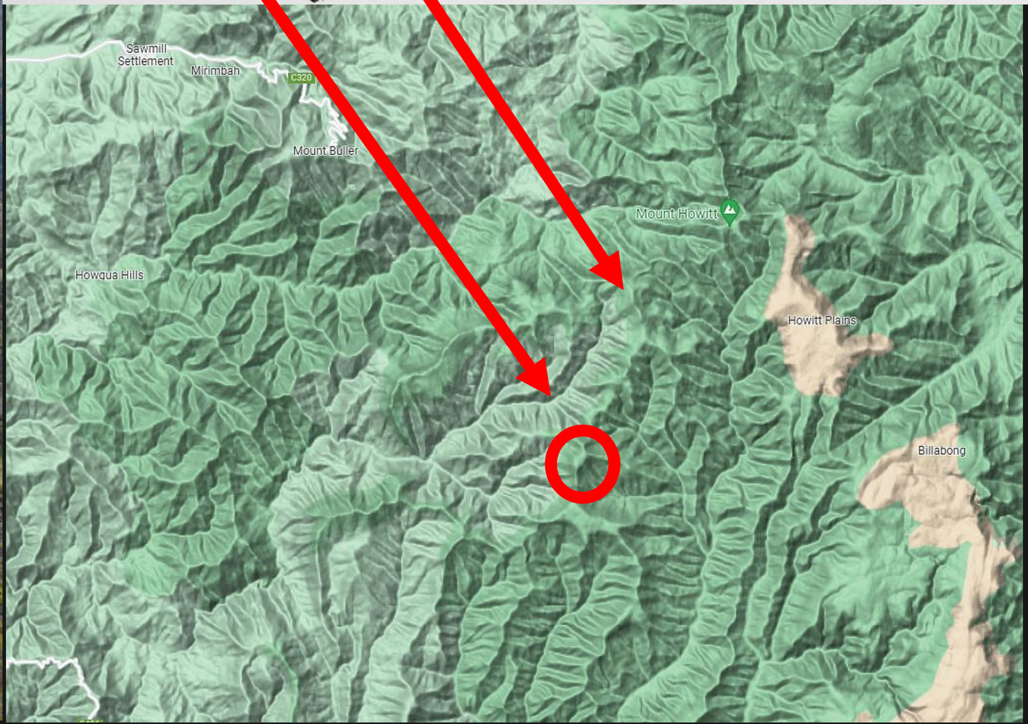




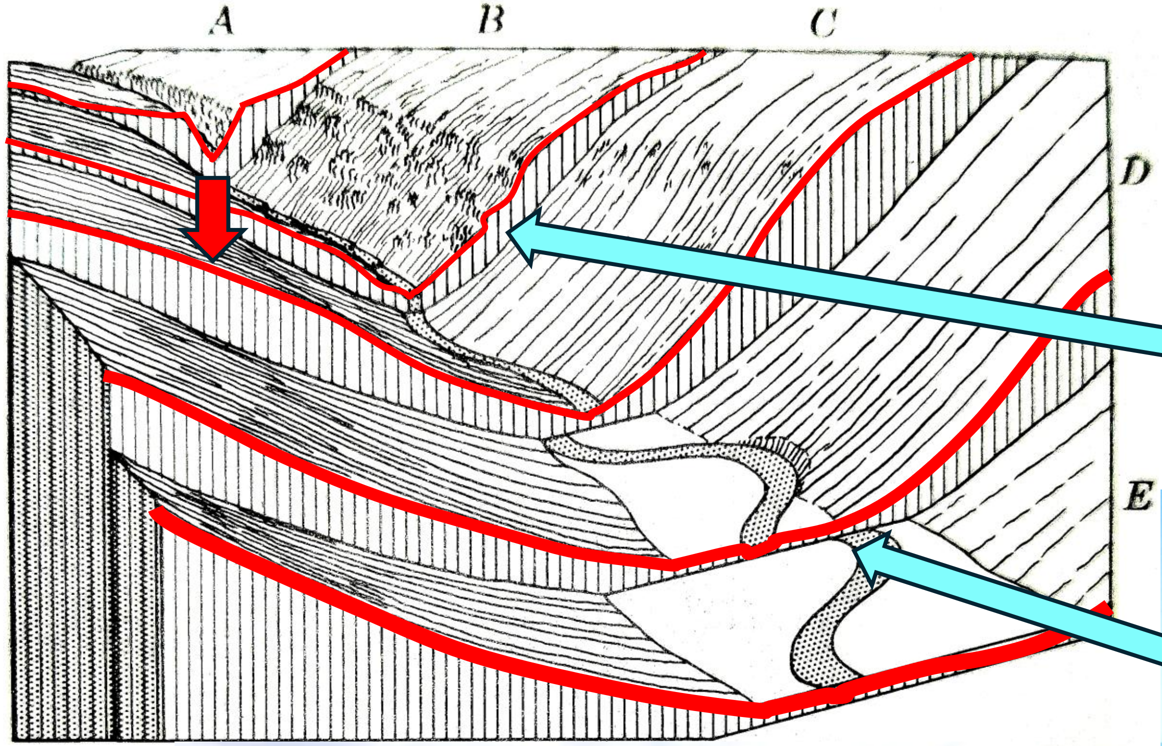




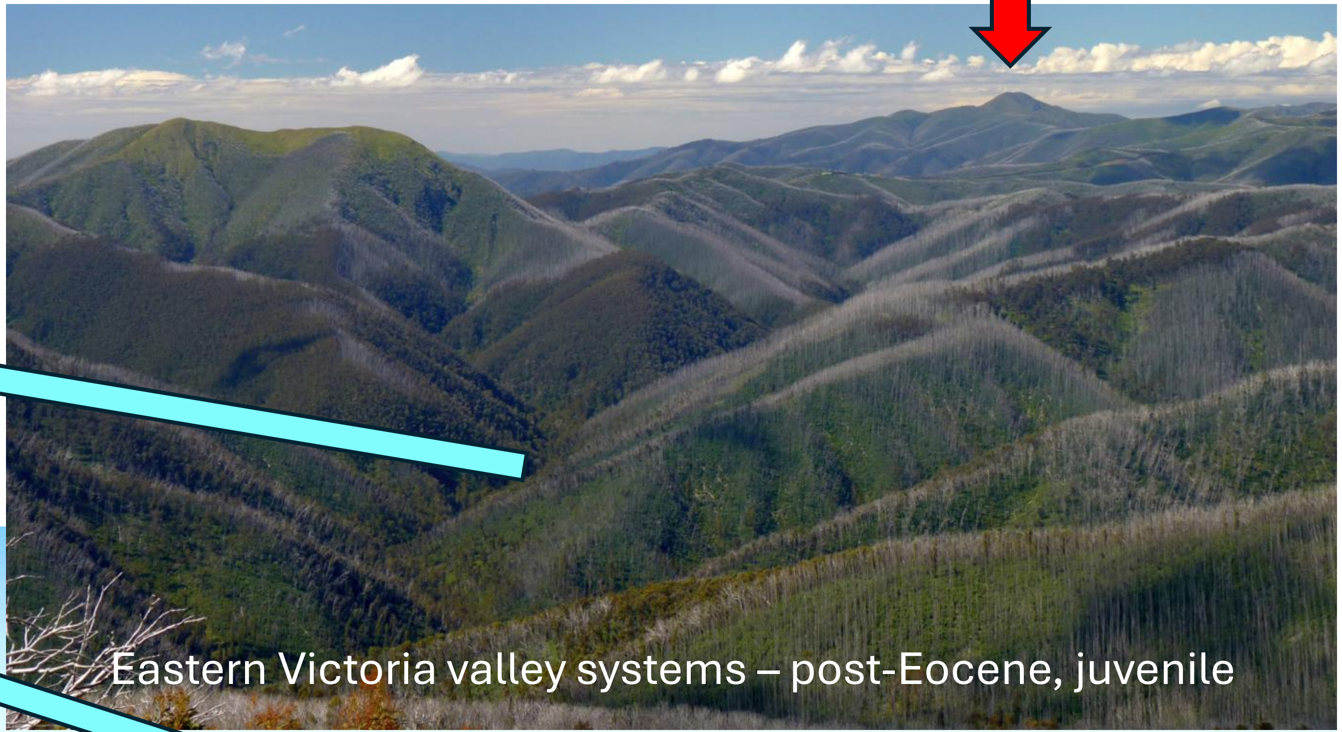
This proves the Alpine deep dissection is post-Eocene (e.g. Holdgate et al. 2008), but it <u>doesn't</u> prove broader Alpine uplift must be post-Eocene. It isn't: (e.g. VandenBerg, 2010; Greenwood et al., 2017; Cayley & Andrews, in prep)

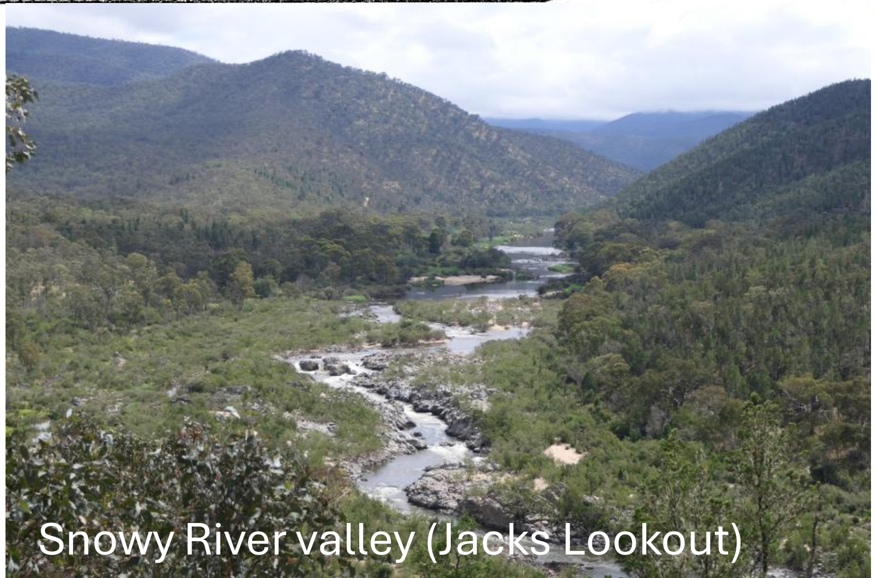


Strahler, 1951



Mount Feathertop





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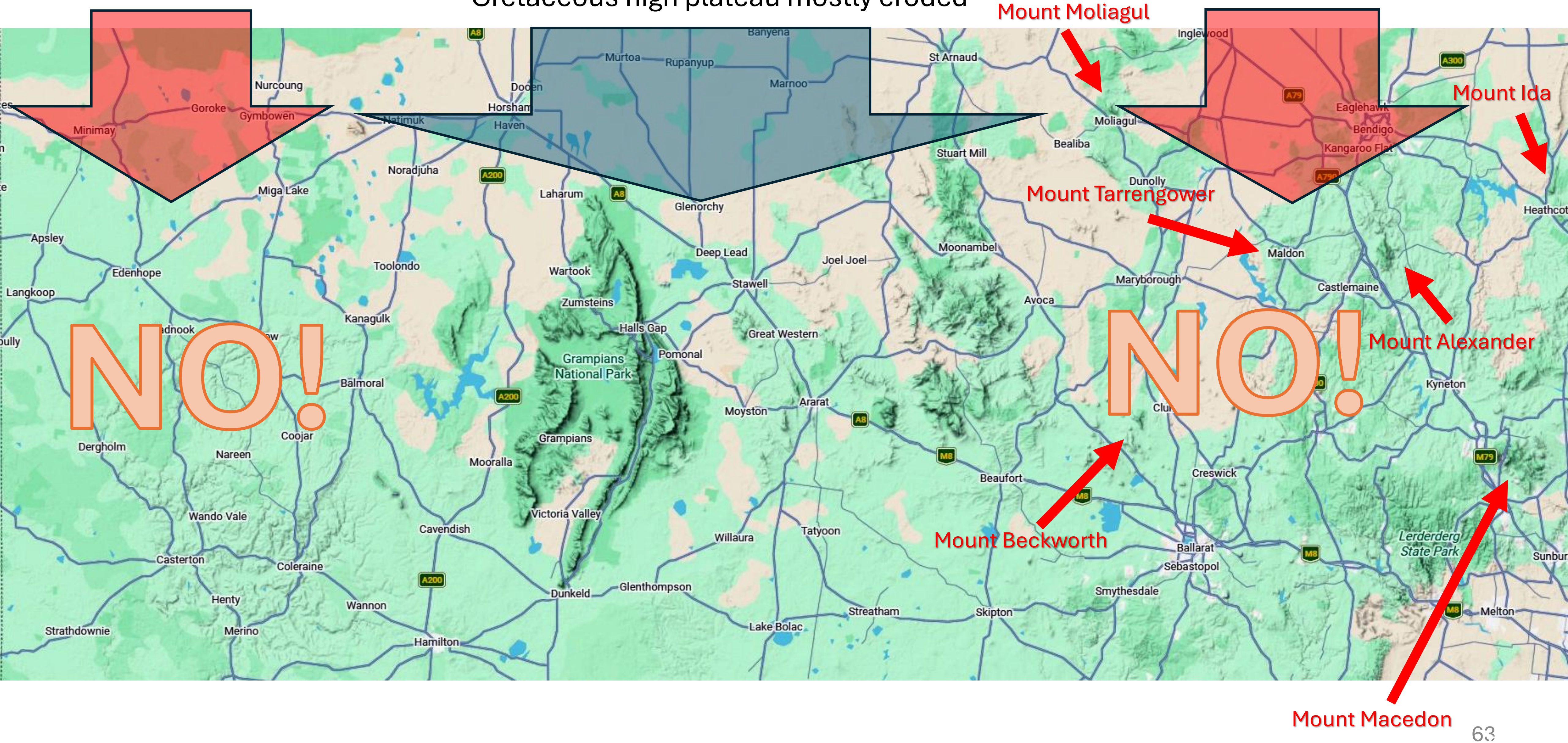
- and – Permian glacial landscapes are everywhere!
- Creating a new Permian – Recent narrative for Victorian landscape evolution.

Cretaceous high plateau entirely eroded?

Cretaceous high plateau mostly eroded

Cretaceous high plateau entirely eroded?



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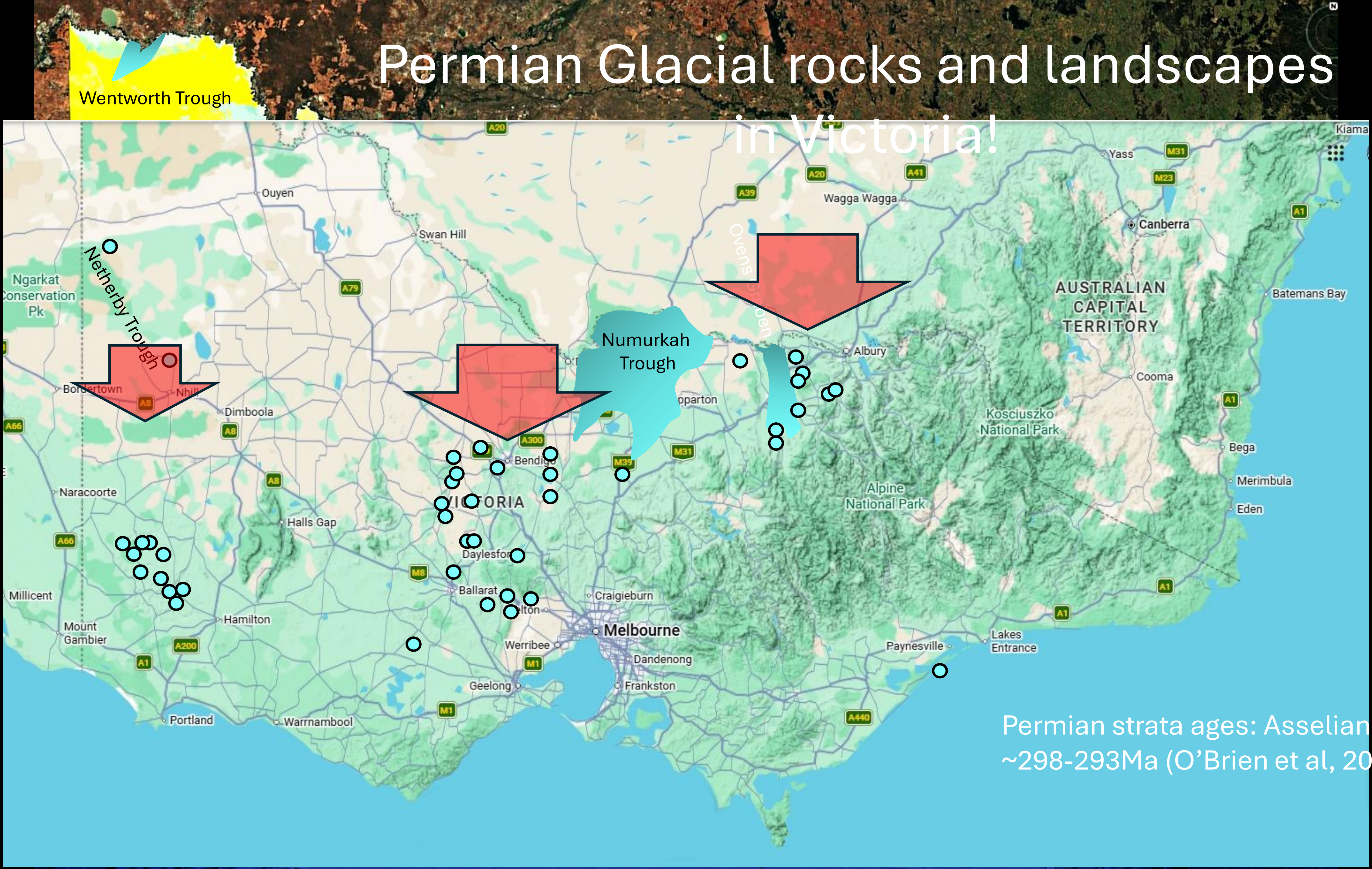
Permian Glacial rocks and landscapes in Victoria!

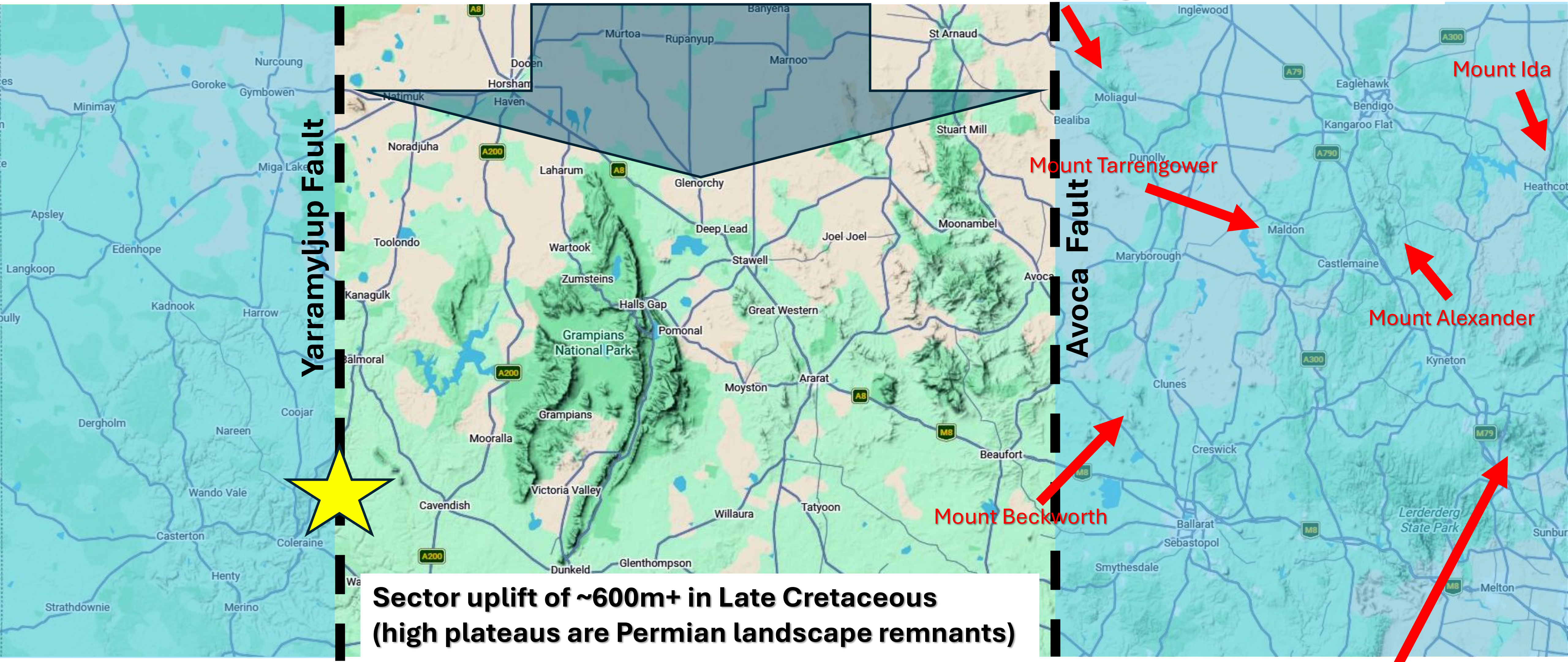


Permian strata ages: Asselian ~298-293Ma (O'Brien et al, 2003)

No Cretaceous uplift
Limited erosion of
a Permian landscape

Cretaceous high plateau mostly eroded

No Cretaceous uplift
Limited erosion of
a Permian landscape



Sector uplift of ~600m+ in Late Cretaceous
(high plateaus are Permian landscape remnants)

Log Hut Creek,
Glenelg Zone
Morand et al., 2003

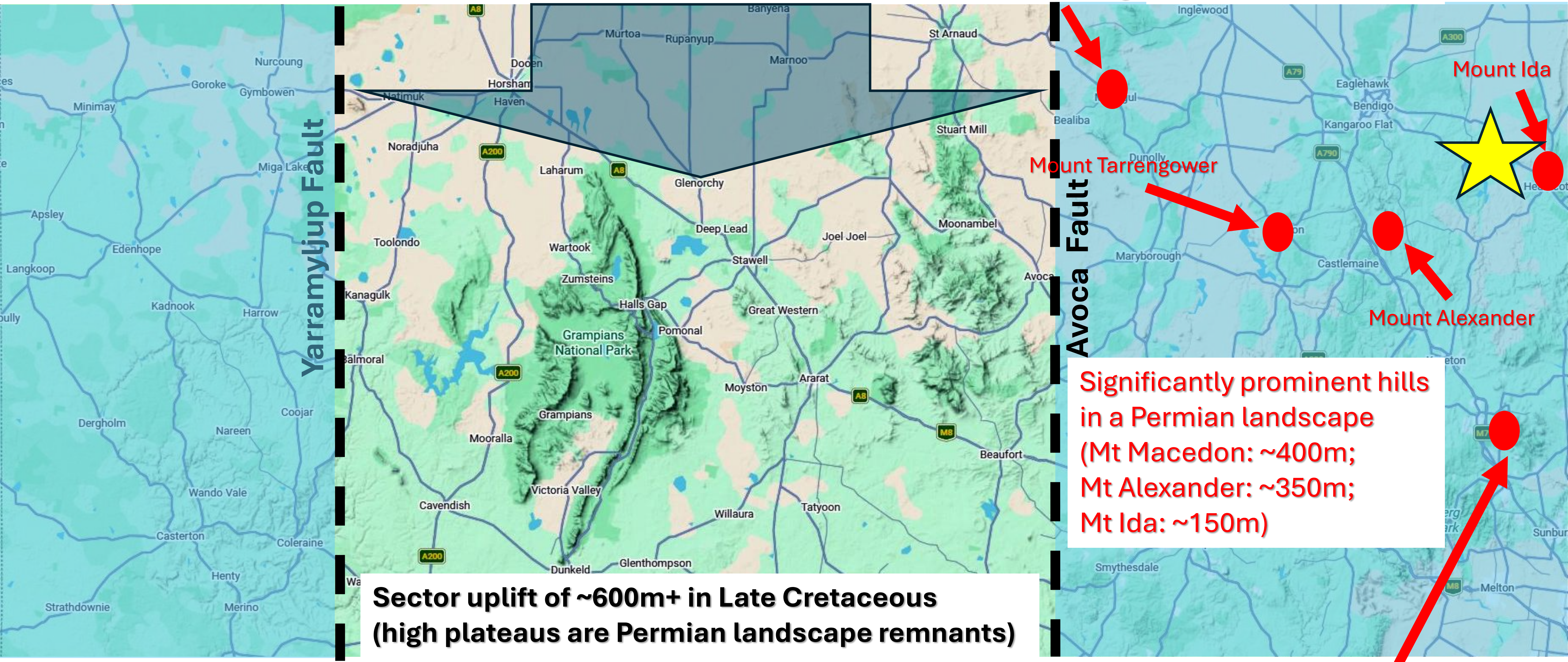
‘Dropstones’ into blue mud varves
(proof of icebergs shedding into still water)

Wennicott Creek,
Glenelg Zone
Morand et al., 2003

No Cretaceous uplift
Limited erosion of
a Permian landscape

Cretaceous high plateau mostly eroded

No Cretaceous uplift
Limited erosion of
a Permian landscape

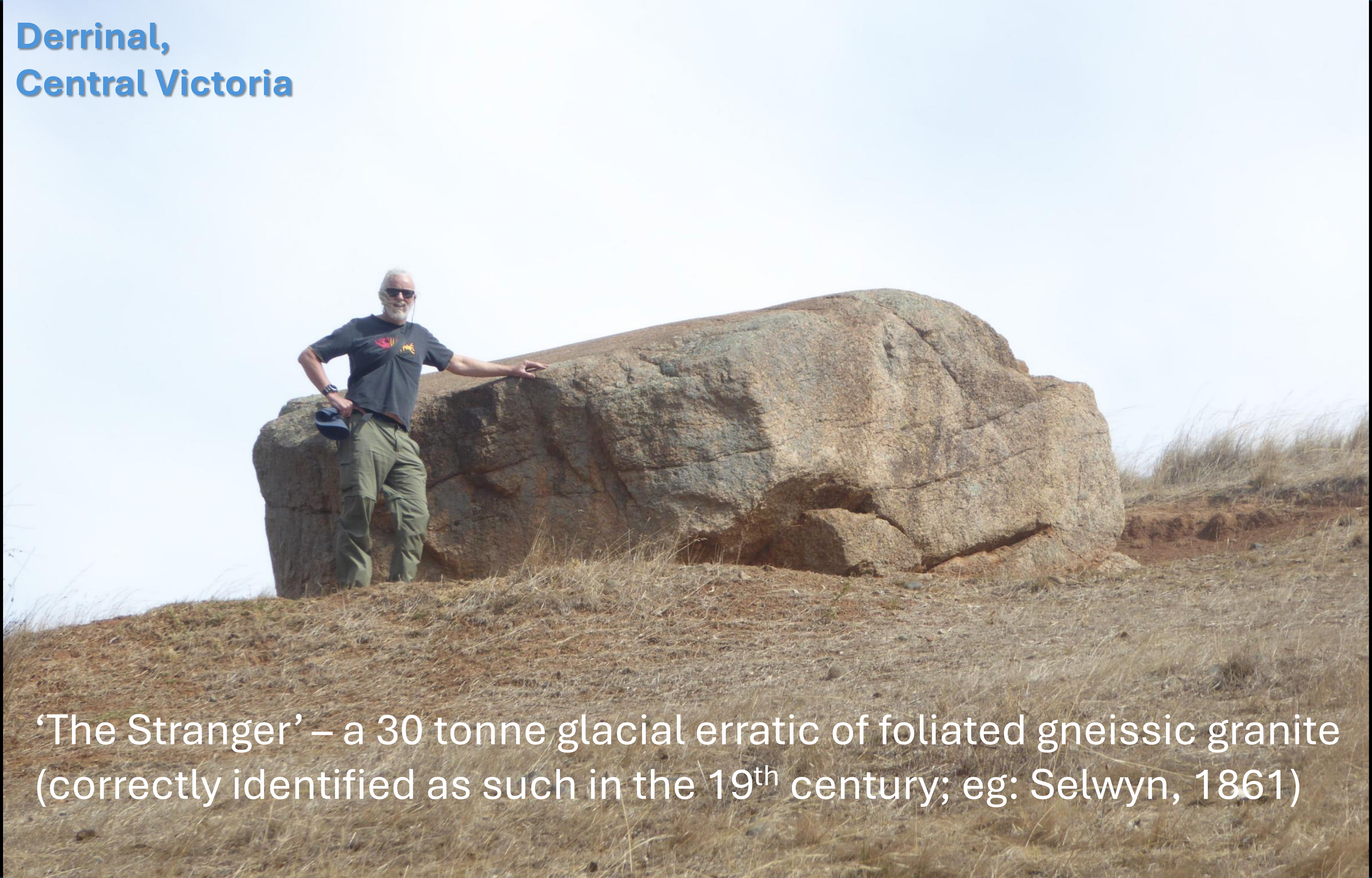


Derrinal, Central Victoria

Faceted and striated pebbles of diverse lithology - diagnostic of glacial deposits


Derrinal / Eppalock

Derrinal, Central Victoria



‘The Stranger’ – a 30 tonne glacial erratic of foliated gneissic granite (correctly identified as such in the 19th century; eg: Selwyn, 1861)


the glacial erratic is faceted and striated

Kellam's Rock – a polished glacial pavement carved in Ordovician bedrock

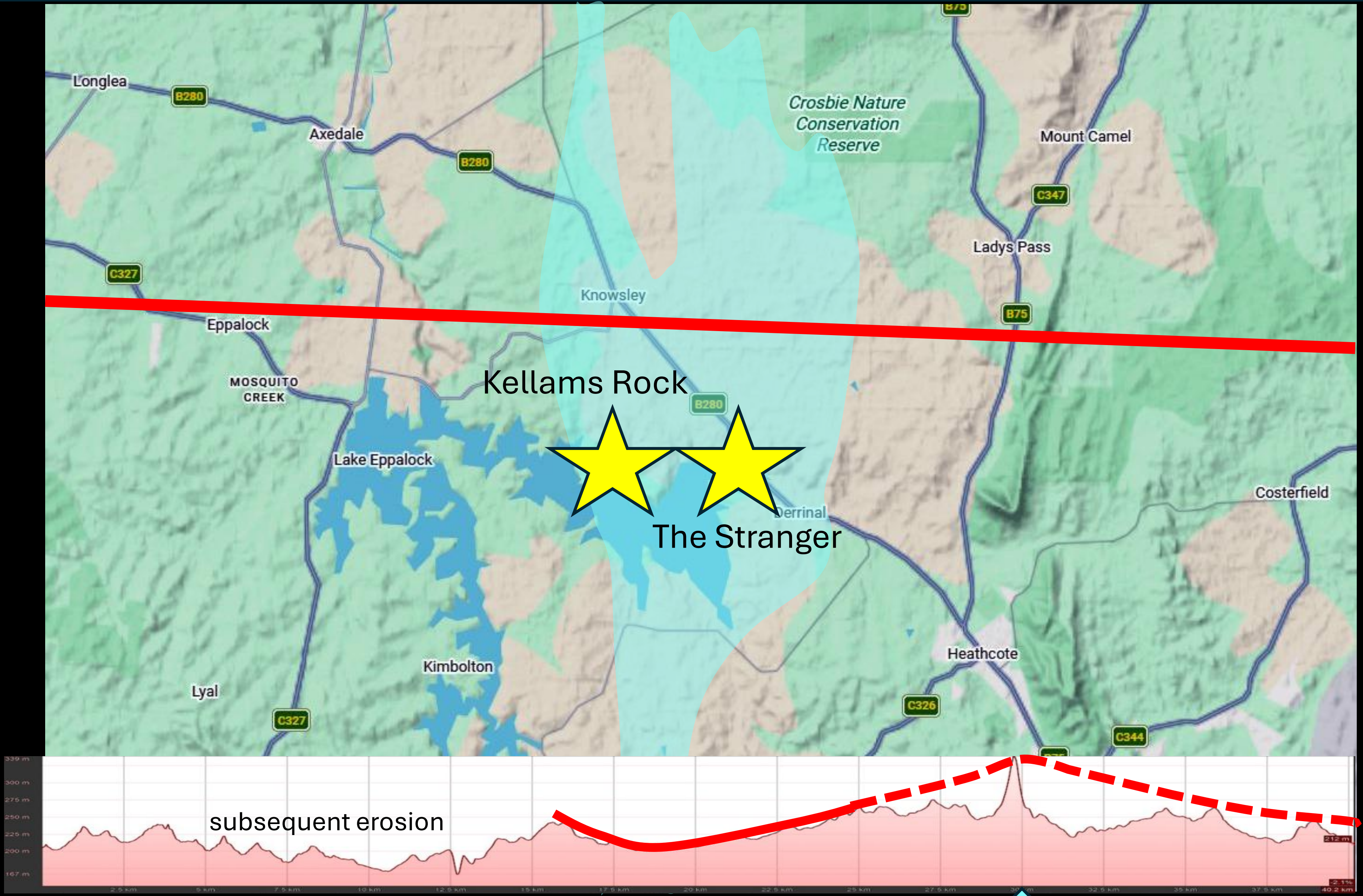
Derrinal,
Central Victoria

Correctly identified as a glacially excavated valley by David (1895)

Length of ice transport paths and aggressive nature of bedrock gouging Statewide require ice thicknesses in excess of 1 km (but not Polar scale).

It was a continental –scale ice sheet (e.g. O’Brien et al., 2003).

Analogues: Pleistocene northern Canada and Scandinavia

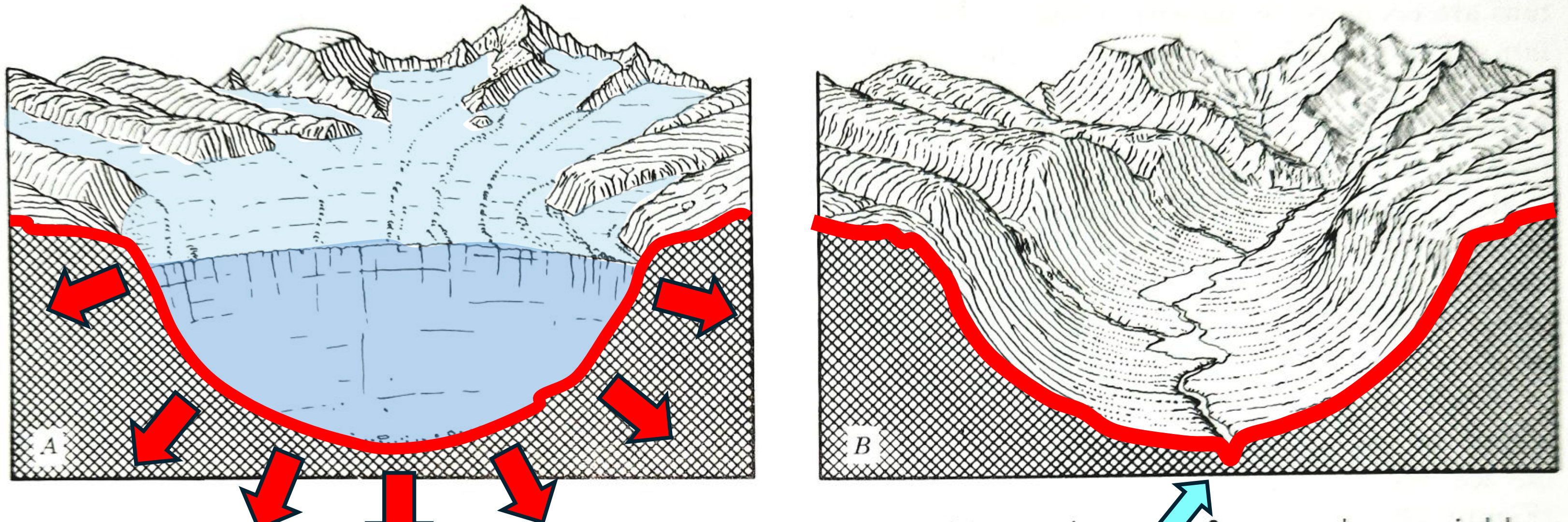


Permian glacials in boreholes east of range

Broad, U-shaped glacial valley with in-situ tillite

Similar U-shaped profiles across Permian-filled valleys at Tylden, and at Clunes (Loddon / Chalks Lead)

Permian subglacial ridge, modified by subsequent (Palaeocene) erosion

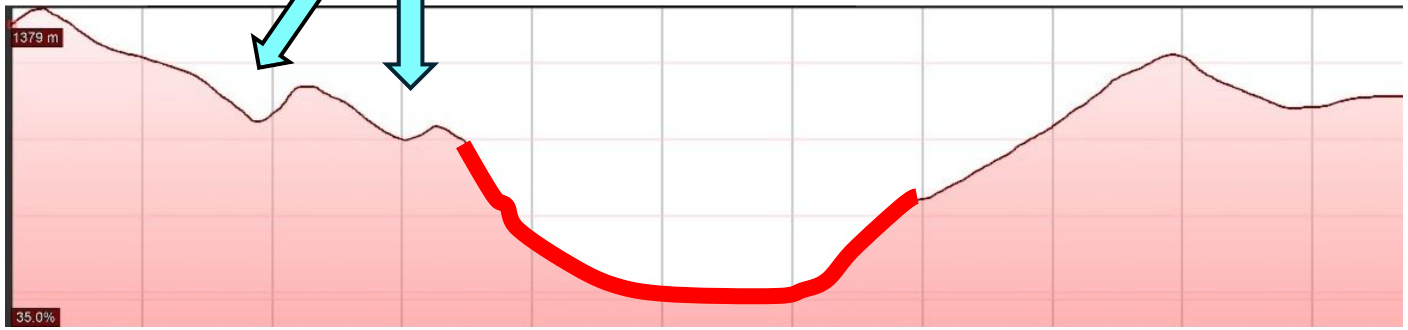


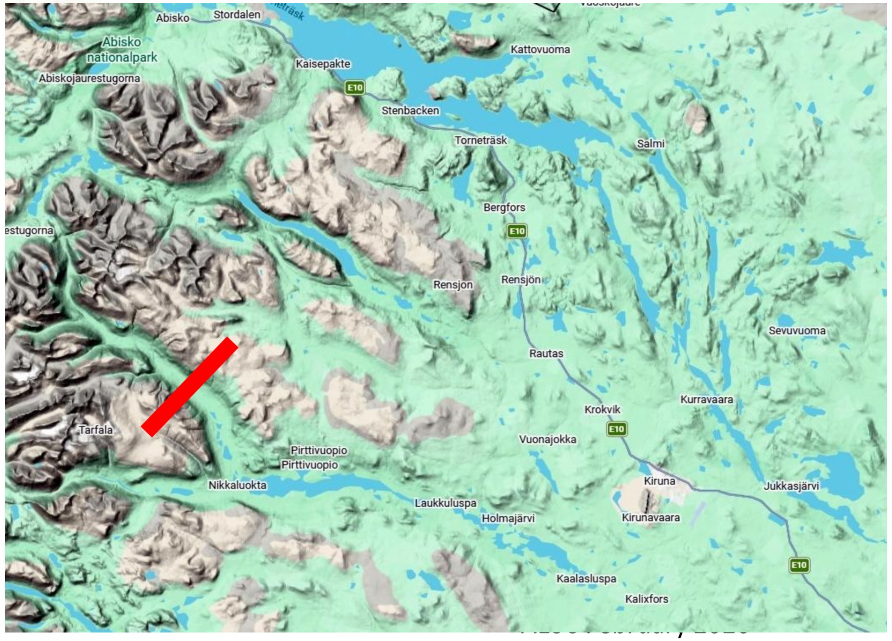
A. During maximum glaciation the U-shaped trough is filled by ice to the level of the small tributaries.

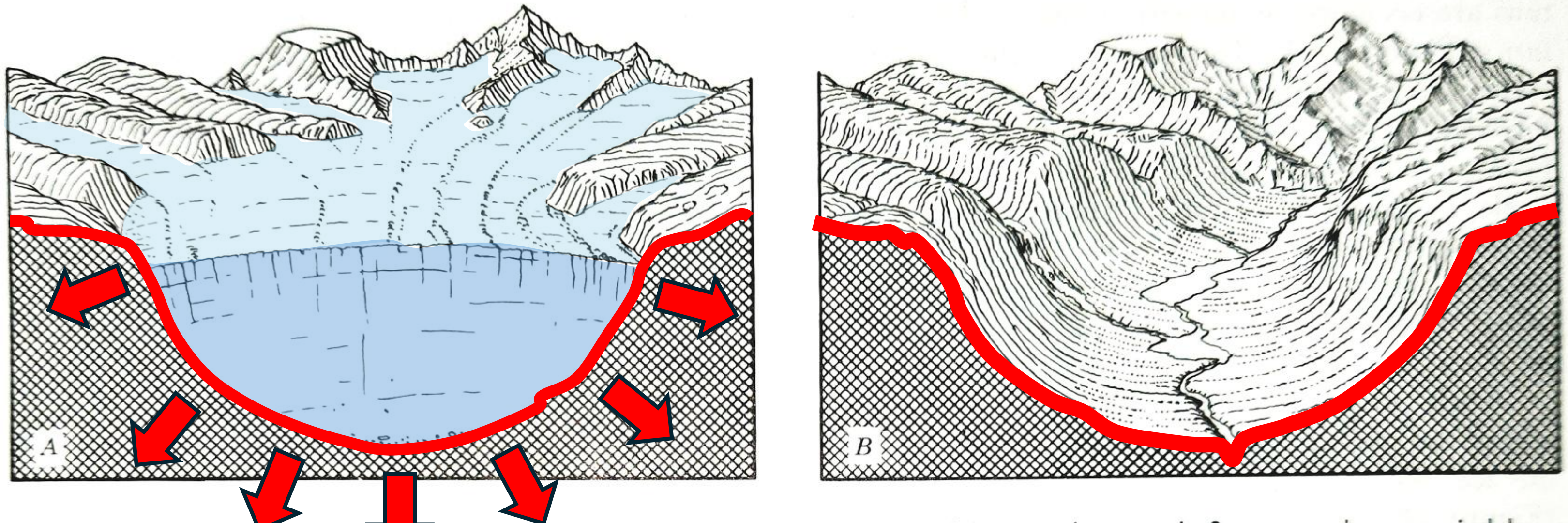
B. After glaciation the trough floor may be occupied by a stream and lakes.

Strahler, 1951

Superimposed
V-shaped river valley







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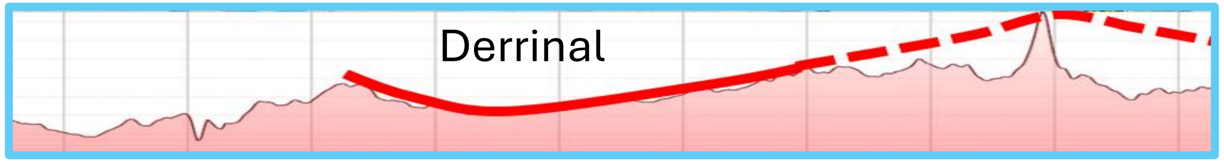
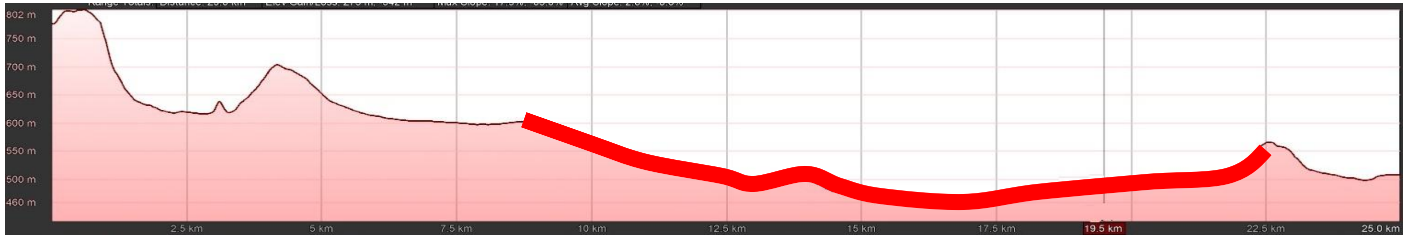
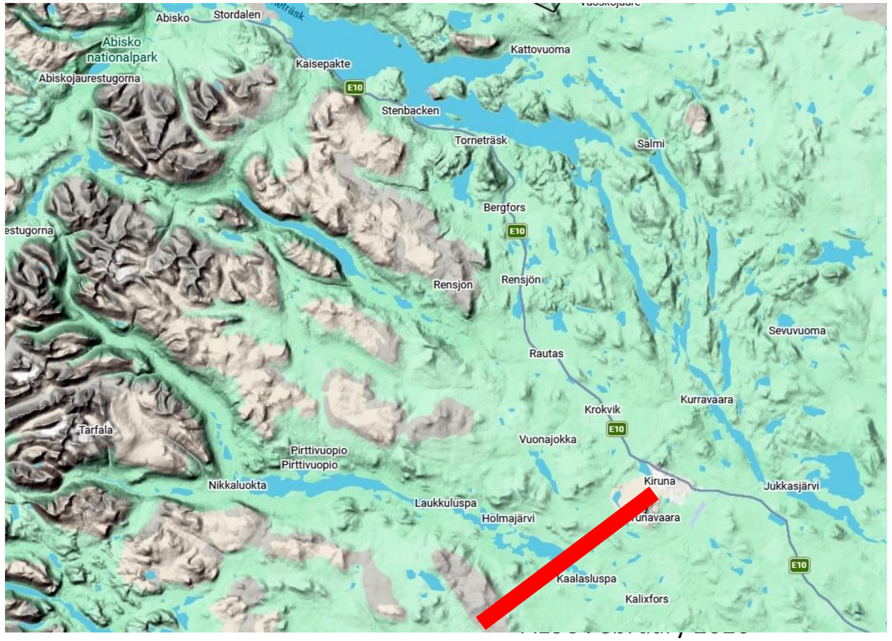
Strahler, 1951

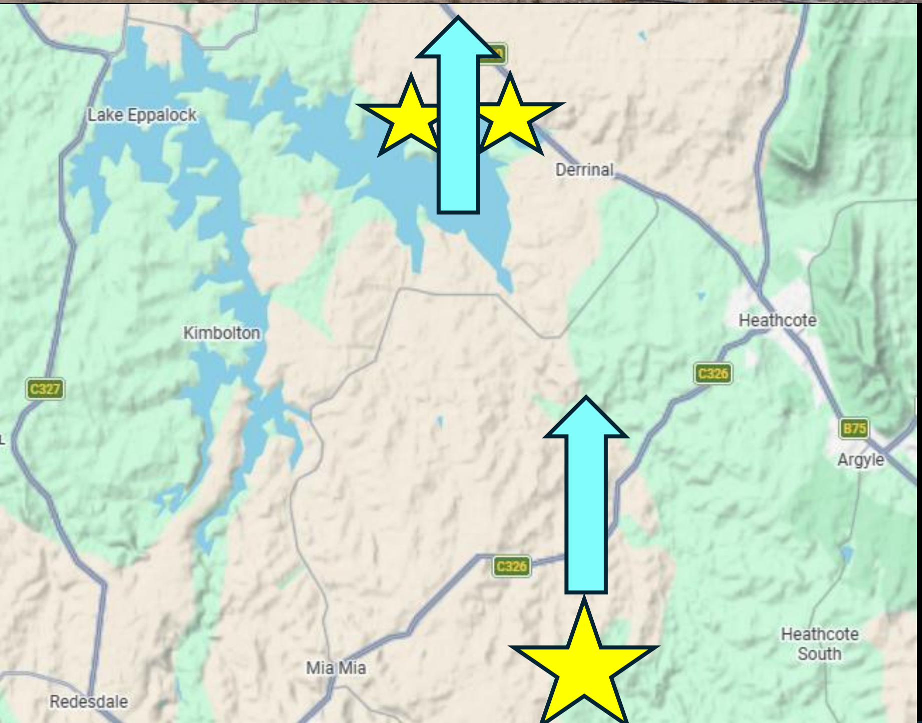


Note similarity between sub-icesheet valley profiles in Sweden and Derrinal

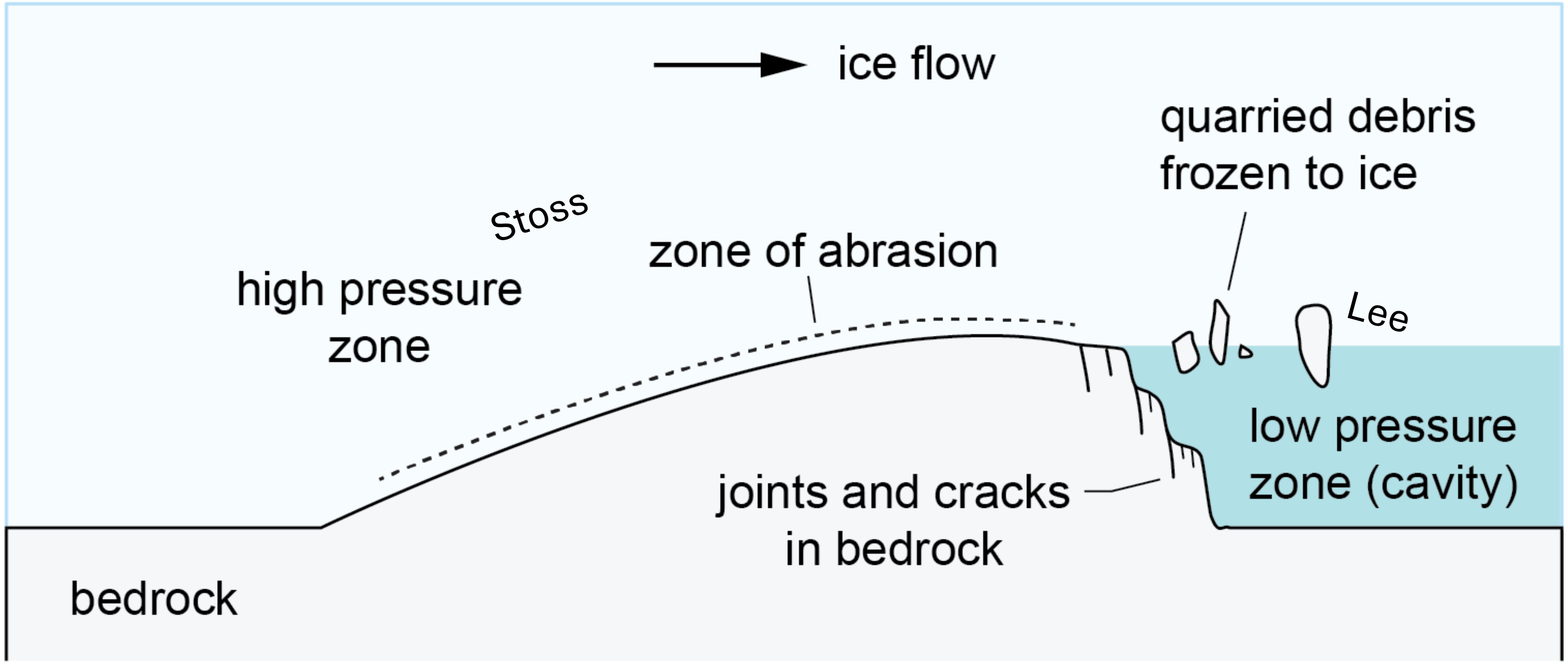




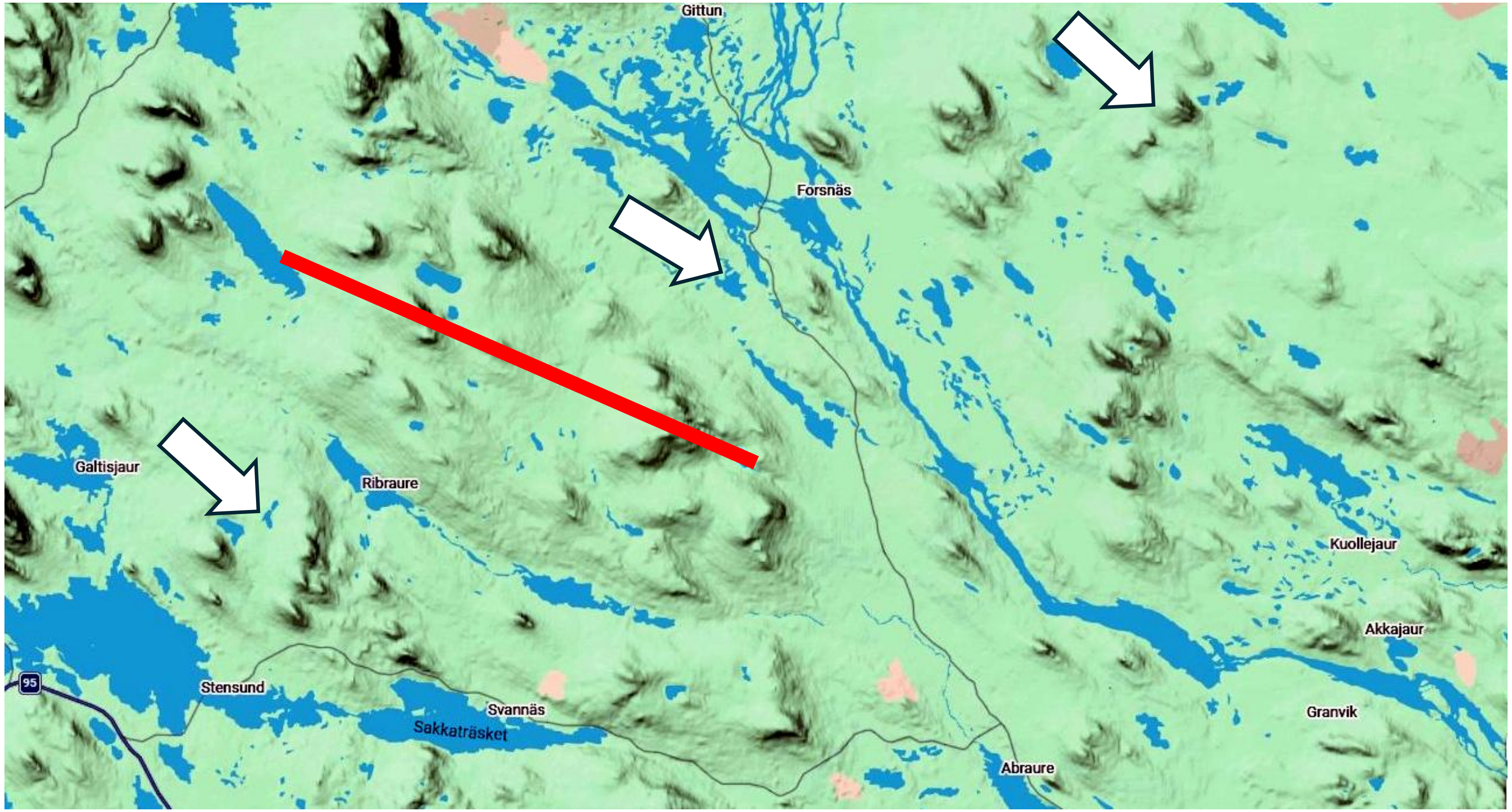
Roche moutonnée at Mia Mia.



Subglacial peaks (Nunataks) also often exhibit a stoss-lee effect, with smooth, abraded lower angle upstream sides (stoss) and steeper plucked downstream side

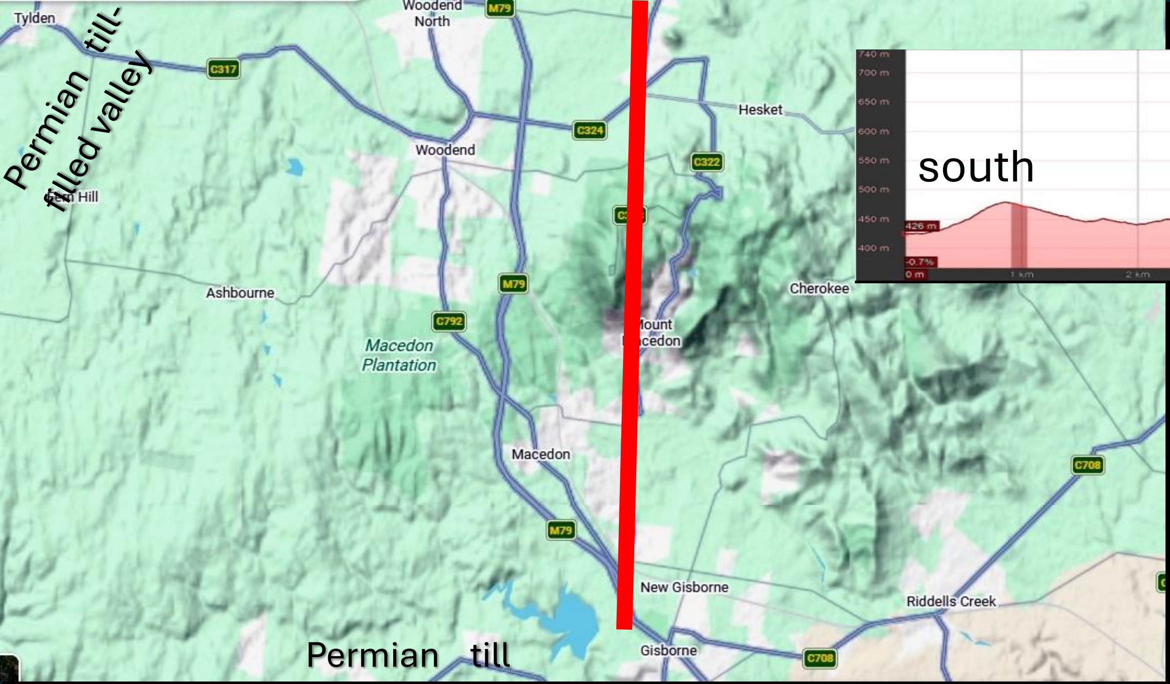


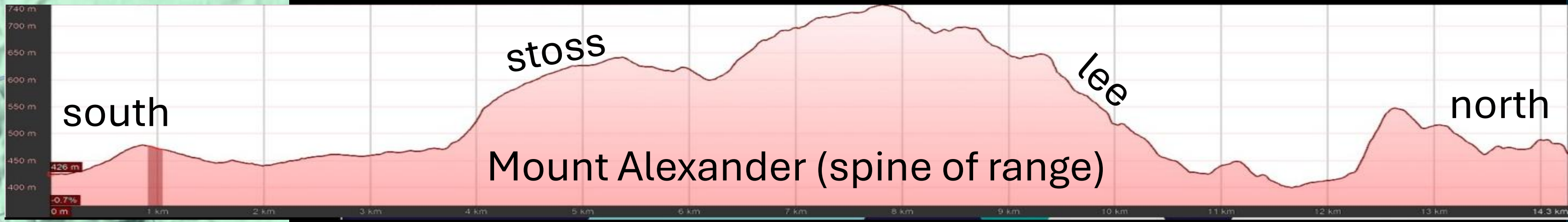
J. Bendle (2020)


Gittun
Forsnäs
Galtisjaur
Ribraure
Kuollejaur
Akkajaur
95
Stensund
Svannäs
Sakkaträsket
Granvik
Abraure


Sweden
Norway
Finland
Gulf of Bothnia
Oslo
Stockholm
Baltic Sea
Estonia
Latvia
Lithuania
Denmark
St Petersburg
Санкт-Петербург
Moscow
Москва


690m
520m
Stoss
Lee
Stoss
Lee





Mounts: Beckworth, Ercildoune, Bolton, Tarrengower, Moliagul, Puckapunyal, Hope, Pyramid Hill, YouYangs

Mounts Wombat, Delegate

Mount Macedon – a Permian subglacial peak (or nunatak)?

Ignore this hill (Miocene plug, intruded post-Permian)

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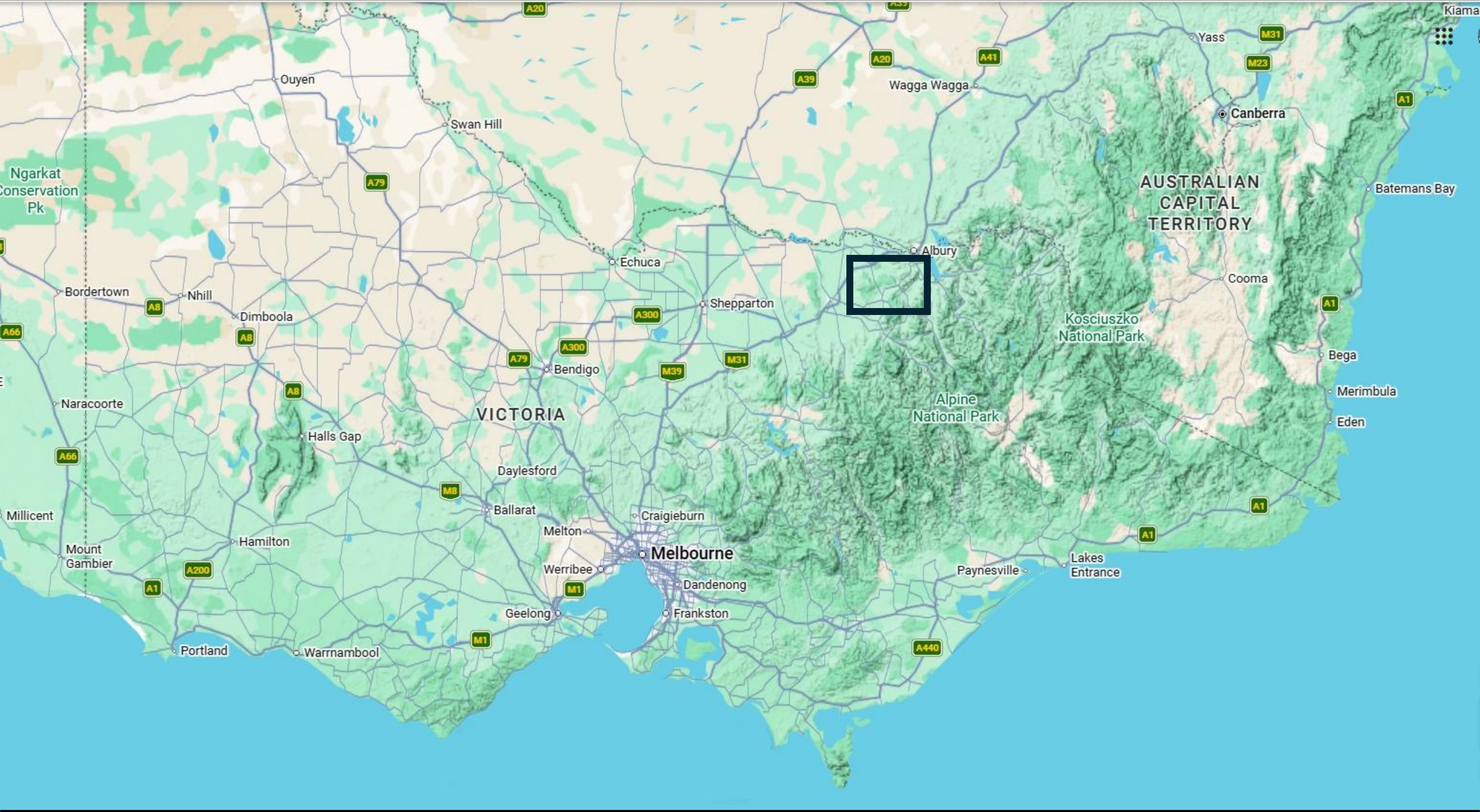
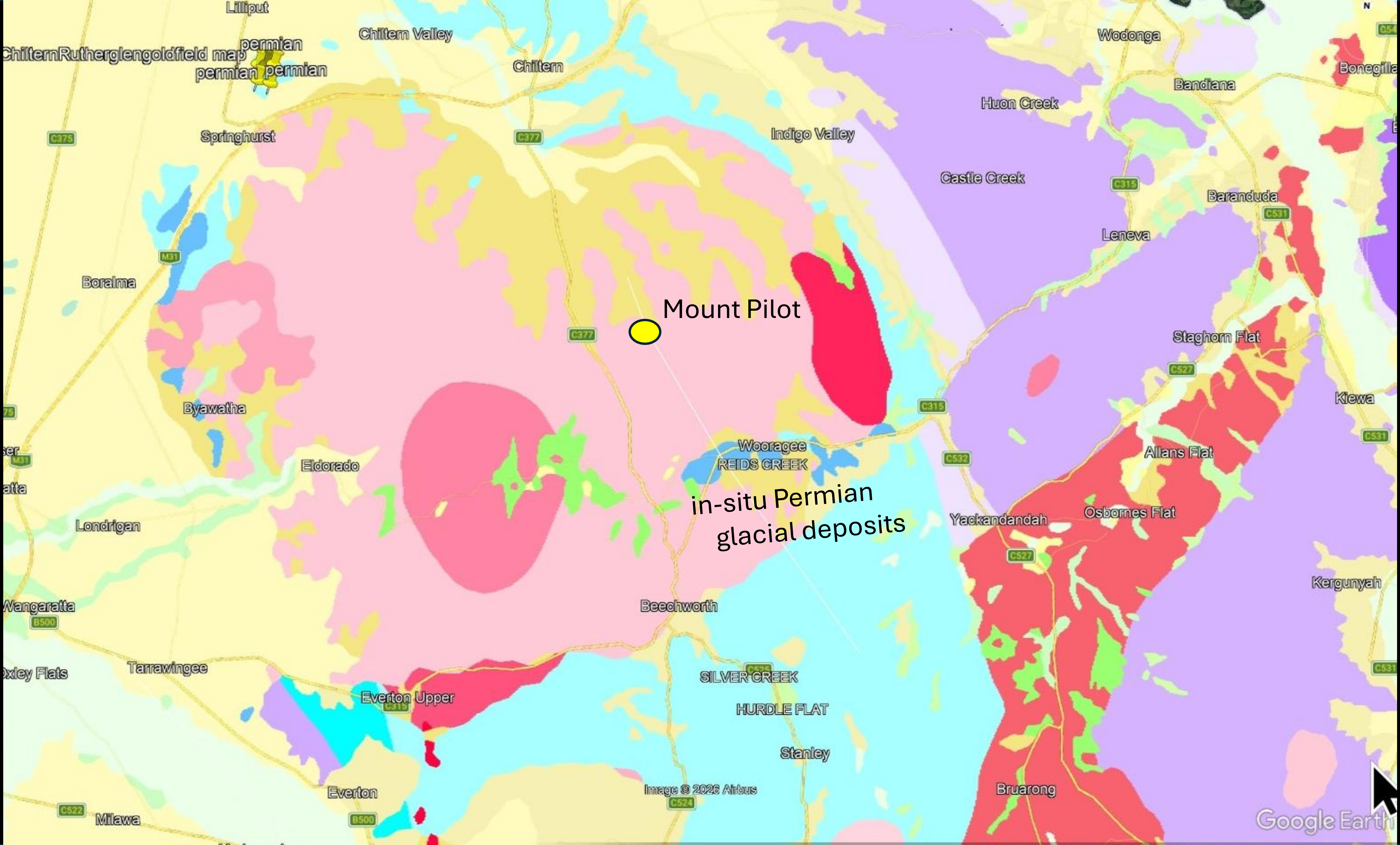
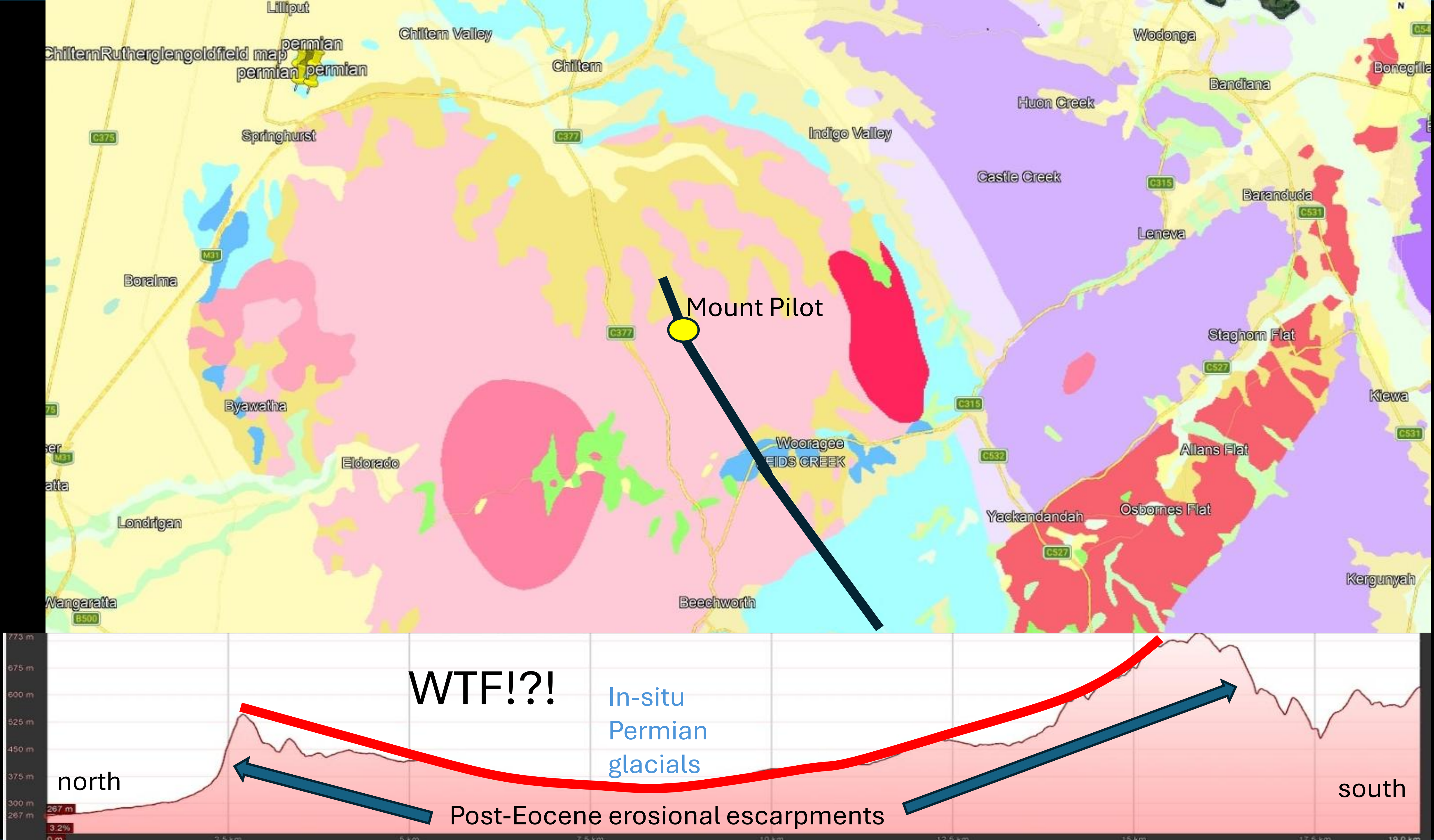
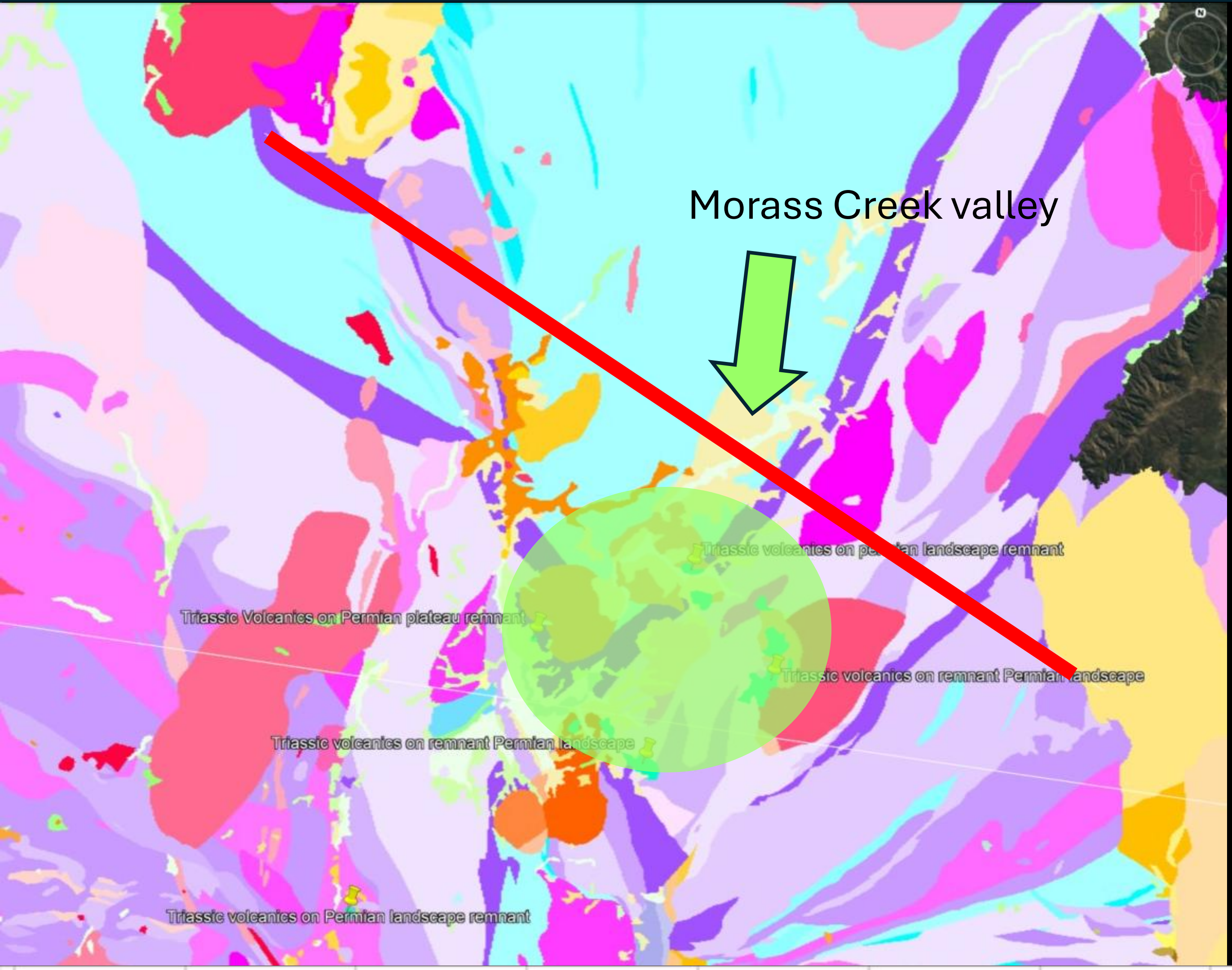


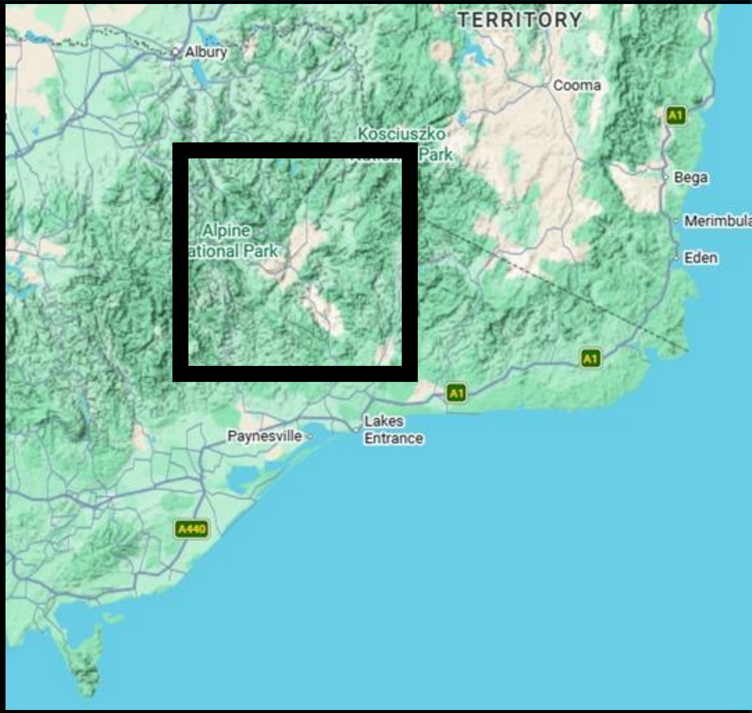
Ouyen
Swan Hill
Wagga Wagga
Yass
Canberra
Kiama
Ngarkat Conservation Pk
AUSTRALIAN CAPITAL TERRITORY
Batemans Bay
Echuca
Albury
Cooma
Bordertown
Nhill
Dimboola
Shepparton
Kosciuszko National Park
Bendigo
Bega
Merimbula
Naracoorte
Alpine National Park
VICTORIA
Eden
Halls Gap
Daylesford
Ballarat
Craigieburn
Millicent
Melton
Mount Gambier
Hamilton
Melbourne
Werribee
Paynesville
Lakes Entrance
Dandenong
Geelong
Frankston
Portland
Warrnambool
A20
A39
A41
M31
M23
A1
A79
A8
A66
A300
M39
M8
A200
M1
A440


Mount Pilot
in-situ Permian
glacial deposits
Lilliput
Chiltern Valley
ChilternRutherglengoldfield map
permian
permian
permian
Chiltern
Wodonga
Bonegilla
Bandiana
Huon Creek
Springhurst
Indigo Valley
Castle Creek
Baranduda
Leneva
Boralma
Staghorn Flat
Byawatha
Kiewa
Wooragee
REIDS CREEK
Allans Flat
Eldorado
Londrigan
Yackandandah
Osbornes Flat
Kergunyah
Wangaratta
Beechworth
Tarrawingee
SILVER CREEK
Everton Upper
HURDLE FLAT
Stanley
Everton
Bruarong
Milawa
Image © 2026 Airbus
Google Earth



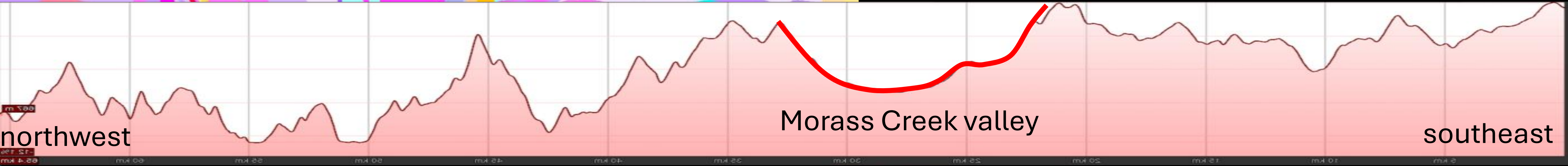
Lilliput
Chiltern Valley
ChilternRutherglengoldfield map
permian
permian
permian
Chiltern
Wodonga
Bonegilla
Bandiana
Huon Creek
C375
Springhurst
C377
Indigo Valley
Castle Creek
C315
Barnawartha
C531
Leneva
M31
Boralma
Mount Pilot
C377
Staghorn Flat
C527
Kiewa
C315
Byawatha
Wooragee
REIDS CREEK
C532
C531
Allans Flat
Eldorado
Yackandandah
Osbornes Flat
Londrigan
C527
Kergunyah
Wangaratta
B500
Beechworth
773 m
675 m
600 m
525 m
450 m
375 m
300 m
267 m
WTF!?!
In-situ
Permian
glacials
north
south
Post-Eocene erosional escarpments





Triassic volcanics – Teapot Creek Formation

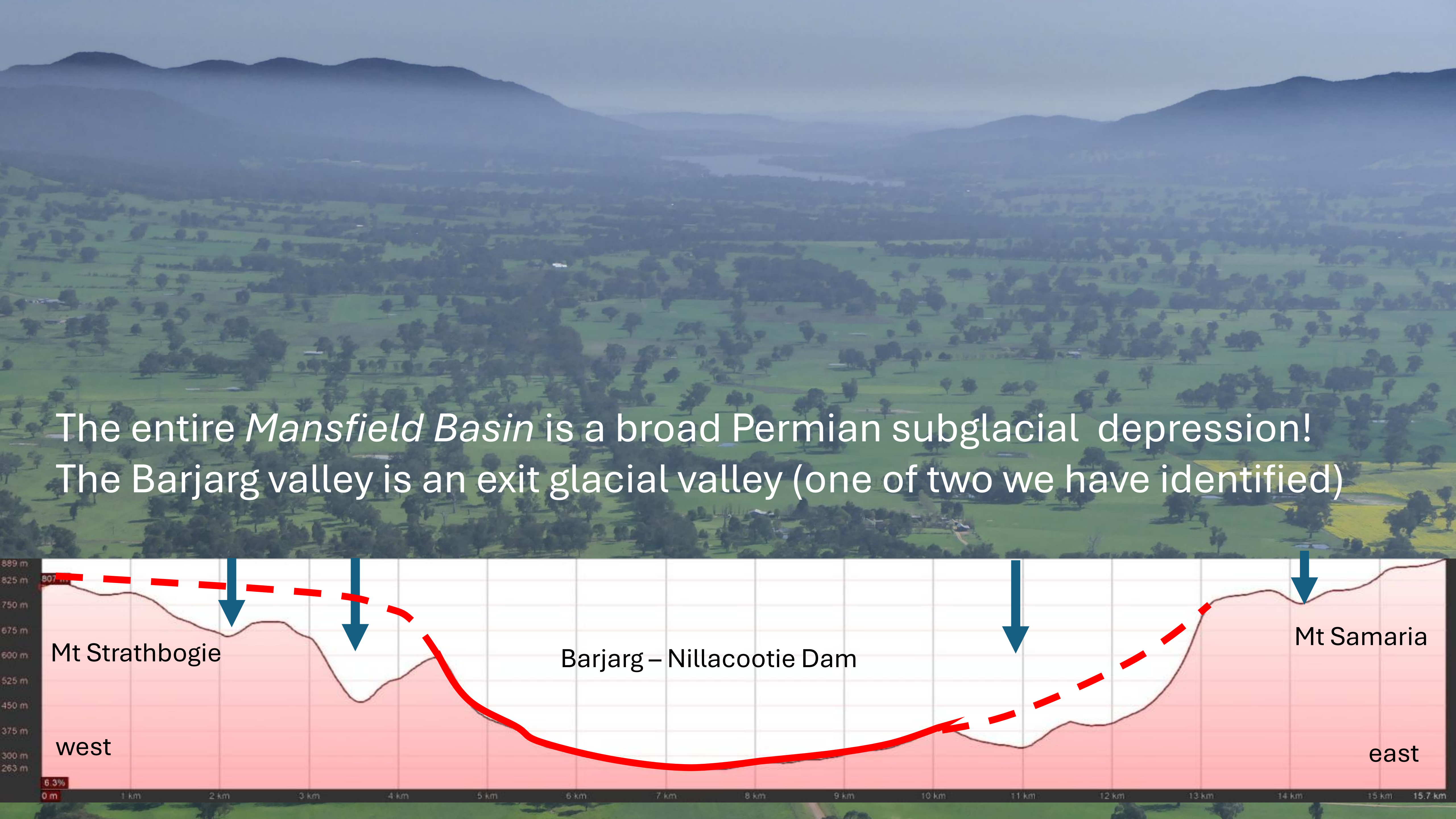
This whole region is a Permian landscape remnant- Benambra – Morass Ck is a sub-icecap depression…. now uplifted in the heart of the Victorian Alps



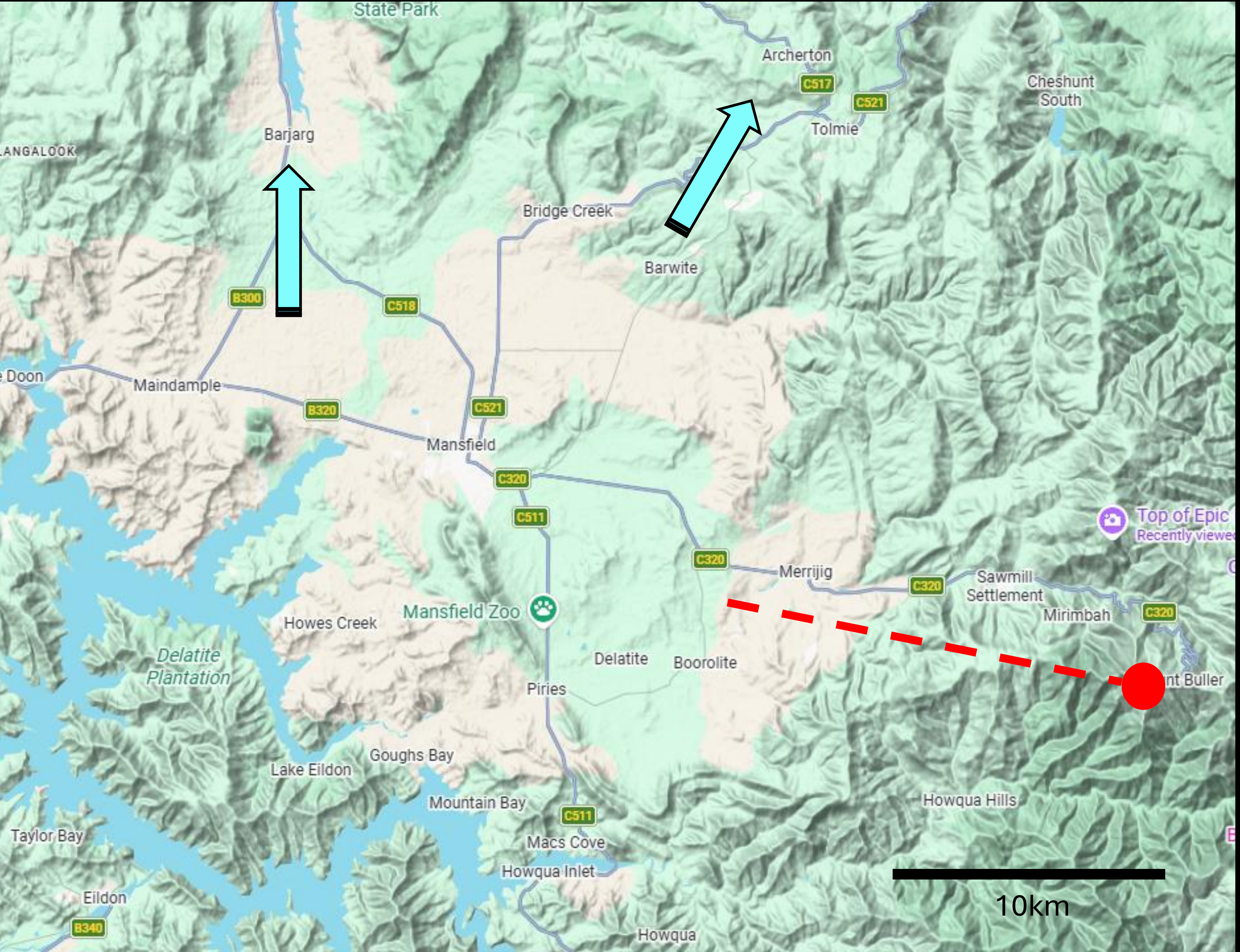
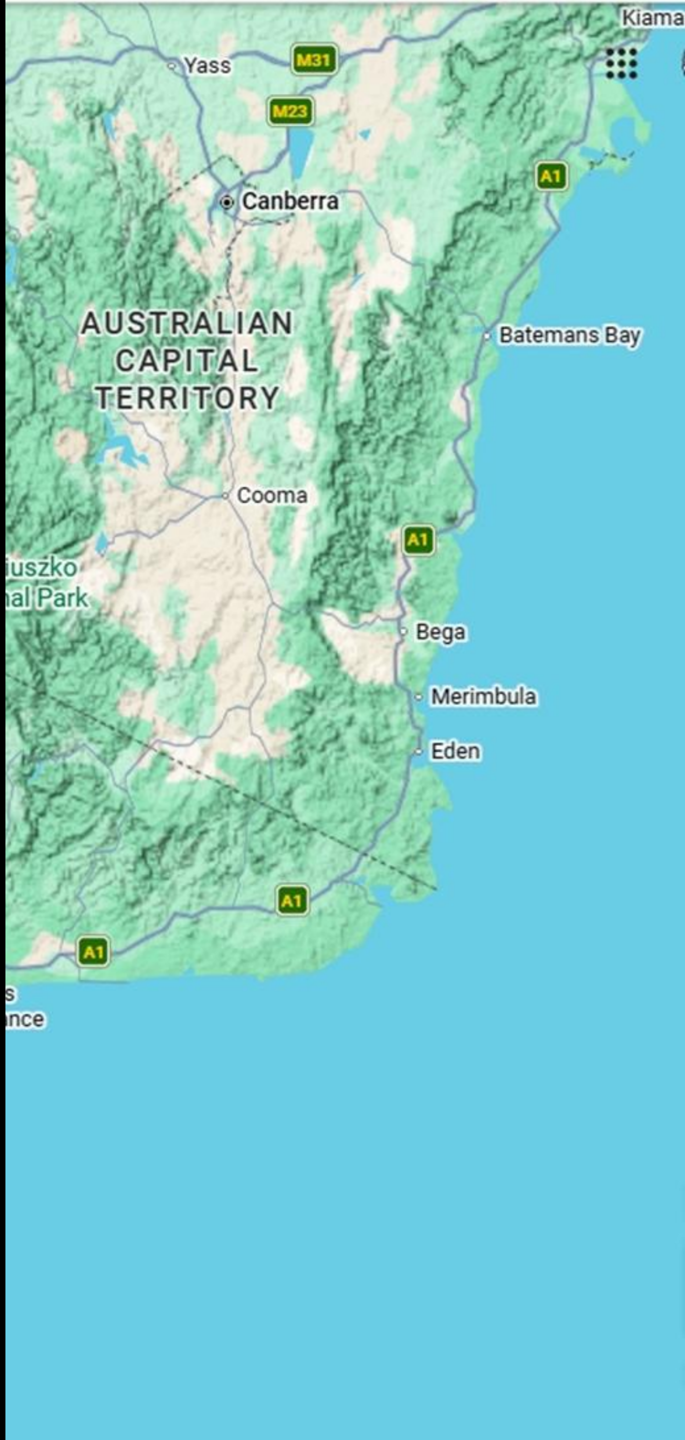
65 km long profile


Ignore these hills (Triassic plugs, intruded post-glaciation)
Benambra – a subglacial depression

Wild Cat Trig – a subglacial rise flanking the Benambra subglacial depresson

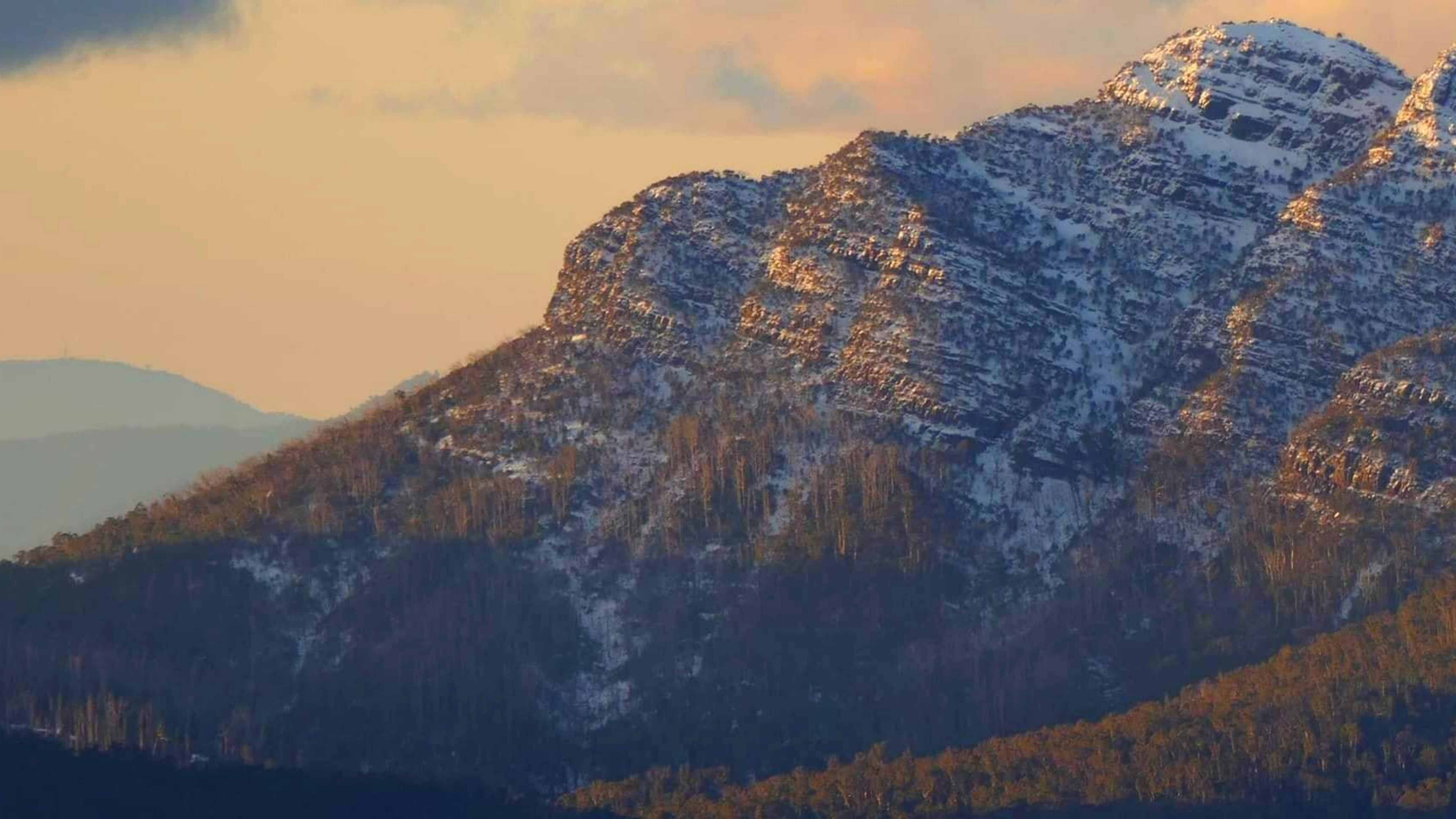

The entire *Mansfield Basin* is a broad Permian subglacial depression!
The Barjarg valley is an exit glacial valley (one of two we have identified)
Mt Strathbogie
Barjarg – Nillacootie Dam
Mt Samaria
west
east
889 m
825 m
750 m
675 m
600 m
525 m
450 m
375 m
300 m
263 m
807 m
6.3%
0 m
1 km
2 km
3 km
4 km
5 km
6 km
7 km
8 km
9 km
10 km
11 km
12 km
13 km
14 km
15 km
15.7 km

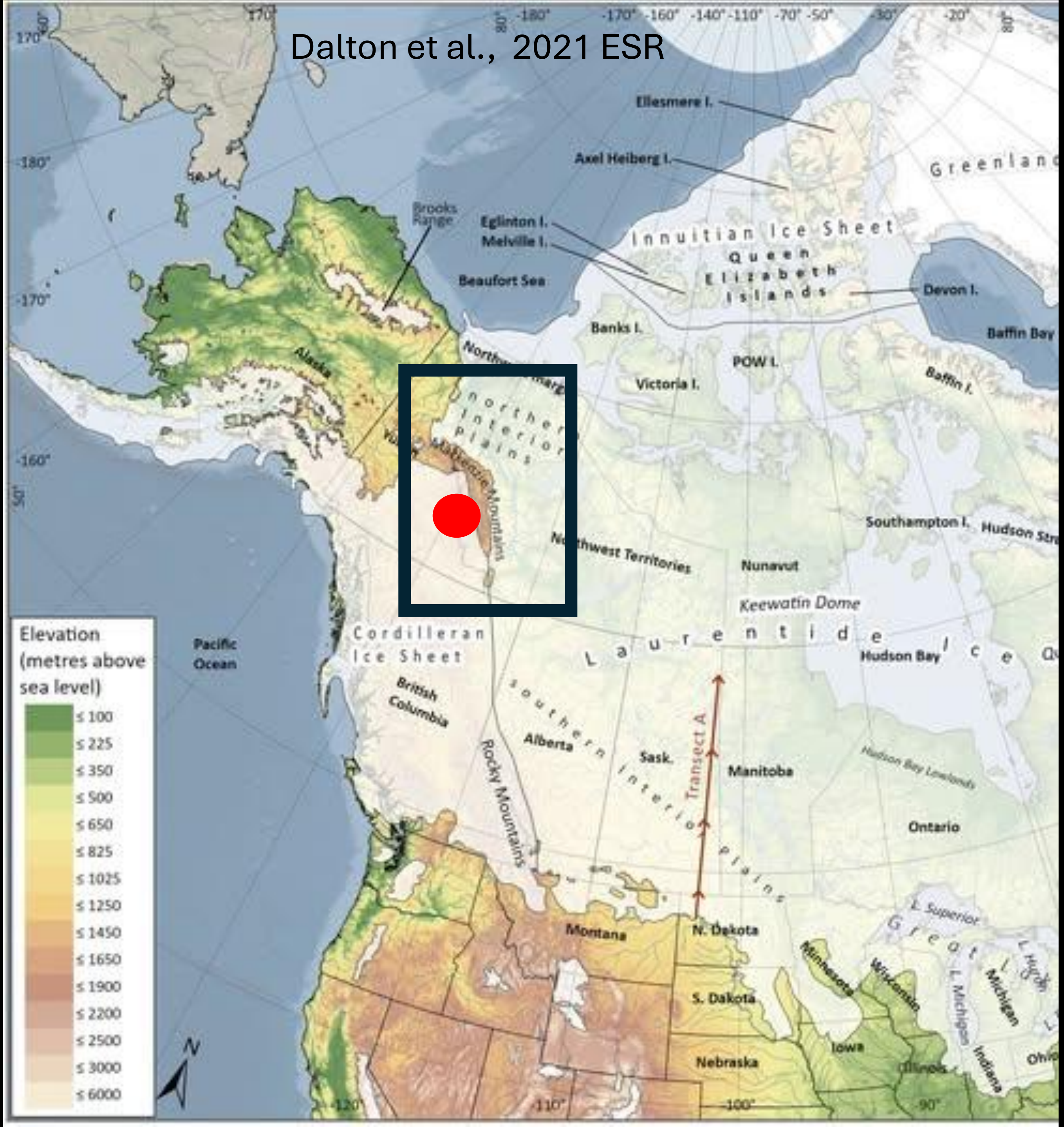

sculpted bedrock
sculpted bedrock
sculpted bedrock


State Park
Archerton
C517
C521
Cheshunt South
Tolmie
Barjarg
LANGALOOK
Bridge Creek
Barwite
B300
C518
Doon
Maindample
B320
C521
Mansfield
C320
C511
Top of Epic
Recently viewed
C320
Merrijig
C320
Sawmill Settlement
Mirimbah
C320
Mansfield Zoo
Howes Creek
Delatite Plantation
Delatite
Boorolite
Piries
nt Buller
Goughs Bay
Lake Eildon
Mountain Bay
C511
Howqua Hills
Taylor Bay
Macs Cove
Howqua Inlet
Eildon
B340
Howqua
10km

Kiama
Yass
M31
M23
A1
Canberra
AUSTRALIAN CAPITAL TERRITORY
Batemans Bay
Cooma
A1
iuszko
al Park
Bega
Merimbula
Eden
A1
A1

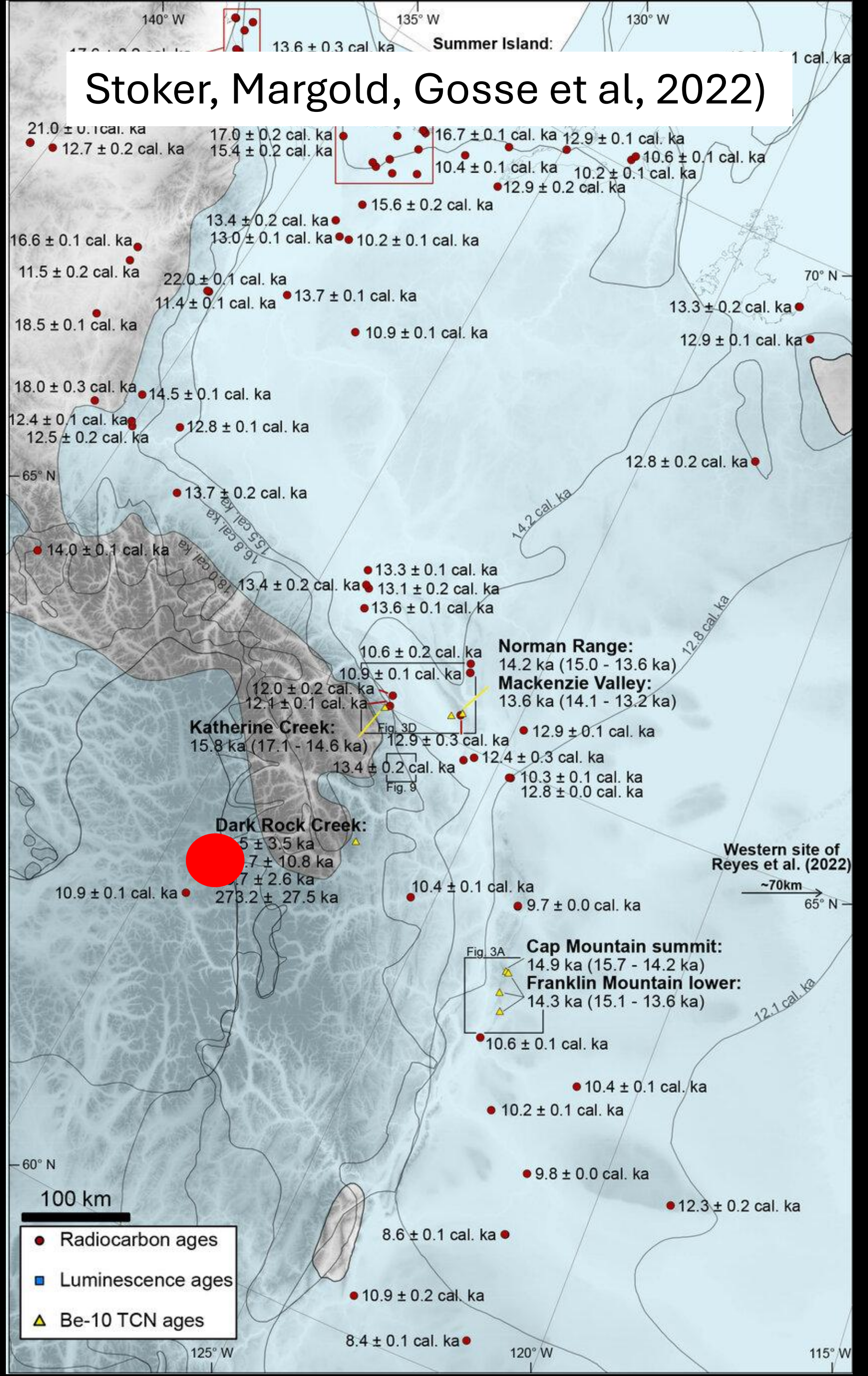

Mount Buller
Mansfield Basin
~1500m local relief in relict Permian landscape

Mount Buller

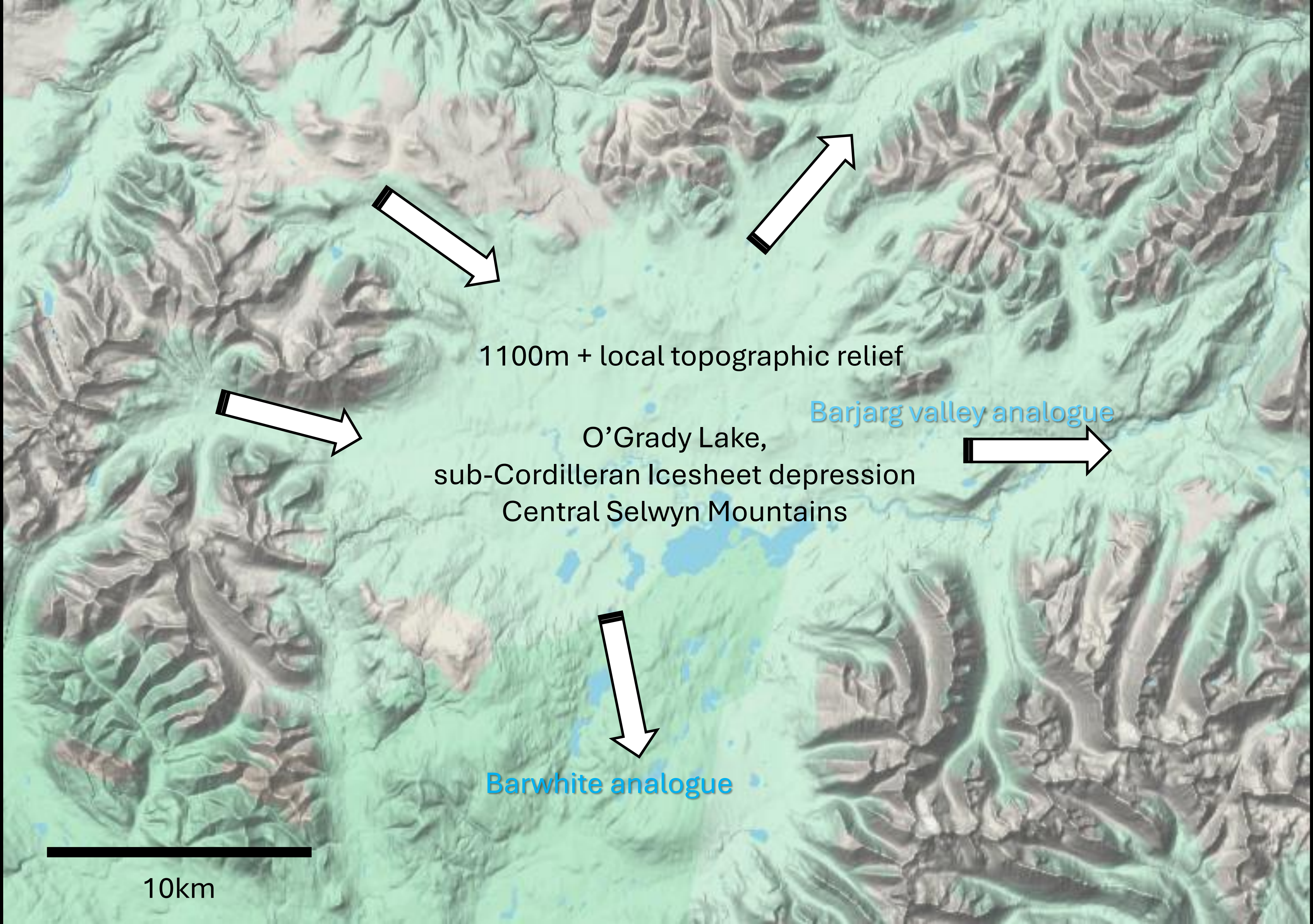




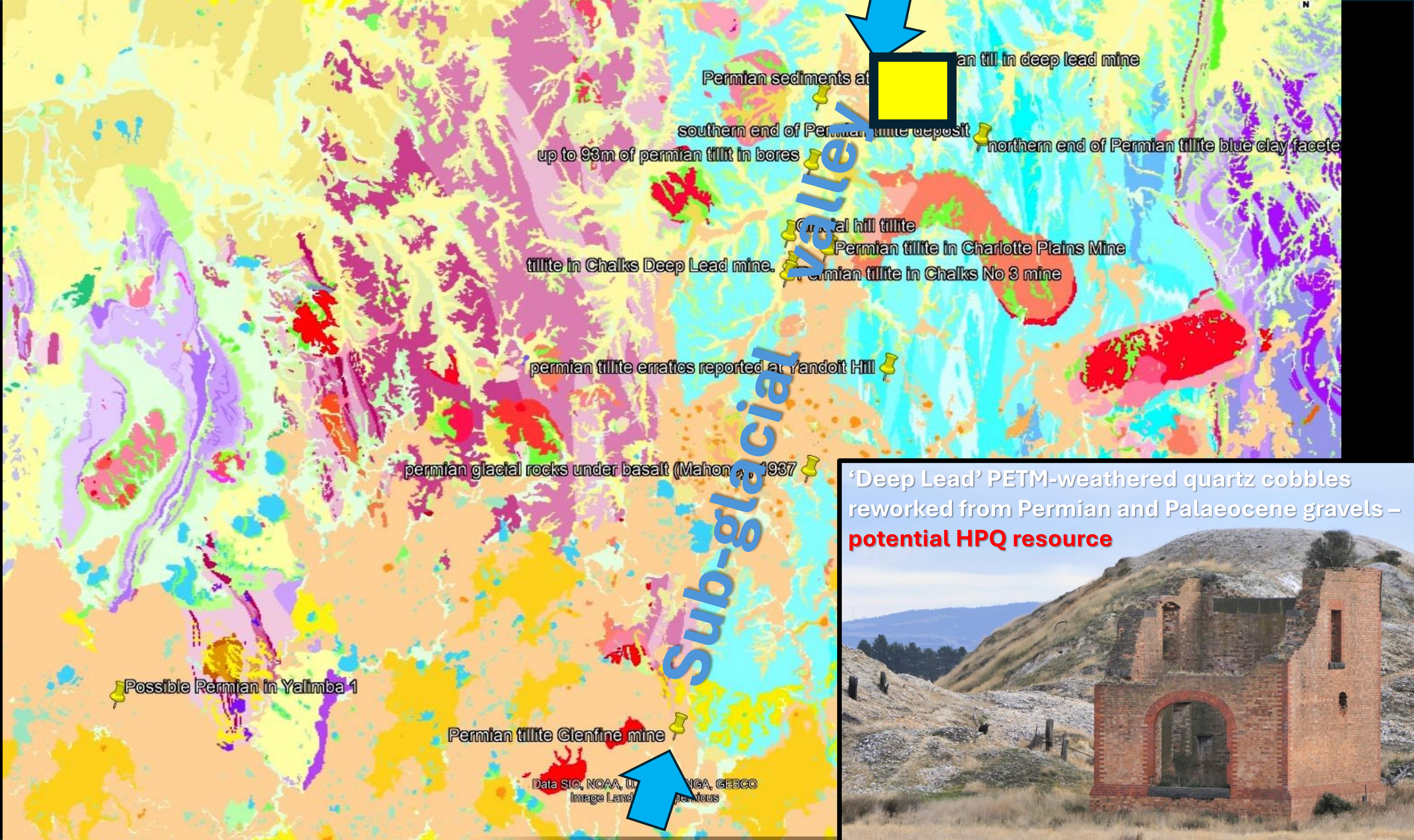
Dalton et al., 2021 ESR
Ellesmere I.
Axel Heiberg I.
Greenland
Brooks Range
Eglinton I.
Melville I.
Innuitian Ice Sheet
Queen Elizabeth Islands
Beaufort Sea
Devon I.
Banks I.
Baffin Bay
POW I.
Victoria I.
Baffin I.
Alaska
northern Interior Plains
Mackenzie Mountains
Southampton I.
Hudson Strait
Northwest Territories
Nunavut
Keewatin Dome
Elevation (metres above sea level)
≤ 100
≤ 225
≤ 350
≤ 500
≤ 650
≤ 825
≤ 1025
≤ 1250
≤ 1450
≤ 1650
≤ 1900
≤ 2200
≤ 2500
≤ 3000
≤ 6000
Pacific Ocean
Cordilleran Ice Sheet
Laurentide Ice
Hudson Bay
British Columbia
southern Interior Plains
Alberta
Sask.
Manitoba
Transect A
Rocky Mountains
Ontario
Hudson Bay Lowlands
Montana
N. Dakota
S. Dakota
Minnesota
Wisconsin
Iowa
Nebraska
L. Superior
L. Michigan
Michigan
N



Stoker, Margold, Gosse et al, 2022)
Summer Island:
Norman Range:
14.2 ka (15.0 - 13.6 ka)
Mackenzie Valley:
13.6 ka (14.1 - 13.2 ka)
Katherine Creek:
15.8 ka (17.1 - 14.6 ka)
Dark Rock Creek:
273.2 ± 27.5 ka
Cap Mountain summit:
14.9 ka (15.7 - 14.2 ka)
Franklin Mountain lower:
14.3 ka (15.1 - 13.6 ka)
Western site of Reyes et al. (2022)
~70km
100 km
Radiocarbon ages
Luminescence ages
Be-10 TCN ages


1100m + local topographic relief
Barjarg valley analogue
O'Grady Lake,
sub-Cordilleran Icesheet depression
Central Selwyn Mountains
Barwhite analogue
10km


Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus
Google Earth


Permian sediments at
an till in deep lead mine
southern end of Permian tillite deposit
northern end of Permian tillite blue clay facete
up to 93m of permian tillit in bores
Permian tillite in Charlotte Plains Mine
tillite in Chalks Deep Lead mine.
mian tillite in Chalks No 3 mine
permian tillite erratics reported at Yandoit Hill
permian glacial rocks under basalt (Mahon 1937
Possible Permian in Yalimba 1
Permian tillite Glenfine mine
Sub-glacial valley
Data SIO, NOAA, NGA, GEBCO
'Deep Lead' PETM-weathered quartz cobbles reworked from Permian and Palaeocene gravels – potential HPQ resource

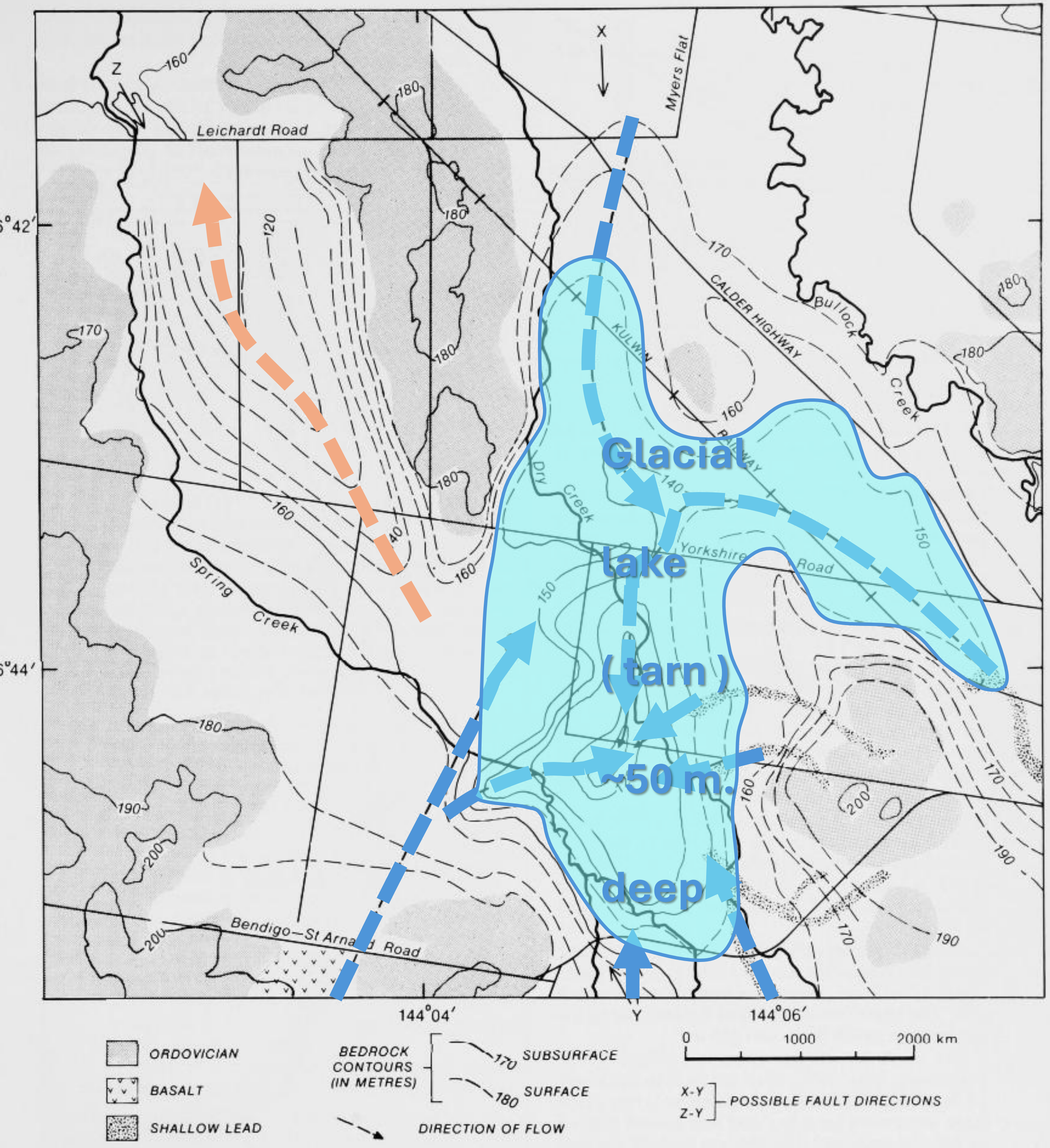
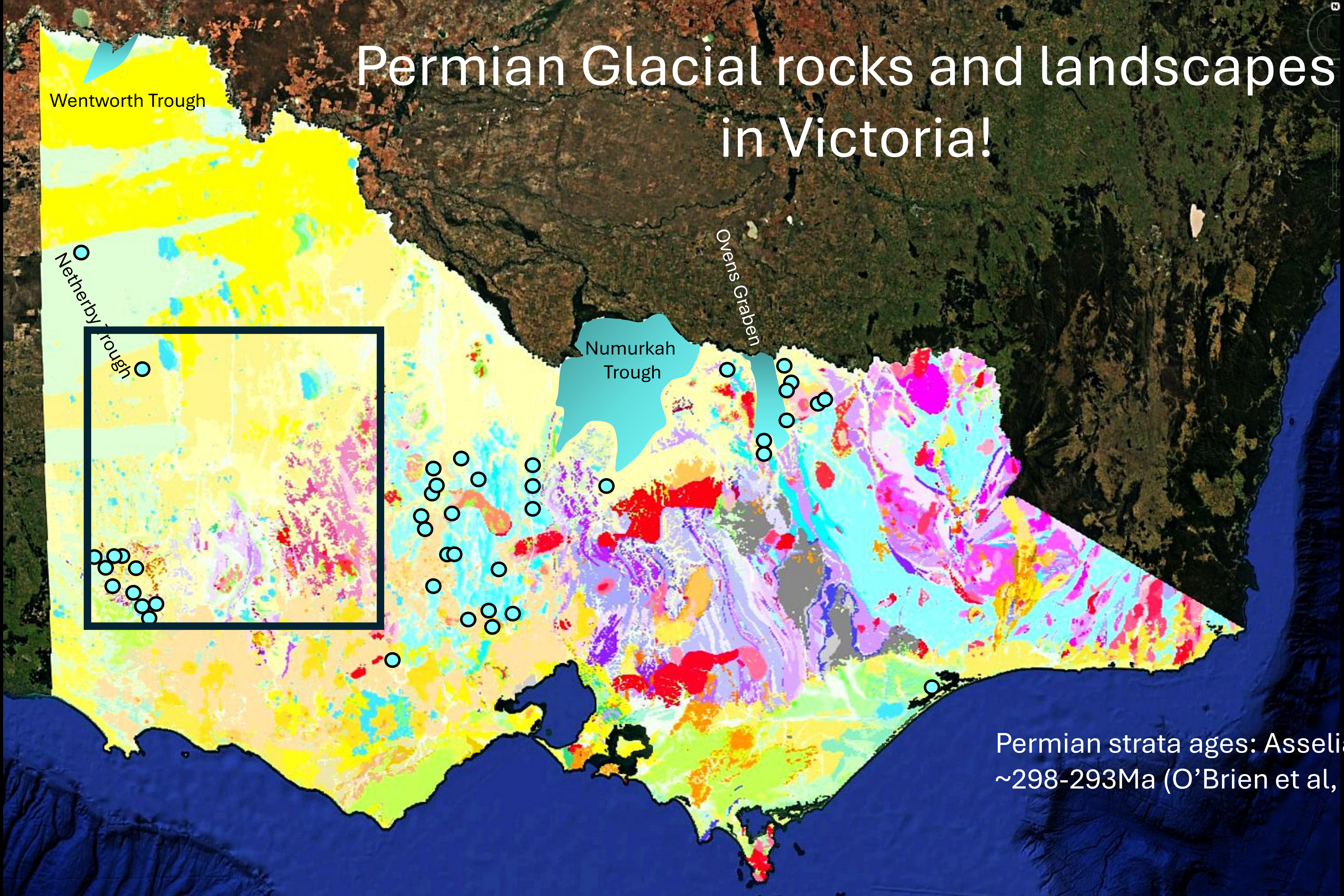


Fig. 7. Bedrock contours, west of Marong

Canavan, 1988

Permian Glacial rocks and landscapes in Victoria!

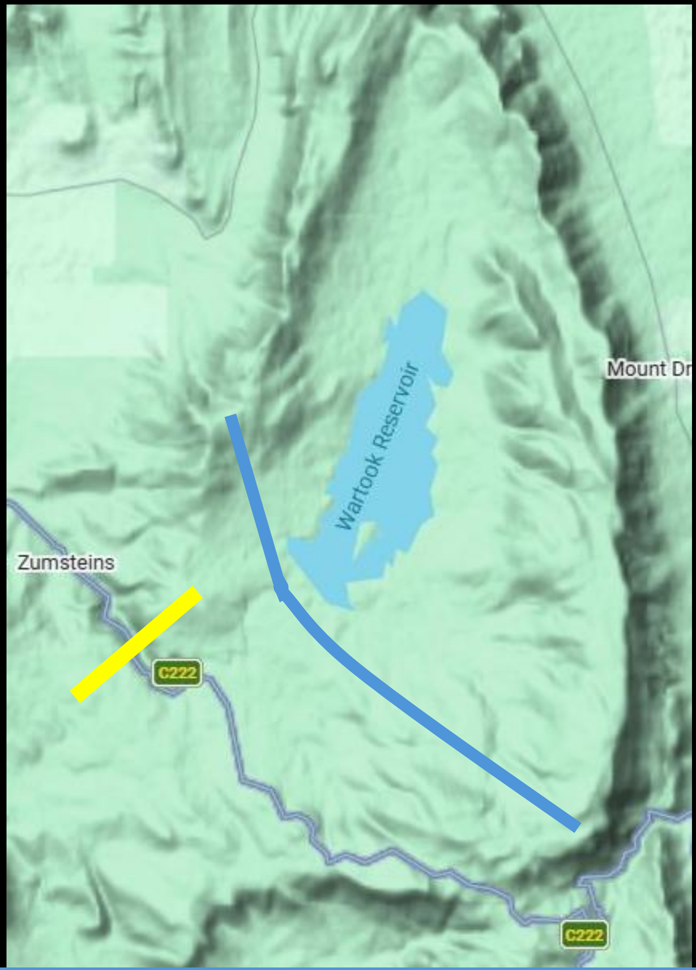


Permian strata ages: Asselian ~298-293Ma (O'Brien et al, 2003)

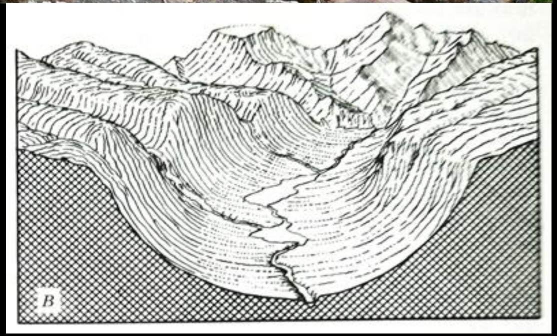

Rainbow
Beulah
Birchip
Wycheproof
Jeparit
Warracknabeal
Charlton
Nhill
Kaniva
A8
Donald
Minyip
A8
Murtoa
St Arnaud
Goroke
Horsham
18
Natimuk
A8
Apsley
Edenhope
Stawell
Halls Gap
A200
Ararat
M8
Beaufort
1100m
0m


Migration
'pull-up'
GUNAMALARY 2
CDP 104
MB
479m
576m
717m
EOH
UF
GG
€
0.00
1.00
2.00
3.00
4.00
Two Way Time (Seconds)
Cayley et al., 2018
beneath Murray Basin:
Permian tillite
overlying
Grampians Group
Netherby 1
Jeparit
Nhill
Goroke
Horsham
A8
Apsley
Edenhope
Stawell
Halls Gap
A200
Sandstone karst
from PETM
Mount William
C216
1100m
0m
Regional tilt due to Late Mesozoic uplift / intracratonic basin sag

Migration
'pull-up'
GUNAMALARY 2
CDP 104
0.00
MB
479m
576m
UF
GG
717m
EOH
€
1.00
2.00
3.00
4.00
Two Way Time (Seconds)
Cayley et al., 2018
beneath Murray Basin:
Permian tillite
overlying
Grampians Group
Netherby 1
Jeparit
Nhill
Goroke
Horsham
A8
Apsley
Edenhope
Stawell
Halls Gap
A200
Sandstone karst
from PETM
Mount William
C216
1100m
0m
Regional tilt due to Late Mesozoic uplift / intracratonic basin sag

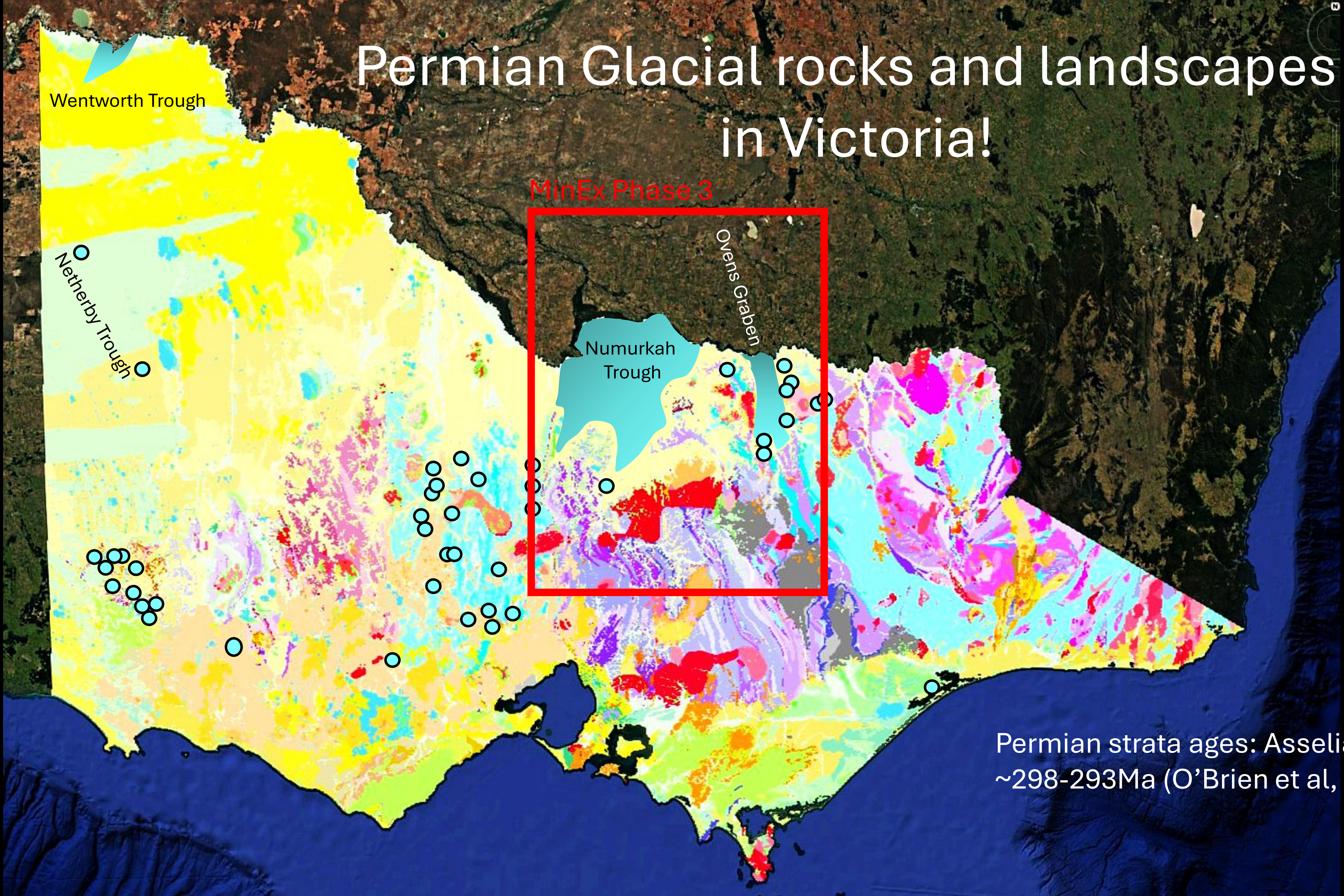


Mackenzie Falls



Classic 'V-shaped' juvenile river valley profile, notched into it

Permian Glacial rocks and landscapes in Victoria!

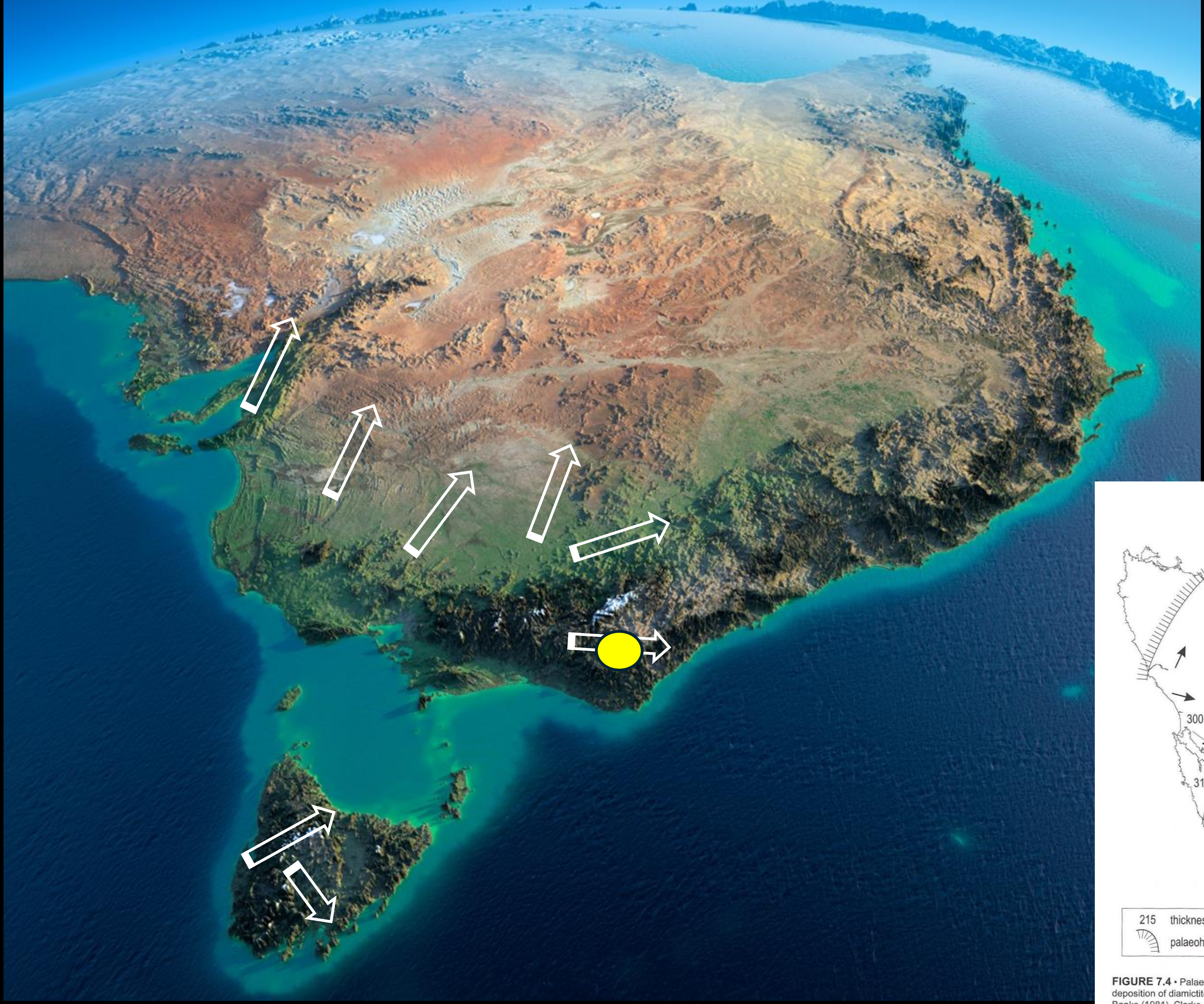


Permian strata ages: Asselian ~298-293Ma (O'Brien et al, 2003)

Talk Outline

- Why did we look into this? The quest for Critical Minerals understanding!
- The PETM – what is it? Why do we consider it so important for landscape history mapping?
- PETM regolith – where is it preserved? What does it look like?
- PETM landscapes – echoes of a very, **very** wet past for west / central Victoria.
- The curious case of the almost entirely missing PETM regolith in the Victorian Alps.
- The curious case of the missing uplifted Mesozoic plateaus of far western and west-central Victoria
- Permian glacial landscapes!
- and – Permian glacial landscapes are everywhere!
- **Creating a new Permian – Recent narrative for Victorian landscape evolution.**

Iceland (AKA Victoria.....in the Permian)



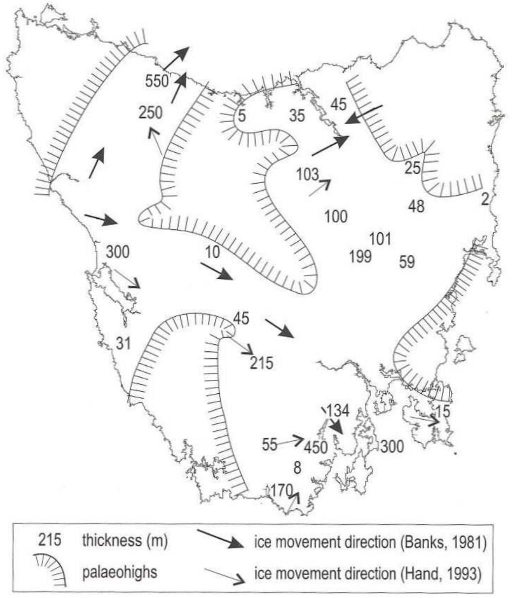
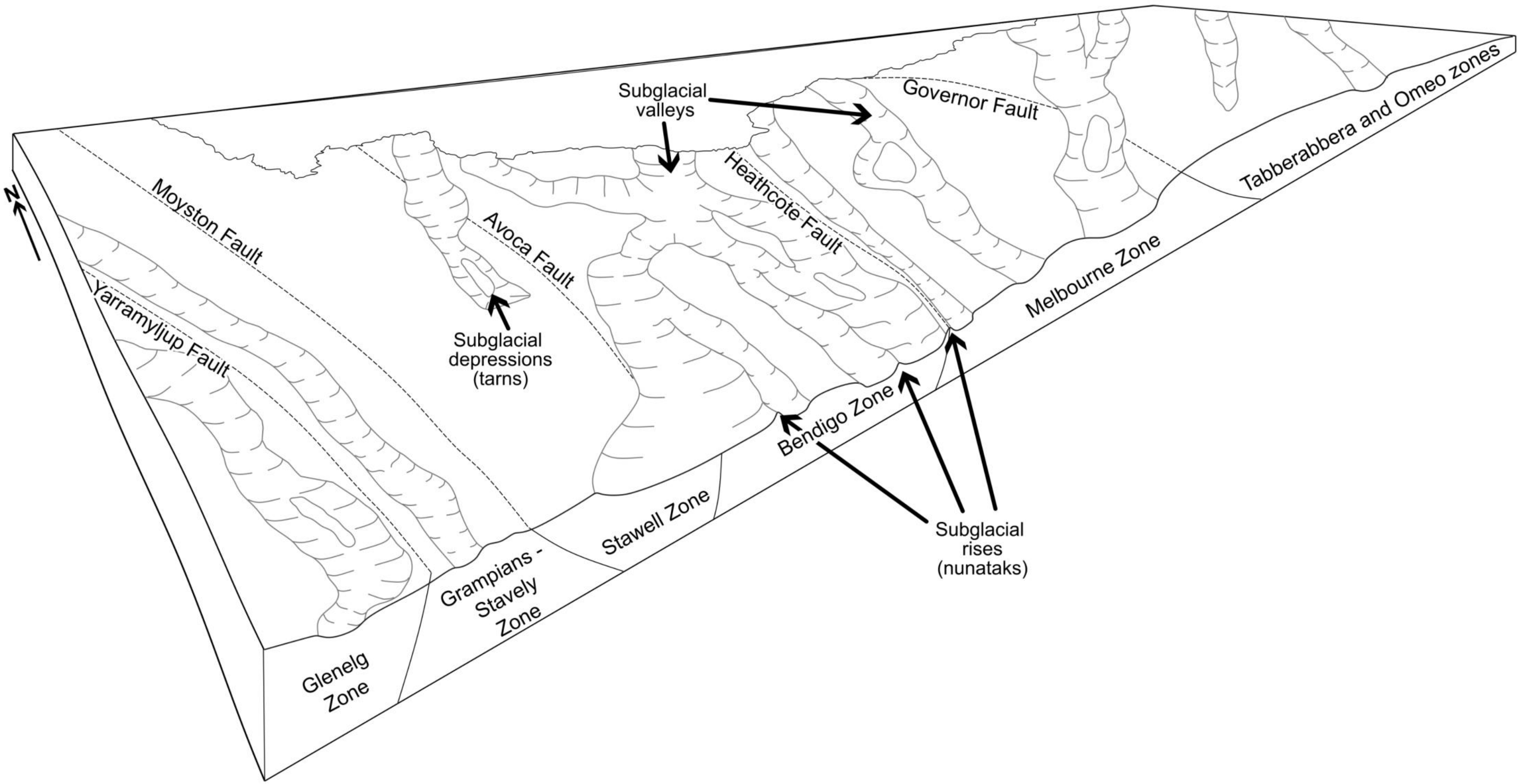


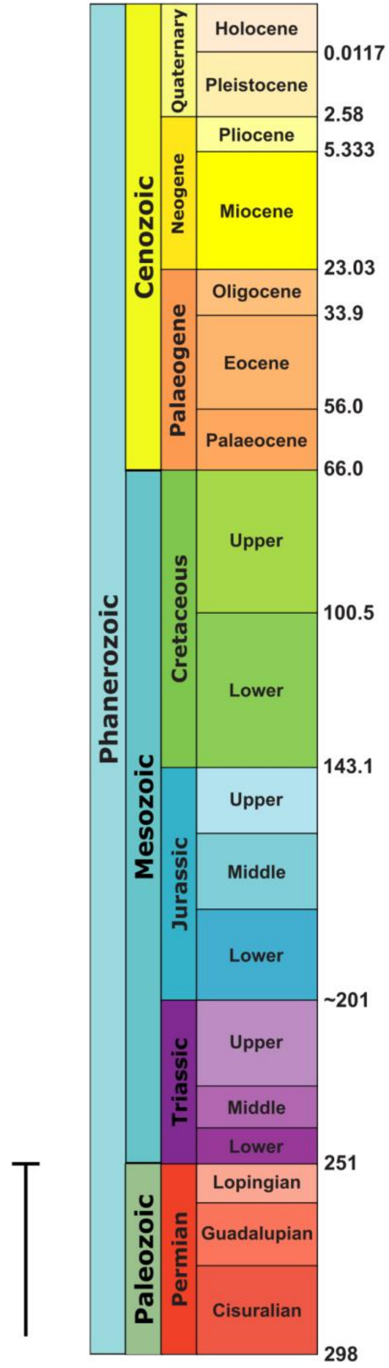
FIGURE 7.4 • Palaeogeographic reconstruction of the Tasmania Basin during deposition of diamictite facies represented by the Wynyard Tillite and correlates. After

Mount Delegate –

A partly eroded Permian nunatak on the Victorian part of the Monaro High Plains.

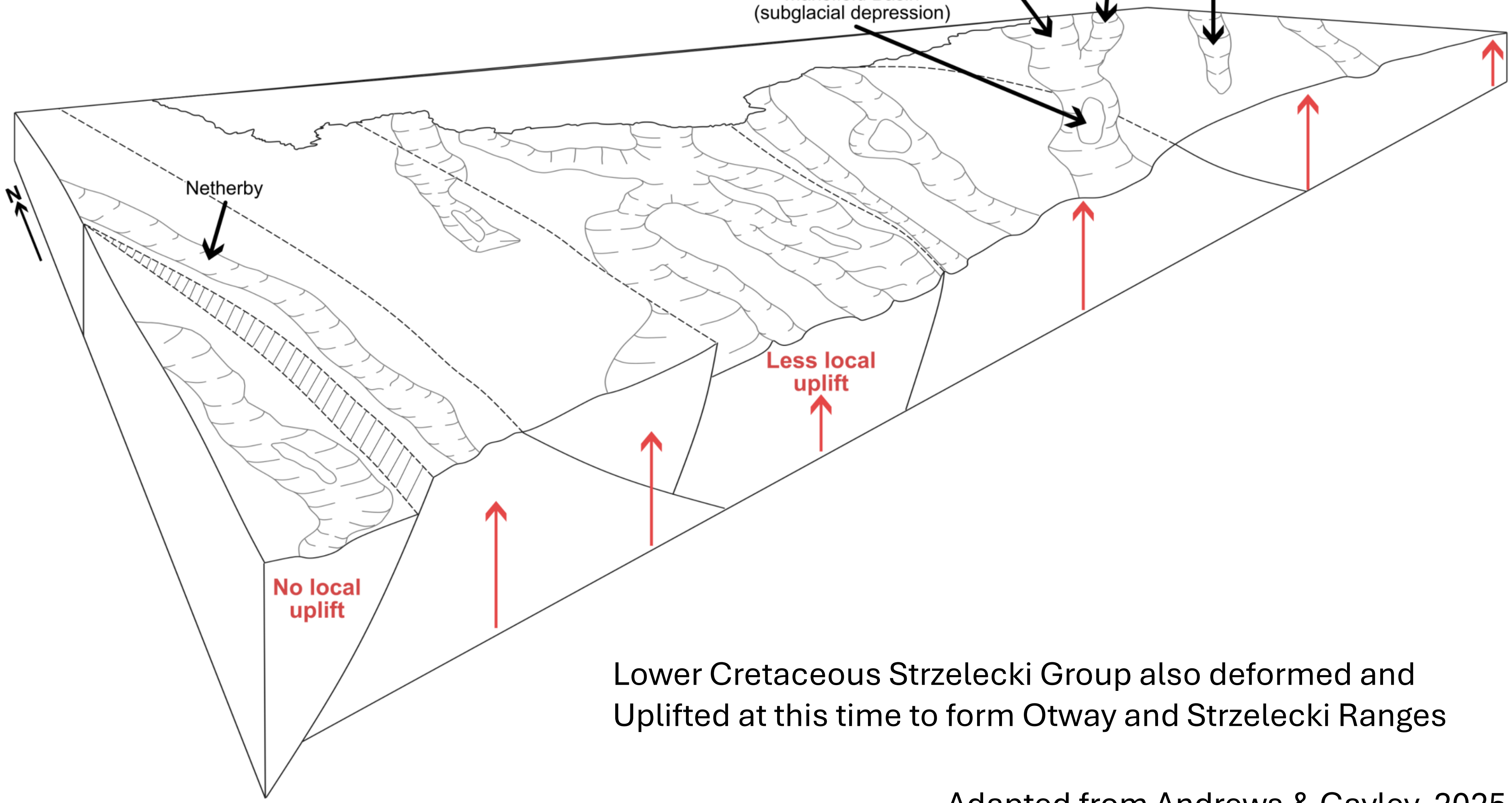
Undulating Permian landscape on Paleozoic bedrock



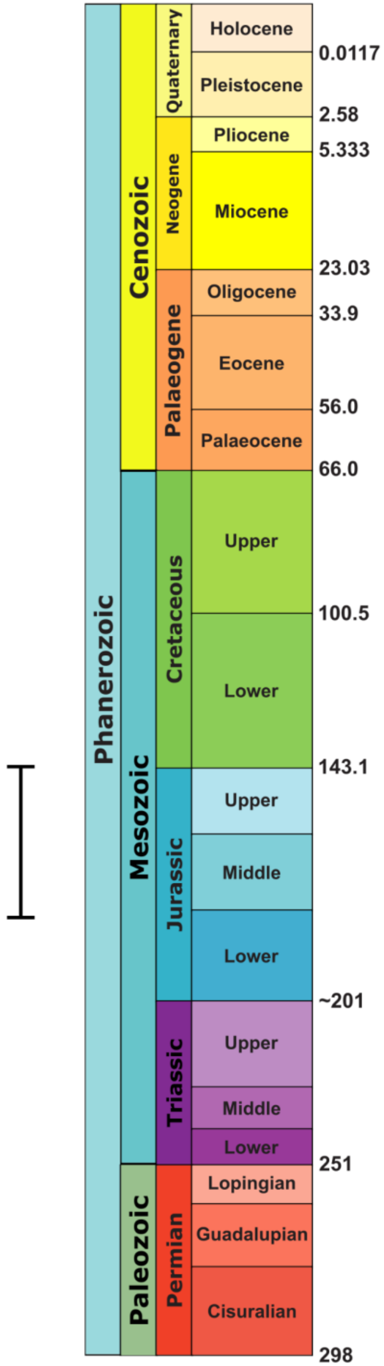


Adapted from Andrews & Cayley, 2025

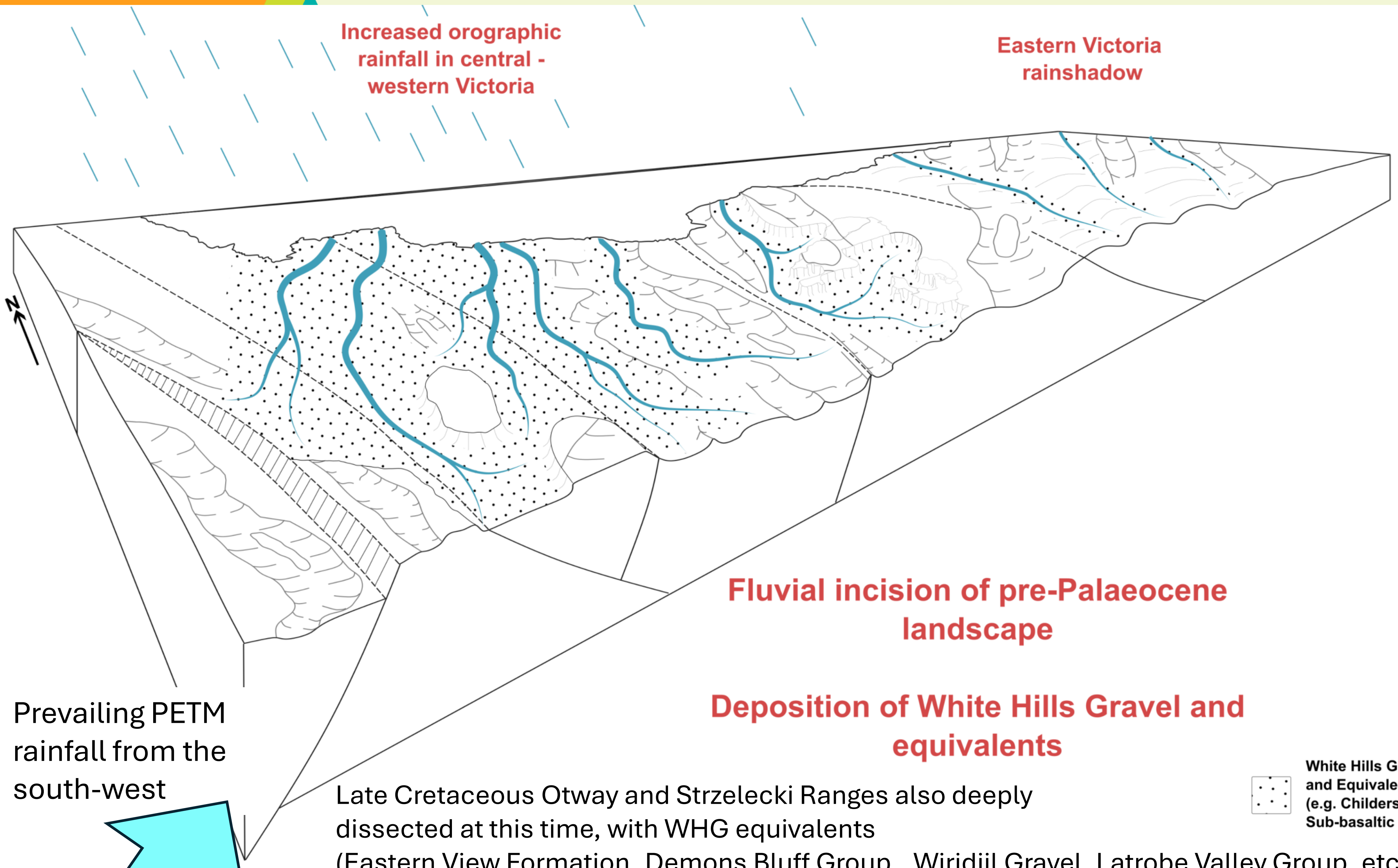
Uplift to form E - W oriented continental divide



Lower Cretaceous Strzelecki Group also deformed and
Uplifted at this time to form Otway and Strzelecki Ranges



Adapted from Andrews & Cayley, 2025



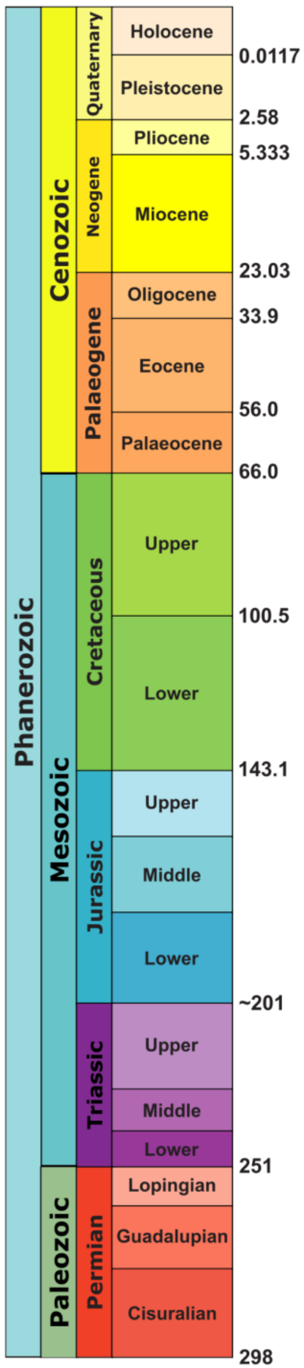
Fluvial incision of pre-Palaeocene landscape

Deposition of White Hills Gravel and equivalents

Prevailing PETM rainfall from the south-west

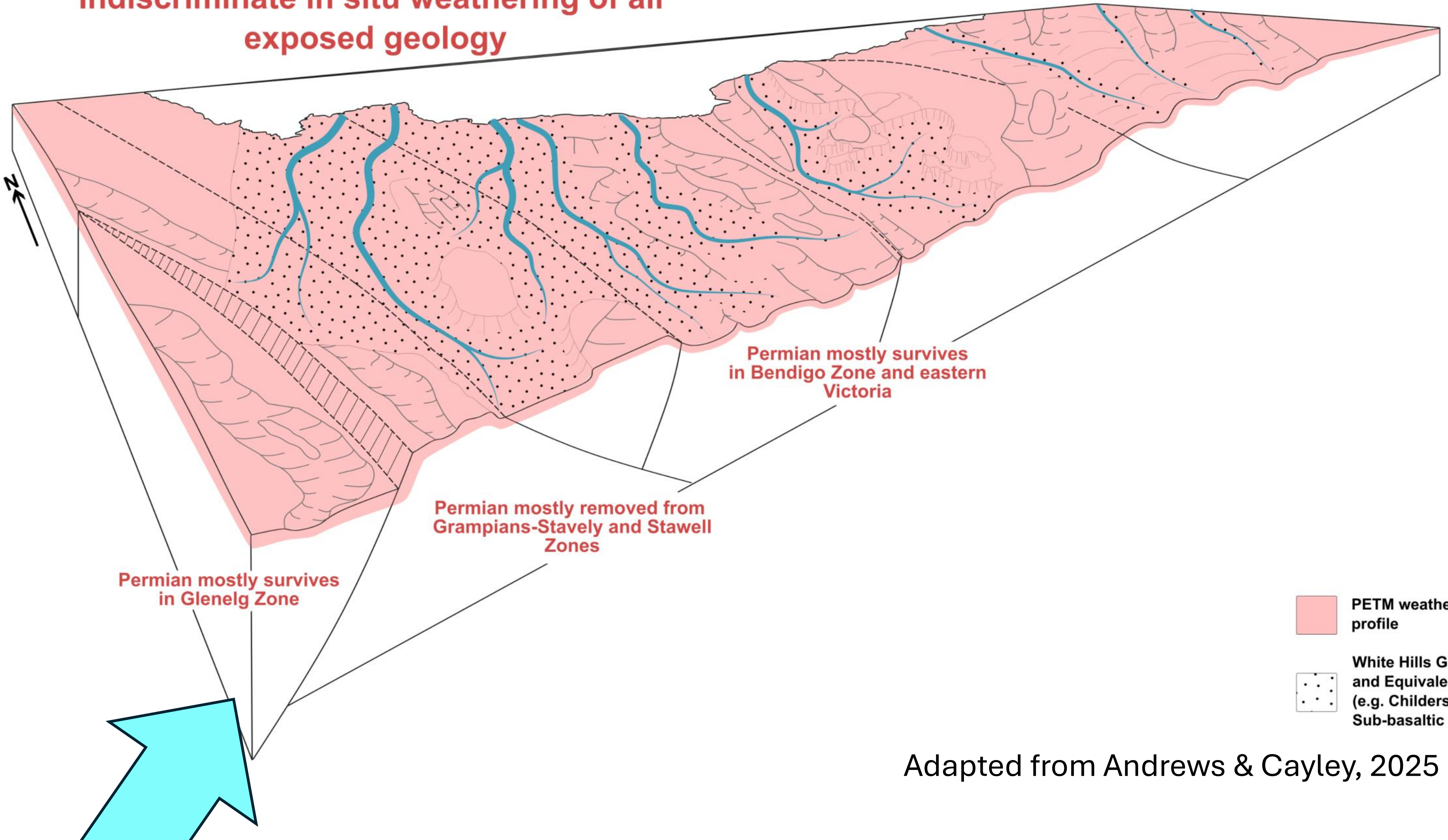
Late Cretaceous Otway and Strzelecki Ranges also deeply dissected at this time, with WHG equivalents (Eastern View Formation, Demons Bluff Group,, Wiridjil Gravel, Latrobe Valley Group, etc.) deposited at bases of erosional escarpments

White Hills Gravel and Equivalents (e.g. Childers Frm, Sub-basaltic gravel)



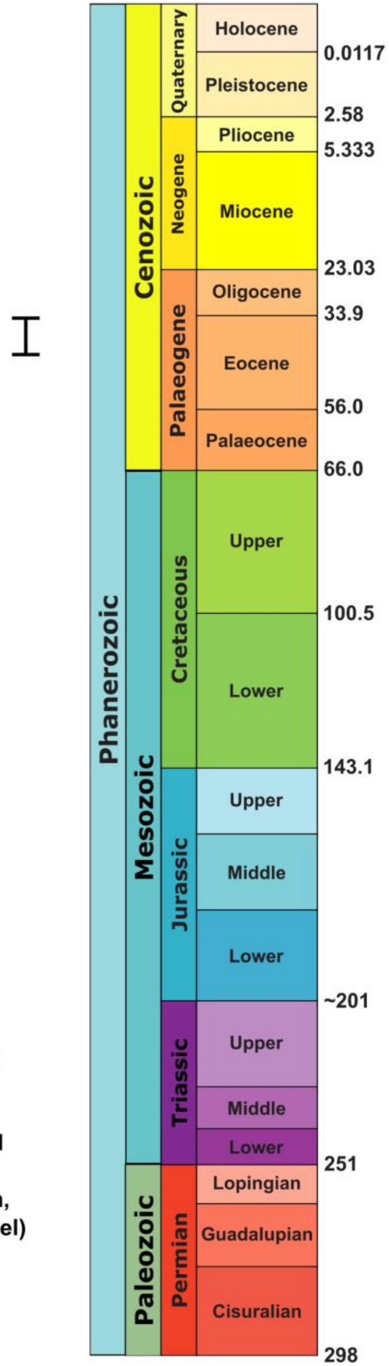
Palaeocene - Eocene Thermal Maximum

Indiscriminate in situ weathering of all exposed geology



PETM weathering profile

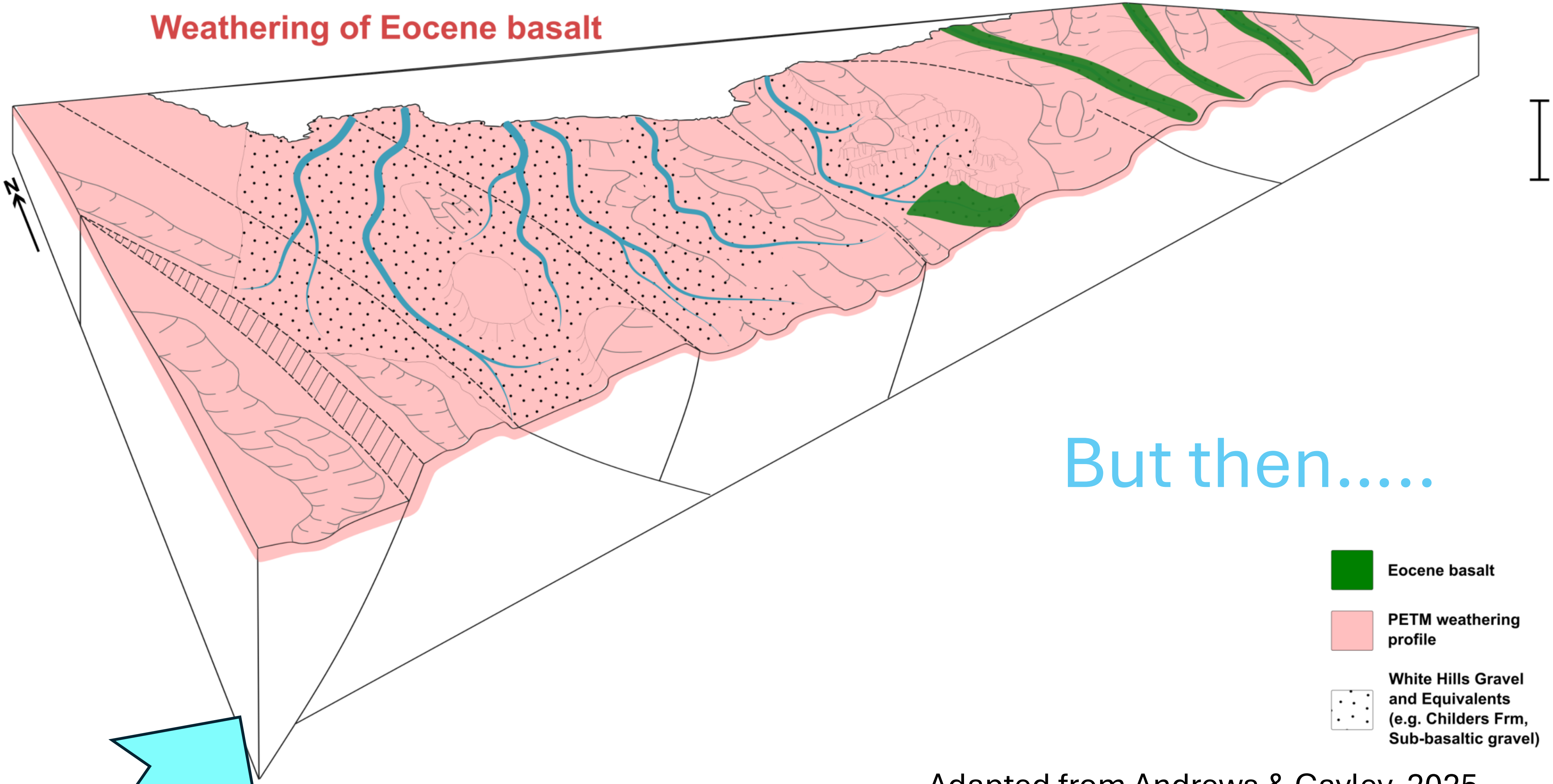
White Hills Gravel and Equivalents (e.g. Childers Frm, Sub-basaltic gravel)



Adapted from Andrews & Cayley, 2025

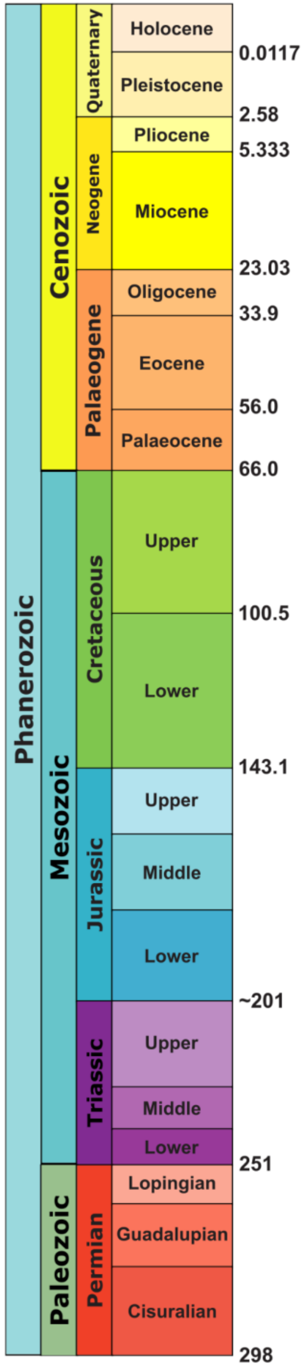
Eruption of Eocene basalt onto White Hills Gravel

Weathering of Eocene basalt



But then.....

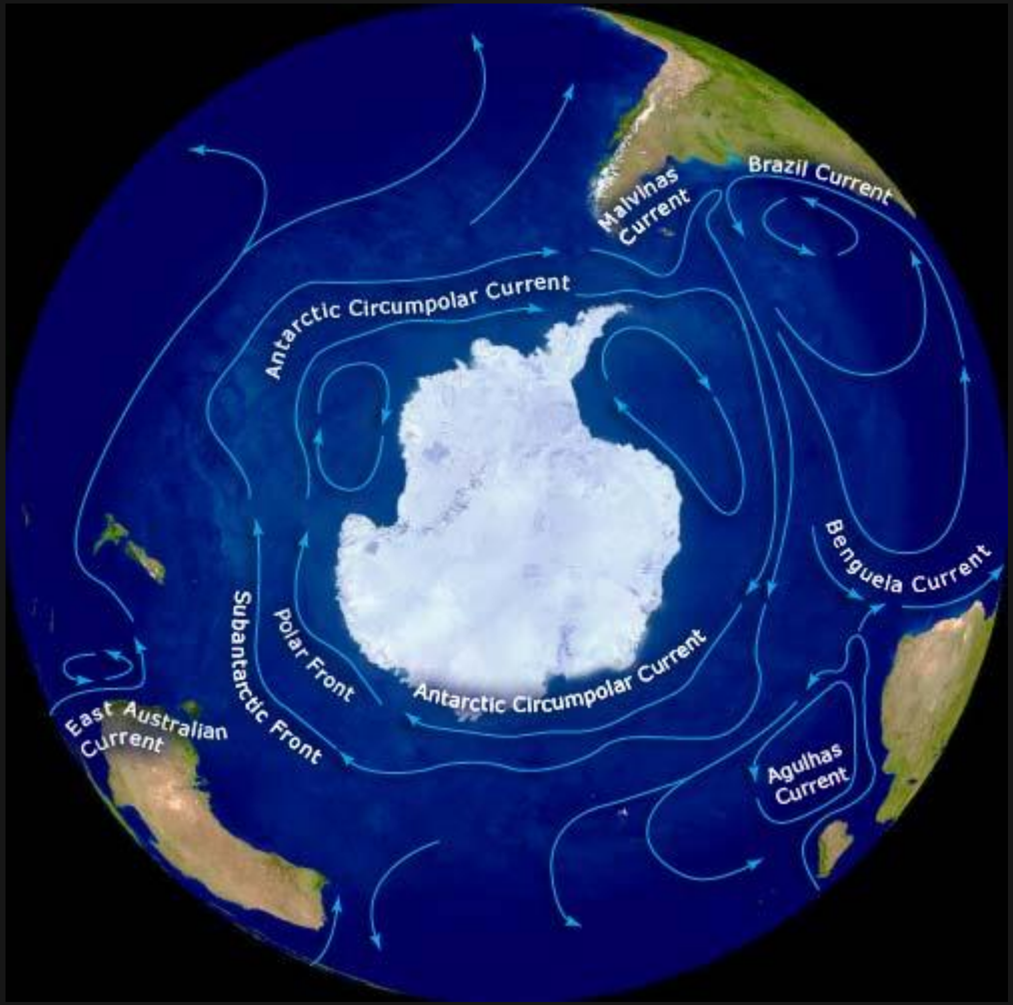
Adapted from Andrews & Cayley, 2025



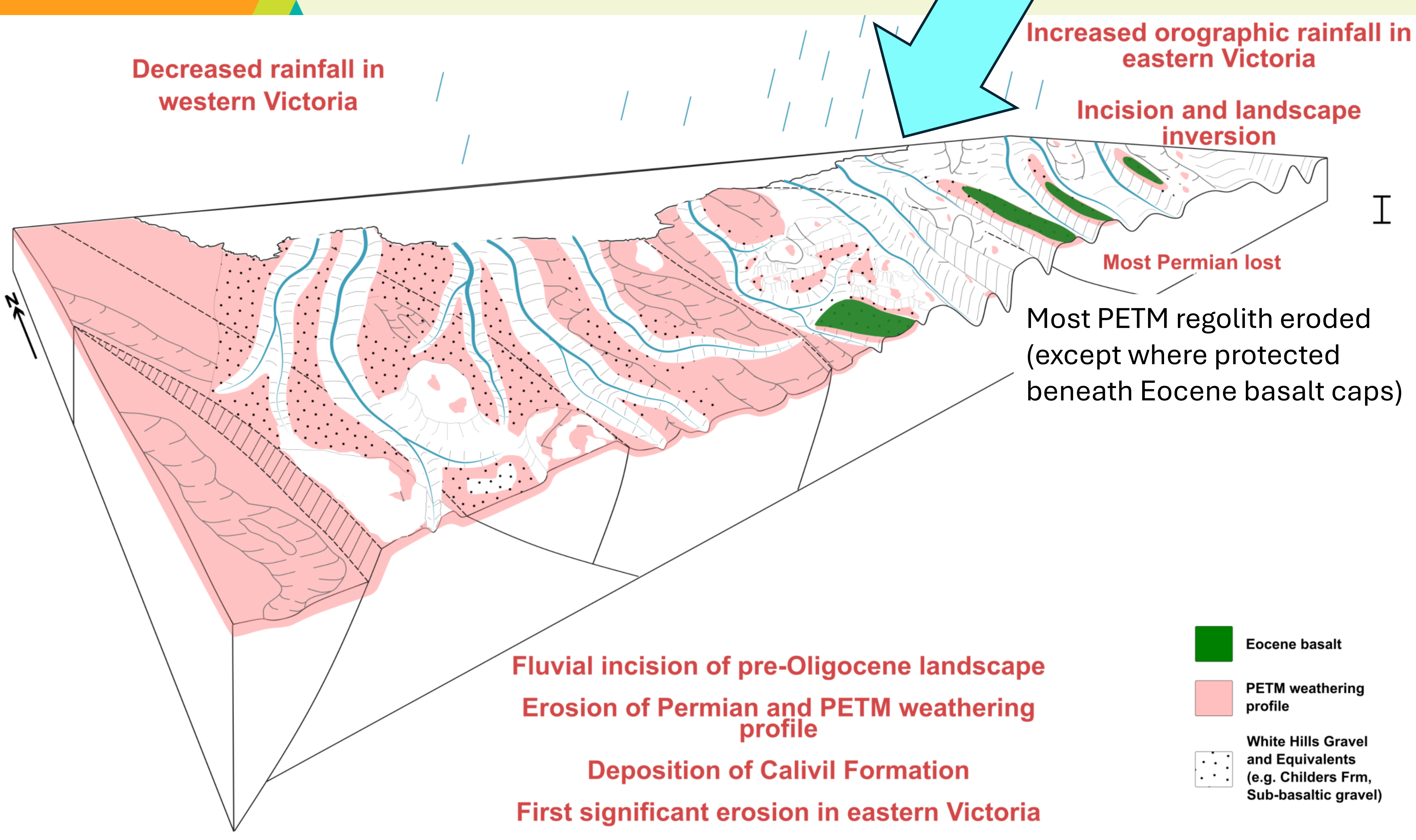
South America – Australia – Antarctica separations finally allowed full development of Circum-Antarctic ocean circulation.

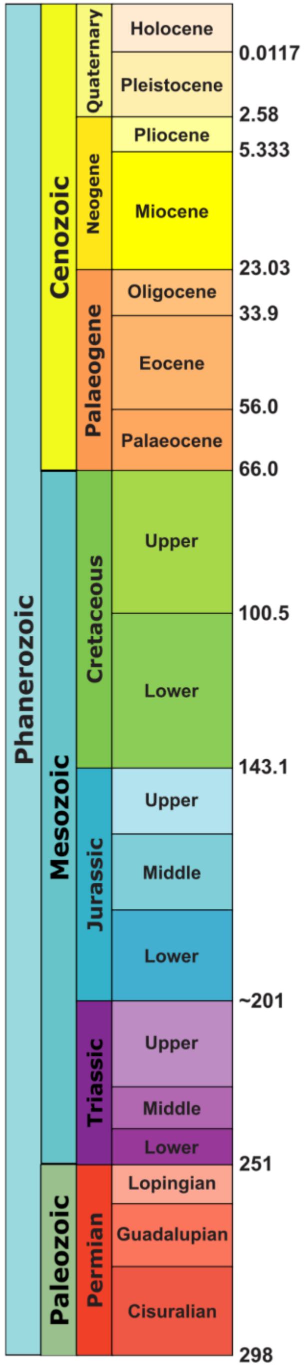
This polarised global temperatures and exposed southern Australia to a cold ocean.

Cold ocean = dry climate. Victoria dried out in the Oligocene. Virtually no erosion evident anywhere.



But then.....





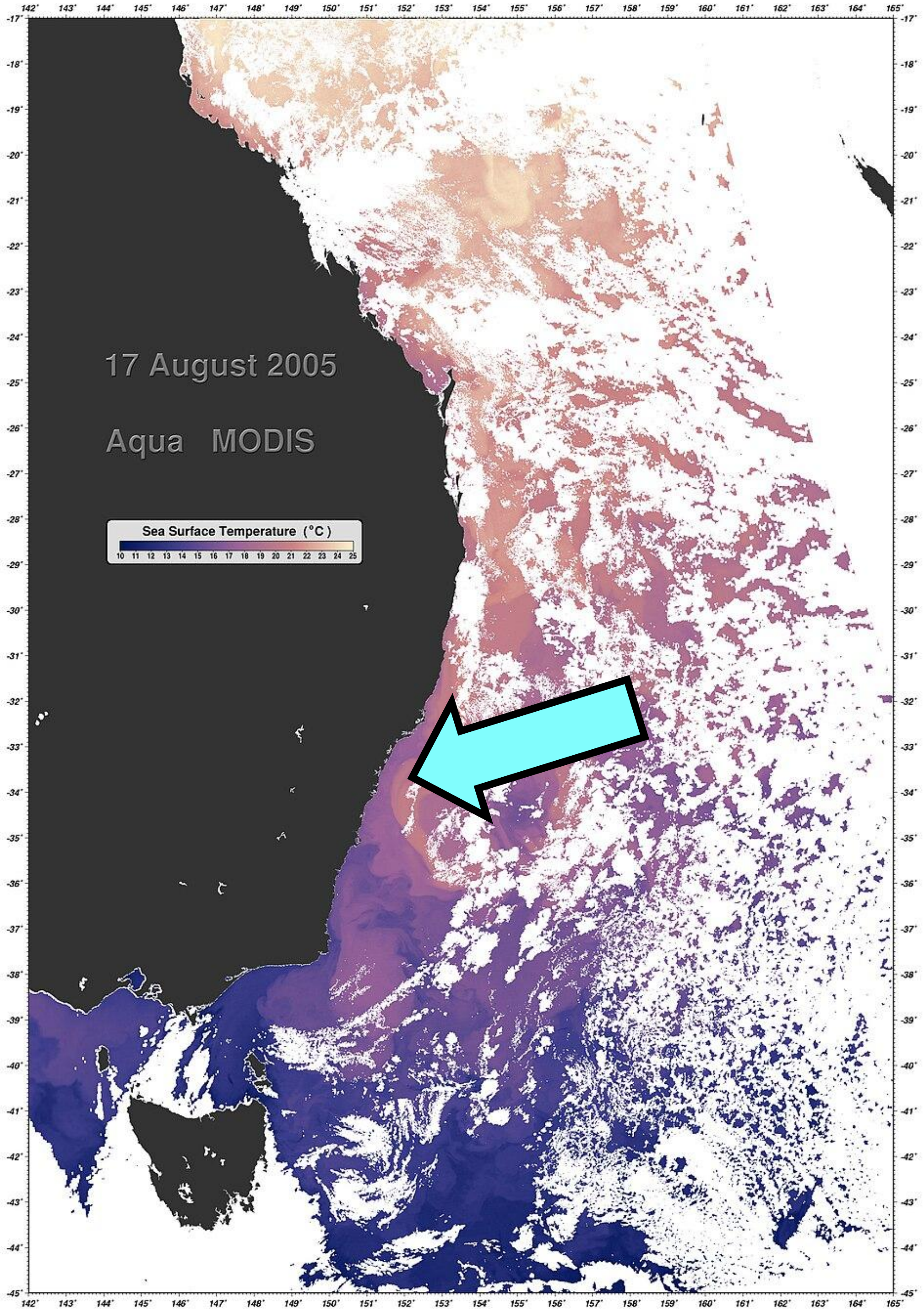
Adapted from Andrews & Cayley, 2025

East Australian Current (EAC) – initiated in the Oligo-Miocene. (e.g. Eberli 2022)

The imposition of a completely new rainfall regime for SE Australia, from the East!

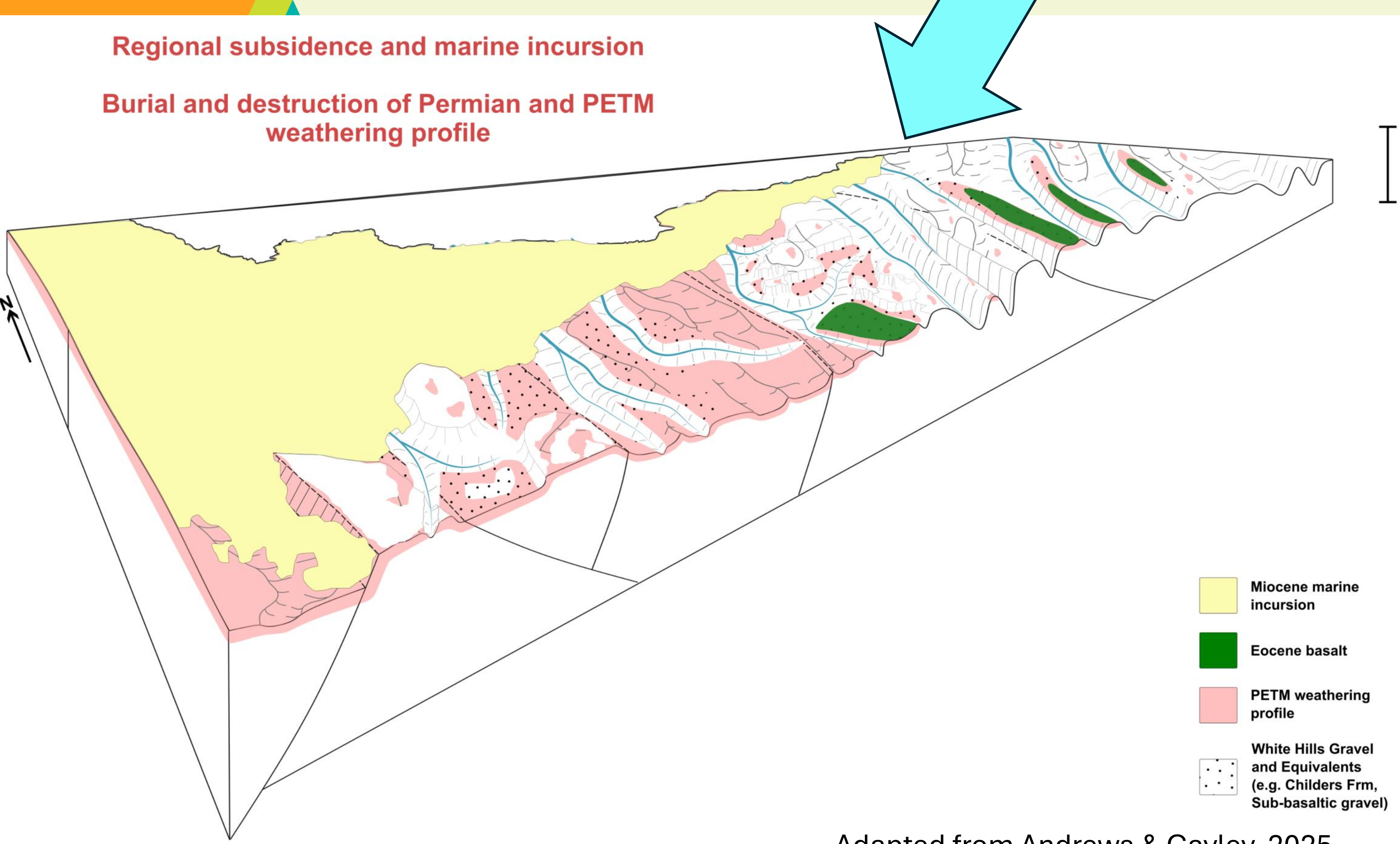
Now its western Victoria's turn to be in a persistent rain shadow!

By NASA - http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=15366, Public Domain, https://commons.wikimedia.org/w/index.php?curid=11578179

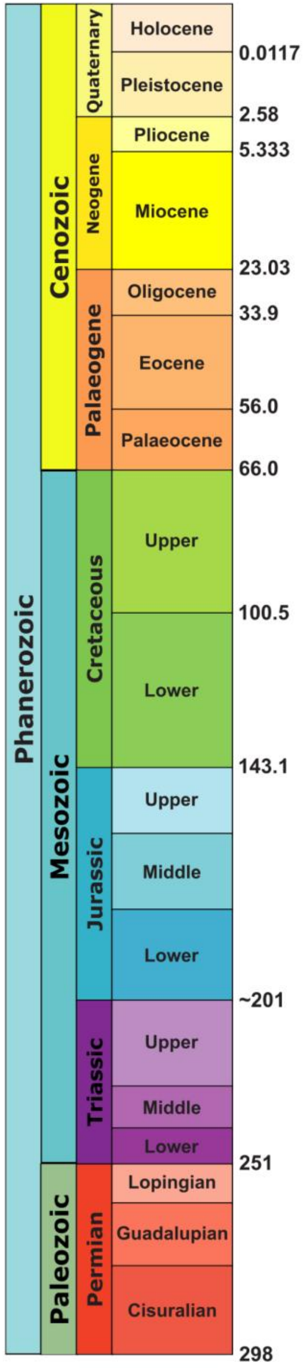


Regional subsidence and marine incursion

Burial and destruction of Permian and PETM weathering profile

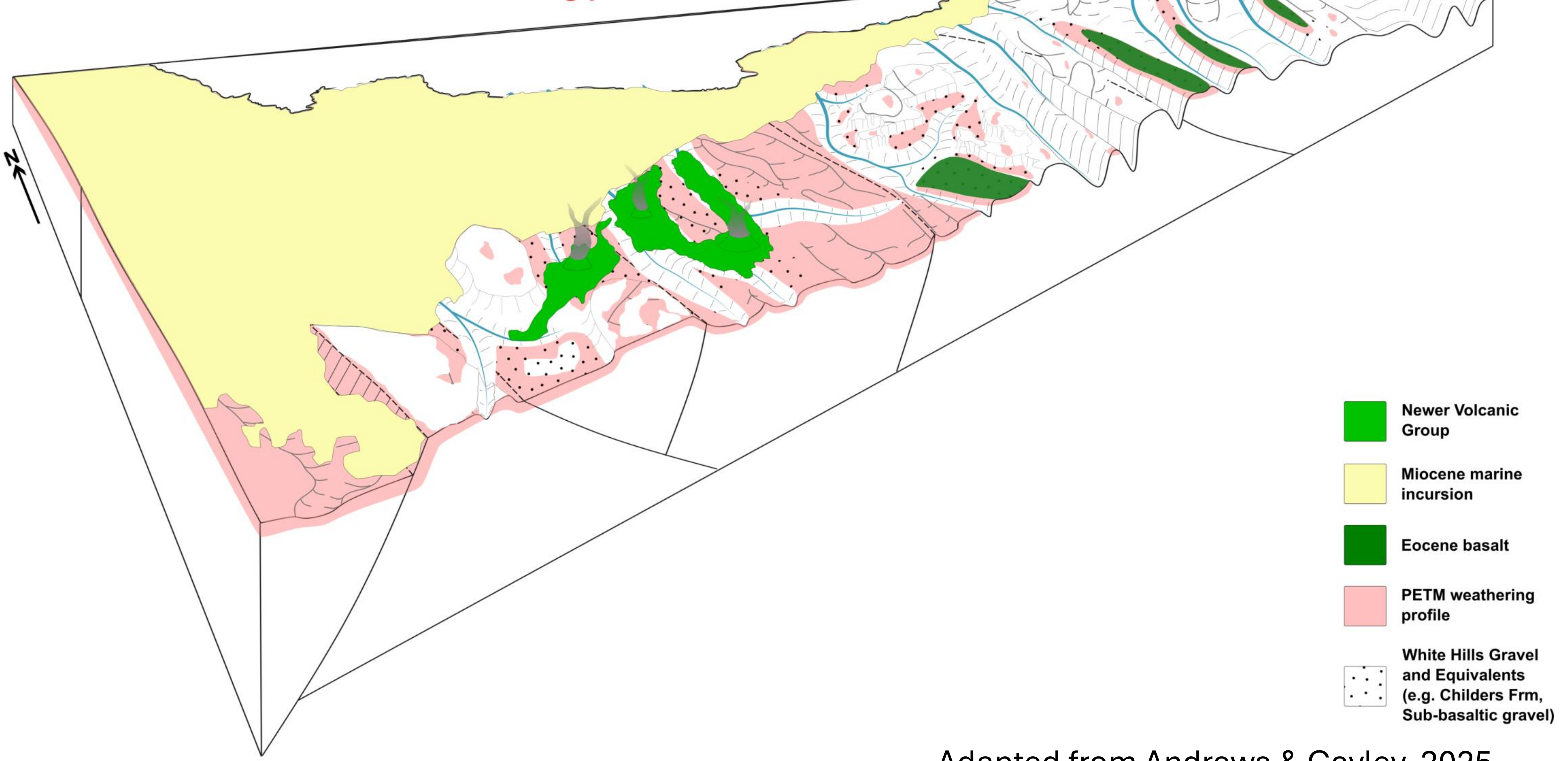


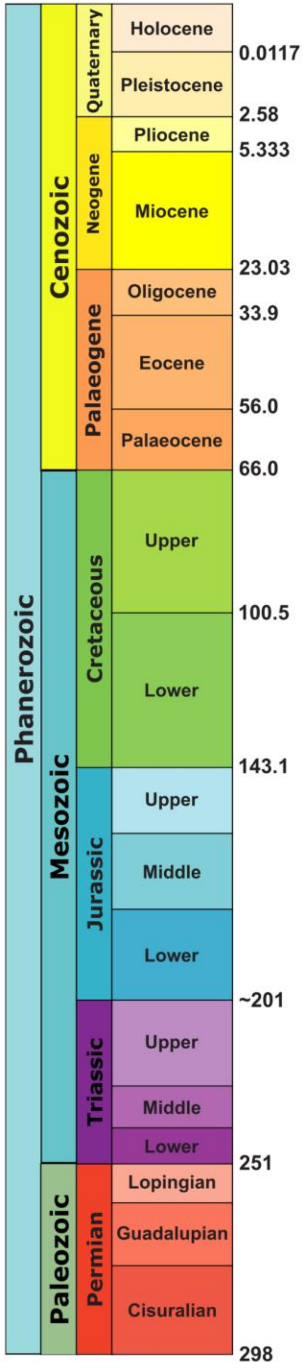
Adapted from Andrews & Cayley, 2025



Eruption of Newer Volcanic Group

Local burial and destruction of Permian and PETM weathering profile





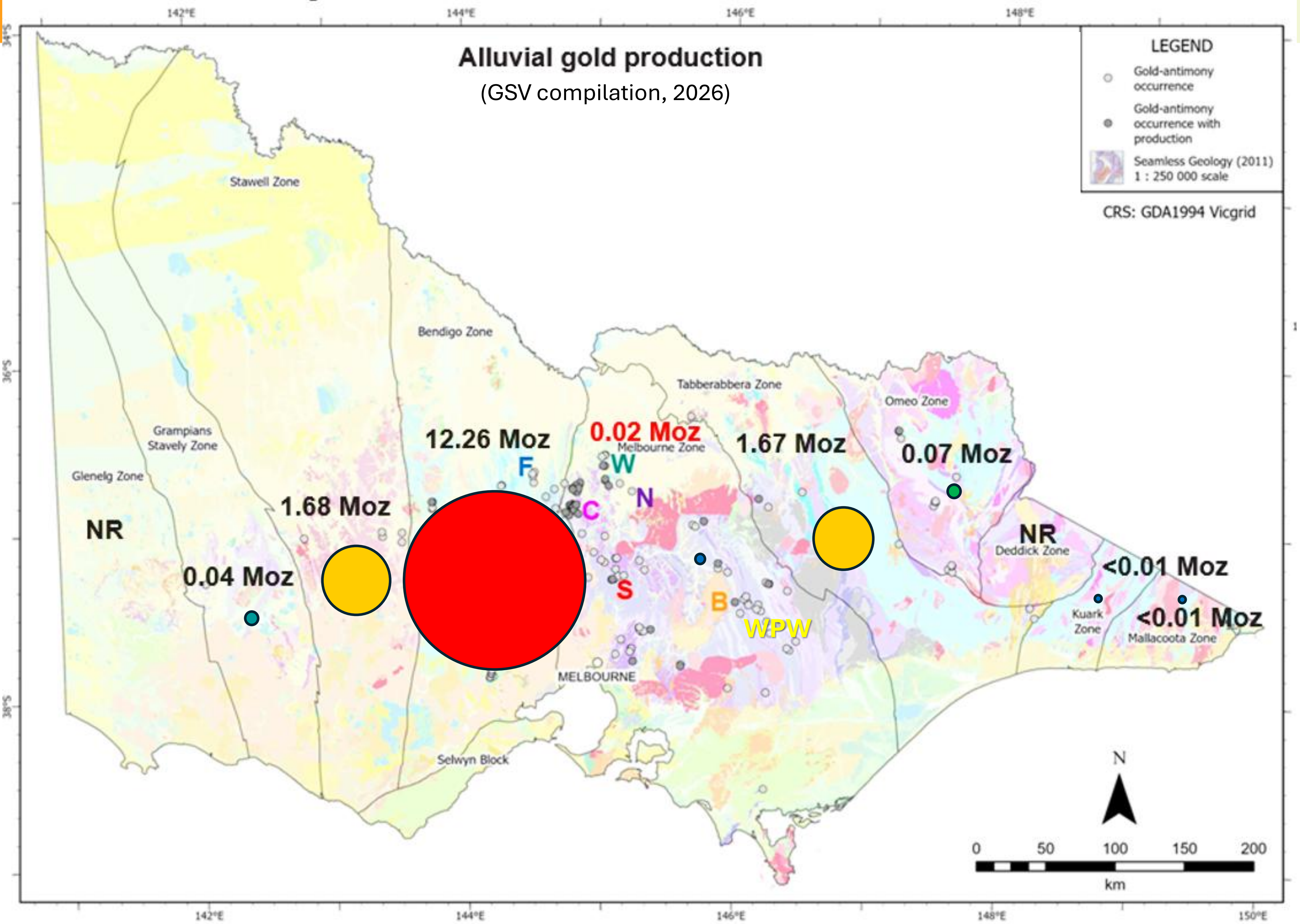
Adapted from Andrews & Cayley, 2025

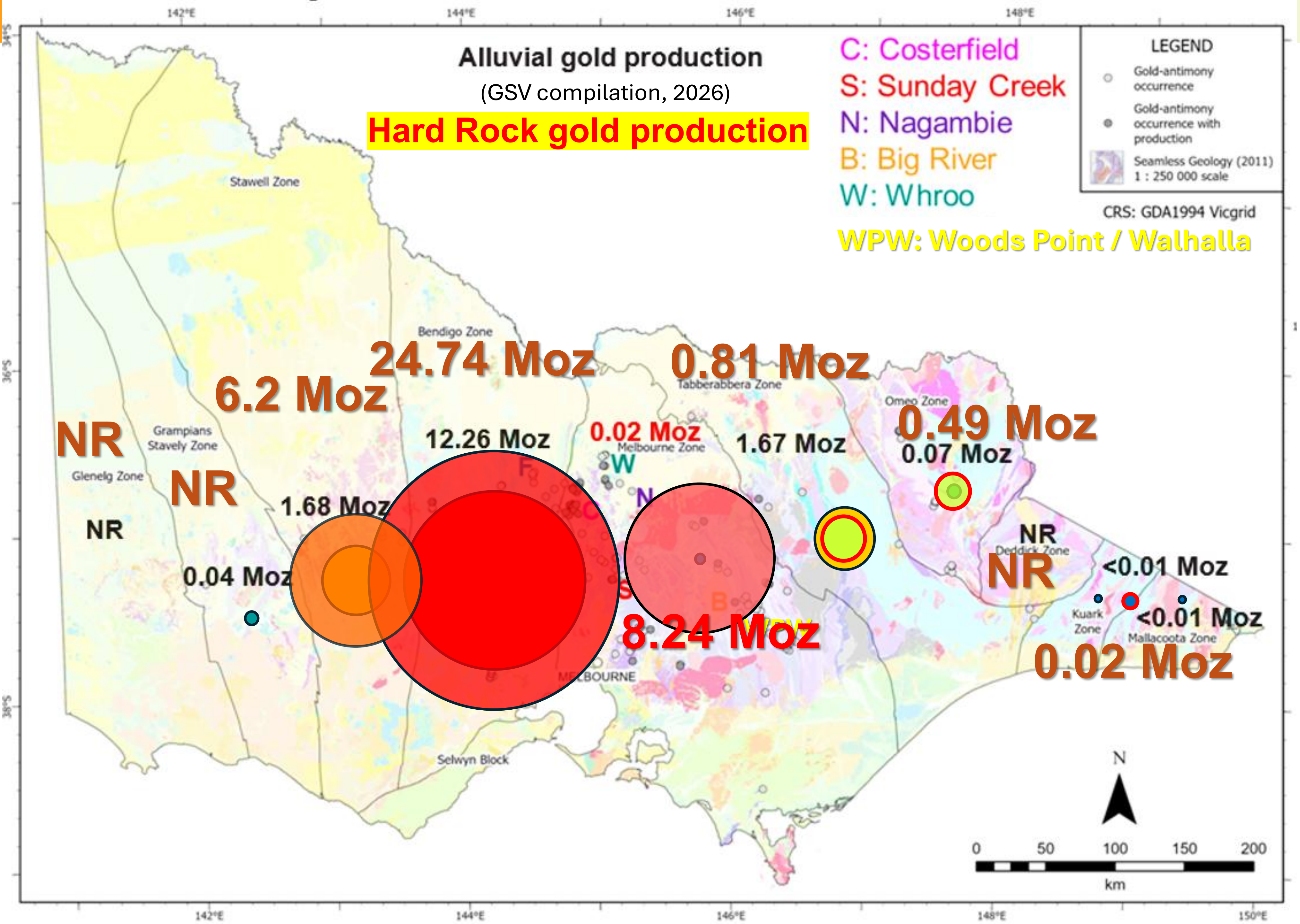
New landscape evolution constraints improve:

Mineral exploration. Prospectivity targeting.

eg: Gold – is historical placer production representative
of primary endowment potential?

If not – have potentially prospective regions been overlooked?


Alluvial gold production
(GSV compilation, 2026)
LEGEND
Gold-antimony occurrence
Gold-antimony occurrence with production
Seamless Geology (2011) 1 : 250 000 scale
CRS: GDA1994 Vicgrid
Stawell Zone
Bendigo Zone
Tabberabbera Zone
Omeo Zone
Grampians Stavely Zone
Glenelg Zone
Melbourne Zone
Deddick Zone
Kuark Zone
Mallacoota Zone
Selwyn Block
MELBOURNE
NR
NR
12.26 Moz
0.02 Moz
1.67 Moz
0.07 Moz
1.68 Moz
0.04 Moz
<0.01 Moz
<0.01 Moz
F
W
C
N
S
B
WPW
N
0 50 100 150 200
km

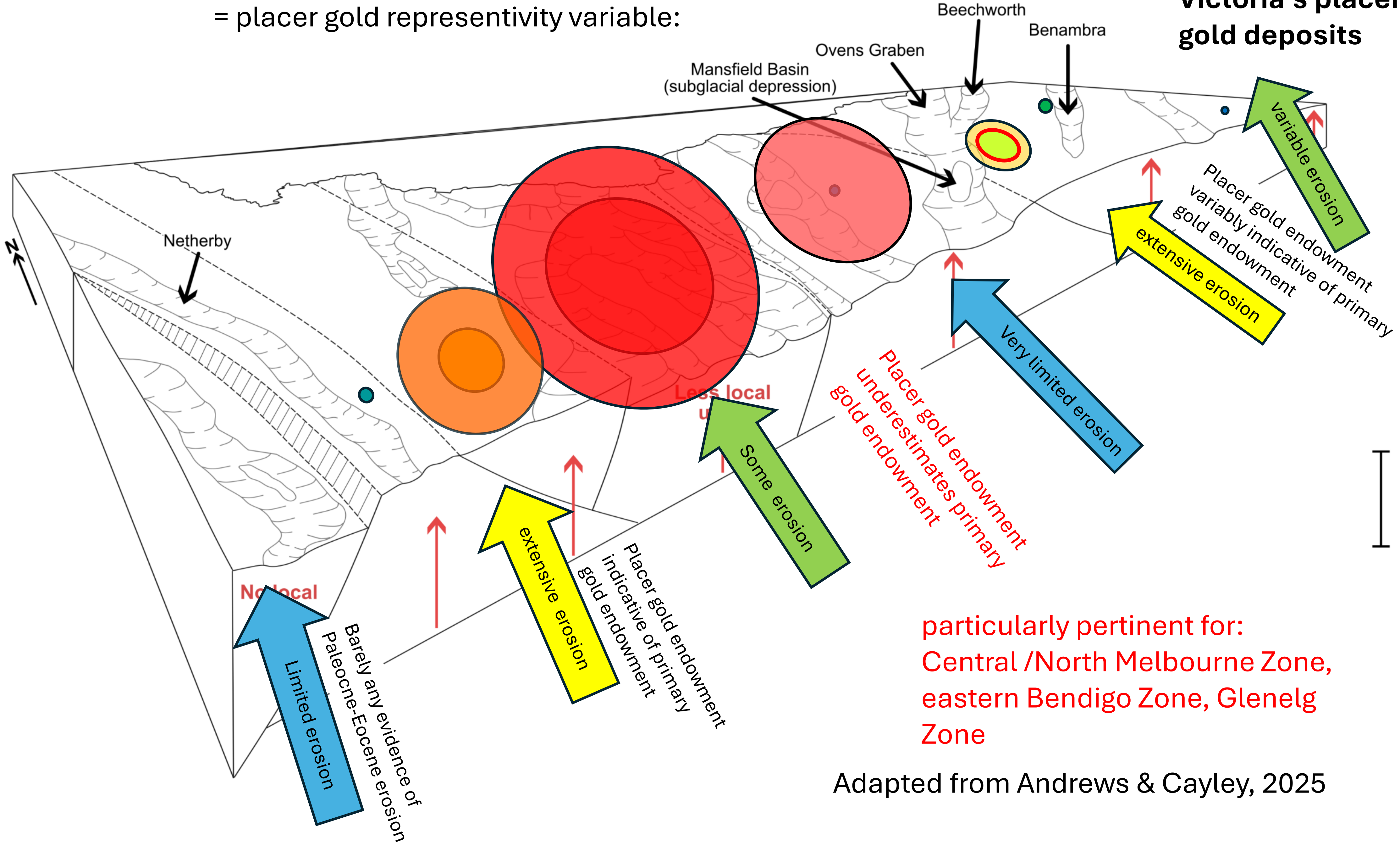


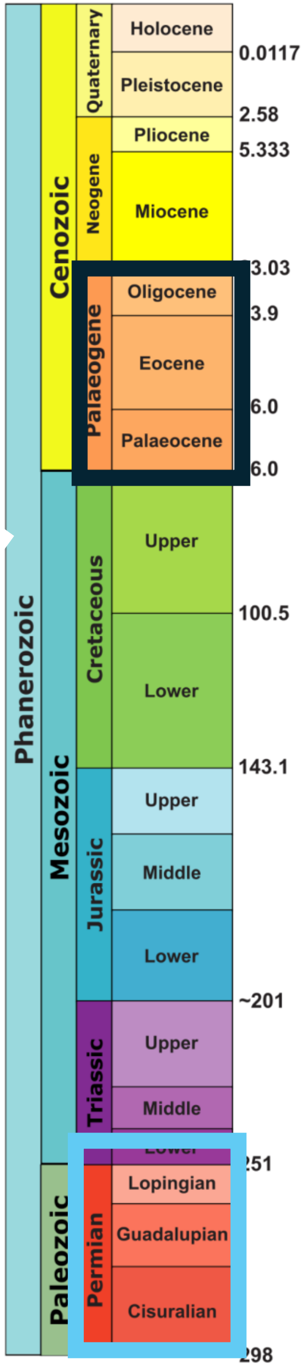
Alluvial gold production
(GSV compilation, 2026)
Hard Rock gold production
C: Costerfield
S: Sunday Creek
N: Nagambie
B: Big River
W: Whroo
WPW: Woods Point / Walhalla
LEGEND
Gold-antimony occurrence
Gold-antimony occurrence with production
Seamless Geology (2011) 1 : 250 000 scale
CRS: GDA1994 Vicgrid
Stawell Zone
Bendigo Zone
Tabberabbera Zone
Omeo Zone
Grampians Stavely Zone
Glenelg Zone
Melbourne Zone
Deddick Zone
Kuark Zone
Mallacoota Zone
Selwyn Block
MELBOURNE
24.74 Moz
0.81 Moz
6.2 Moz
0.49 Moz
0.07 Moz
12.26 Moz
0.02 Moz
1.67 Moz
1.68 Moz
0.04 Moz
8.24 Moz
<0.01 Moz
<0.01 Moz
0.02 Moz
NR
NR
NR
NR
NR
C
S
N
B
W
N
0 50 100 150 200
km
142°E
144°E
146°E
148°E
150°E
36°S
38°S

Post-Permian denudation history variable

= placer gold representivity variable:

Victoria's placer gold deposits

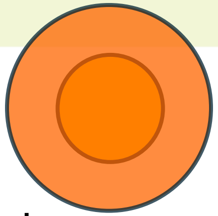




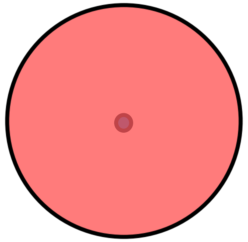
particularly pertinent for:
Central /North Melbourne Zone, eastern Bendigo Zone, Glenelg Zone

Adapted from Andrews & Cayley, 2025

Stawell Zone, Omeo Zone –
(mostly) deeply eroded post-Permian; historical alluvial gold likely ~representative of primary gold endowment.

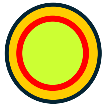


Melbourne Zone –
lack of historical alluvial gold production is due to lack of post-Permian erosion,
NOT lack of primary gold endowment



Bendigo Zone –
quite limited post-Permian erosion. Overall primary gold endowment probably even better than
epic historical alluvial gold production indicates

Tabberabbera Zone –
deeply eroded post-Permian - historical alluvial gold production should be ~representative of gold endowment.
By comparison with Stawell Zone pattern: undiscovered multi-million oz primary gold exists



Grampians-Stavely Zone –
lots of post-Permian erosion but of barren cover rocks (e.g. Grampians Group). Cambrian bedrock under-explored

Glenelg Zone –
hardly any post-Permian erosion but also: little evidence of strong gold endowment anyway.

Far eastern Victoria – variable post-Permian erosion, but little evidence of major gold endowment .