A Geological Tour of Namibia

Dorset Geologist's Association Group

20 February 2024

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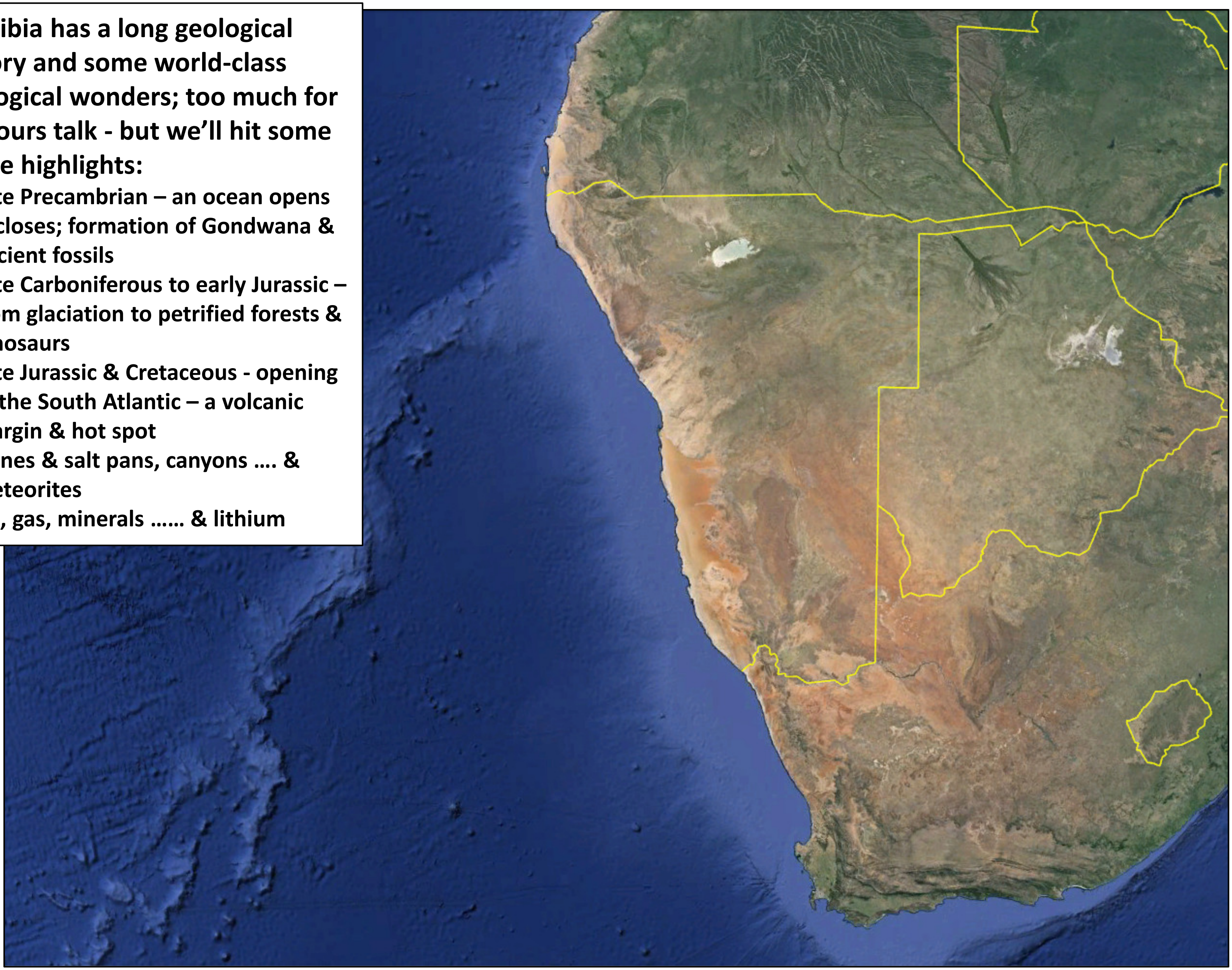
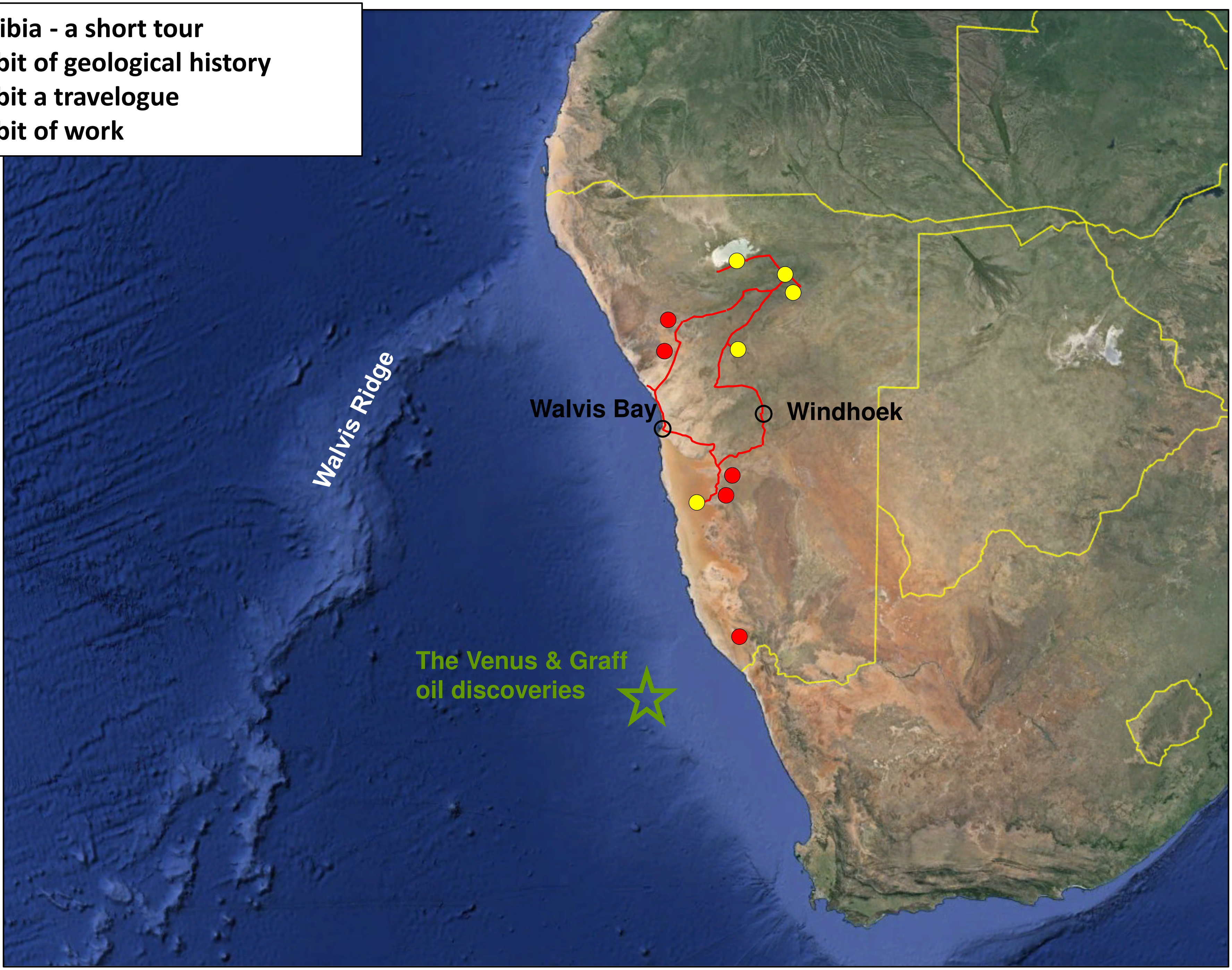
Namibia has a long geological history and some world-class geological wonders; too much for an hours talk - but we'll hit some of the highlights:

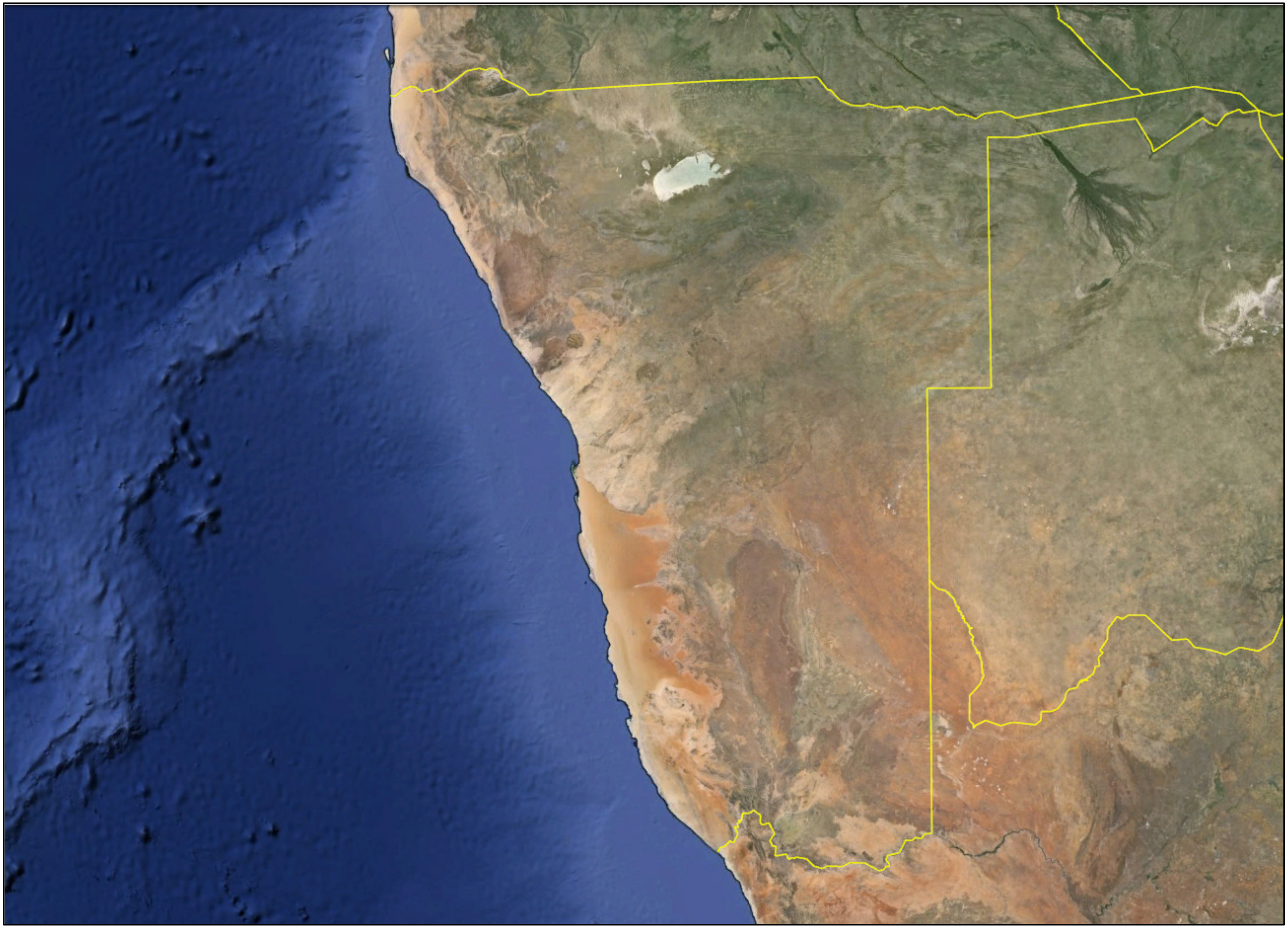
- Late Precambrian – an ocean opens & closes; formation of Gondwana & ancient fossils
- Late Carboniferous to early Jurassic – from glaciation to petrified forests & dinosaurs
- Late Jurassic & Cretaceous - opening of the South Atlantic – a volcanic margin & hot spot
- Dunes & salt pans, canyons …. & meteorites
- Oil, gas, minerals …… & lithium



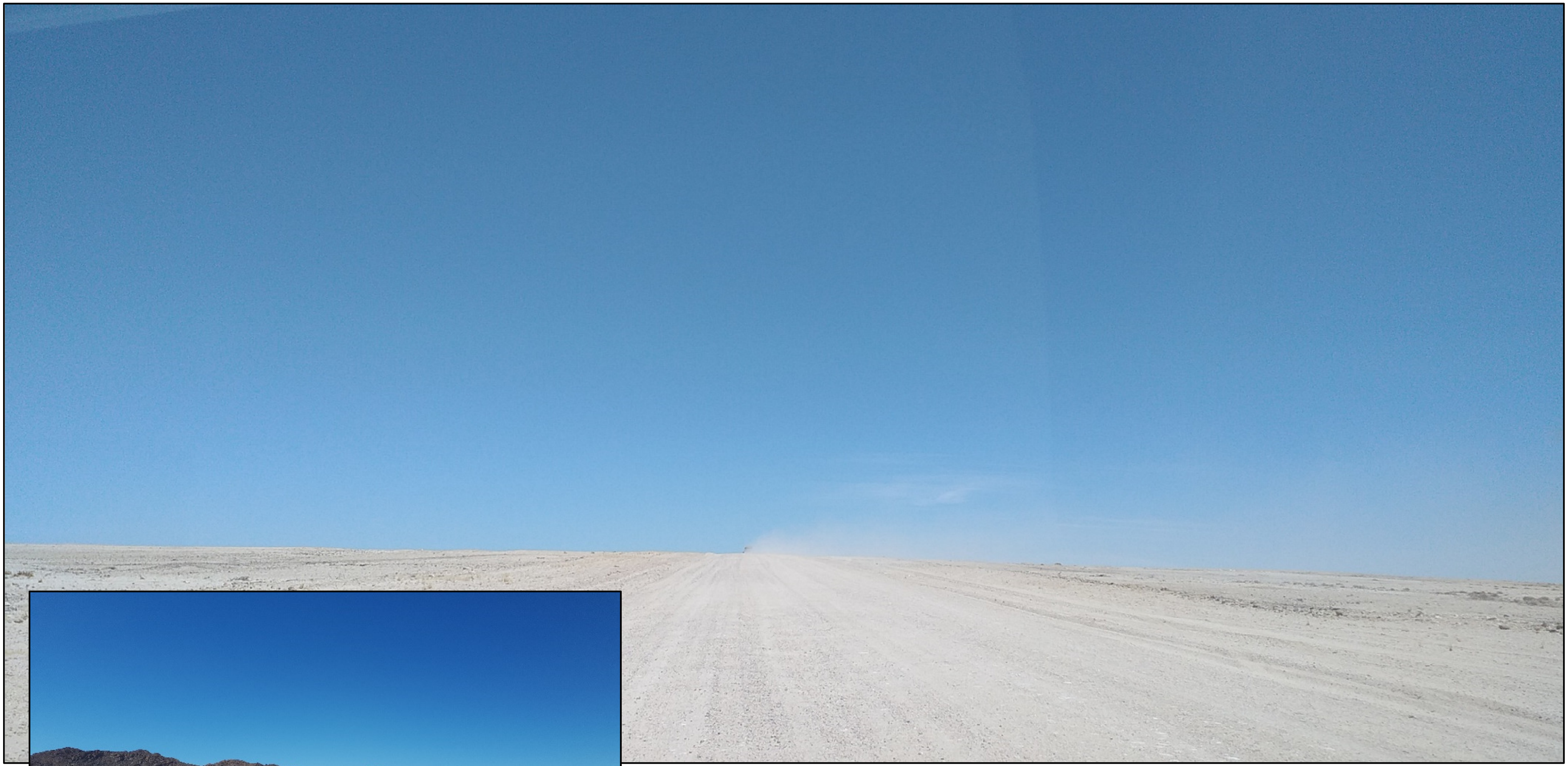
Namibia - a short tour

- A bit of geological history
- A bit a travelogue
- A bit of work

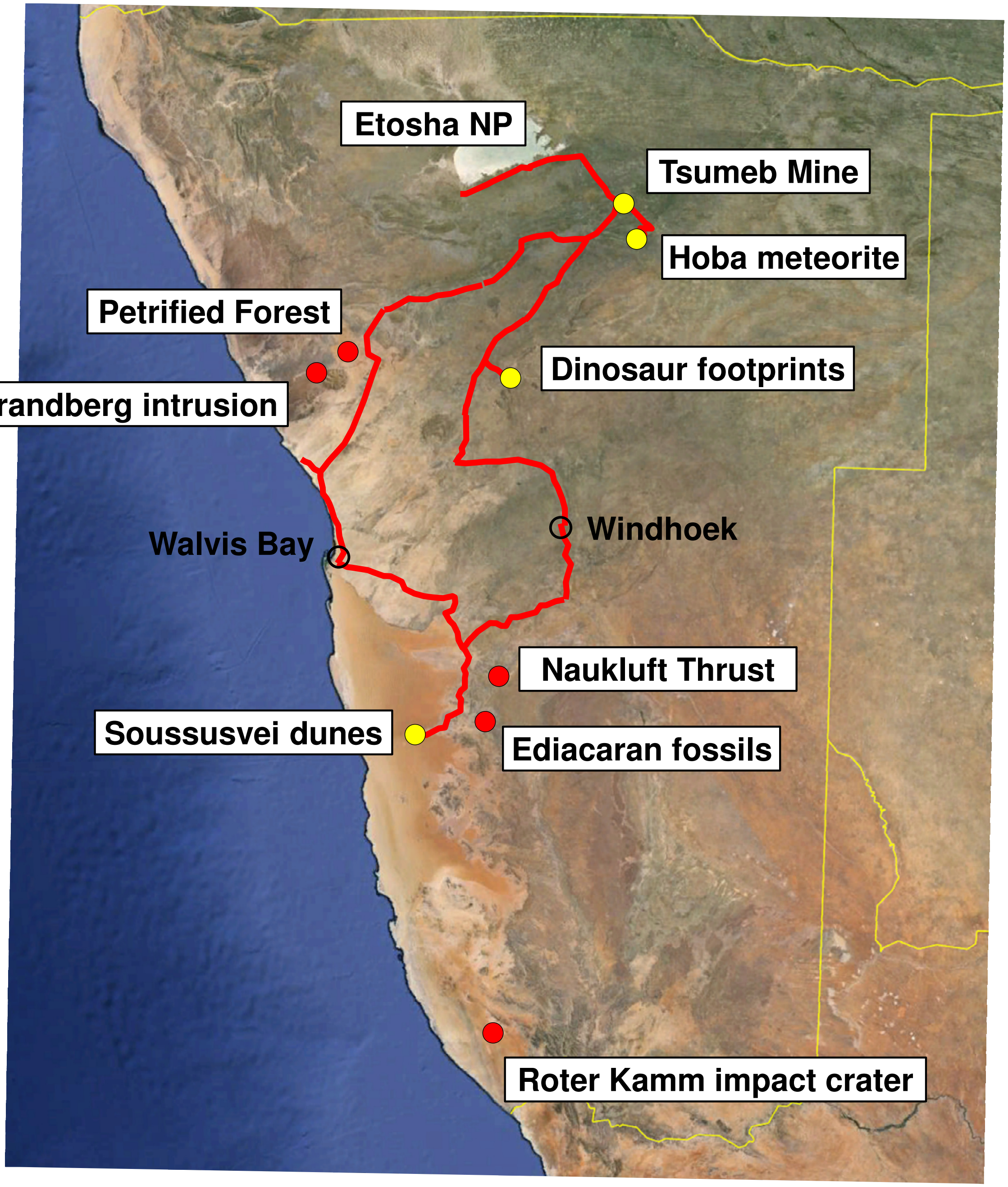


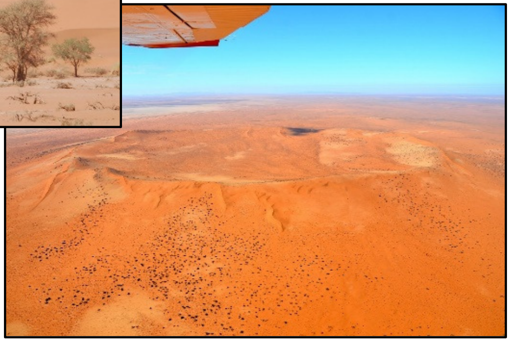



Blackers Bump
St Albans Ledge
Palaeo-river channel
The Well

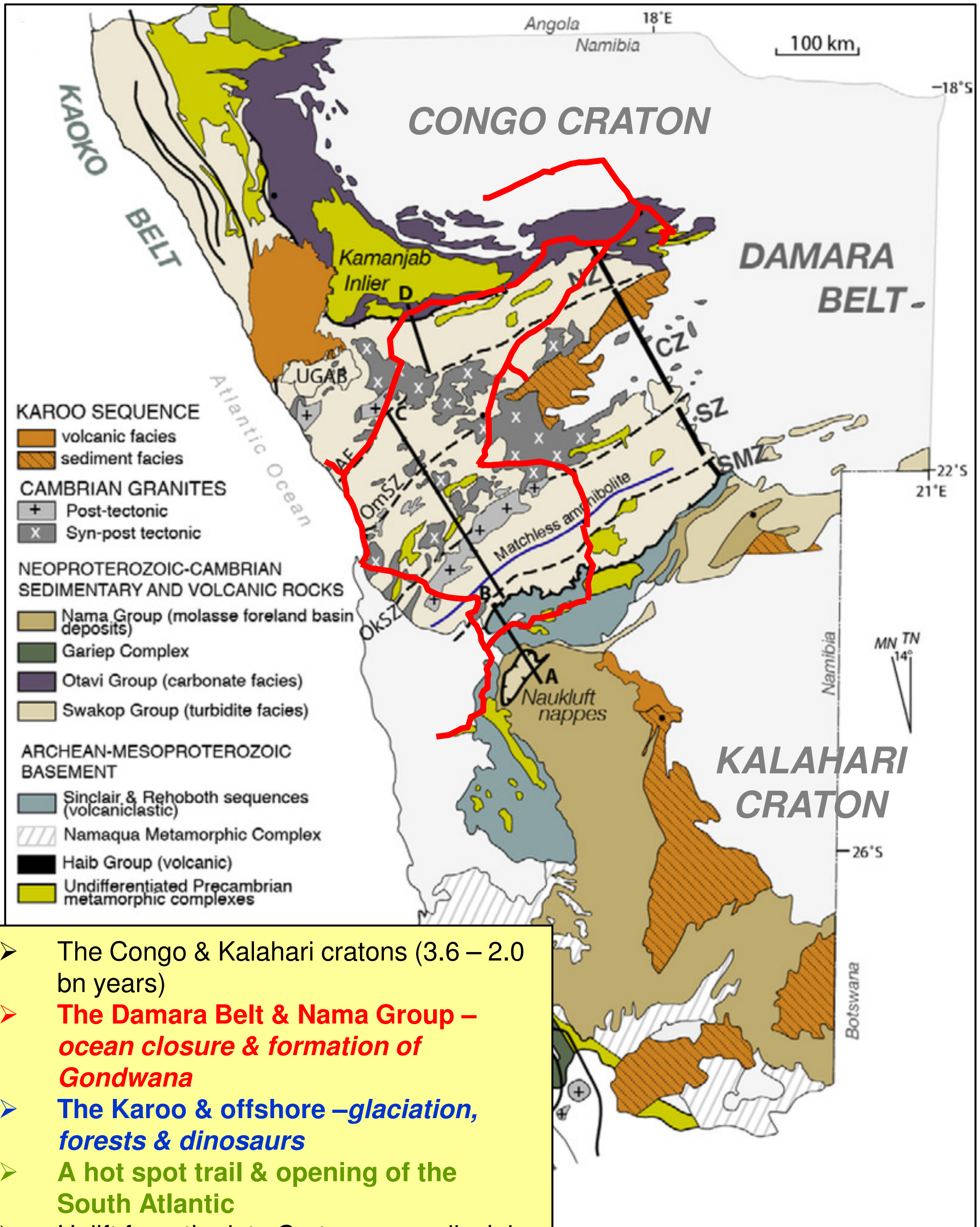


A typical highway

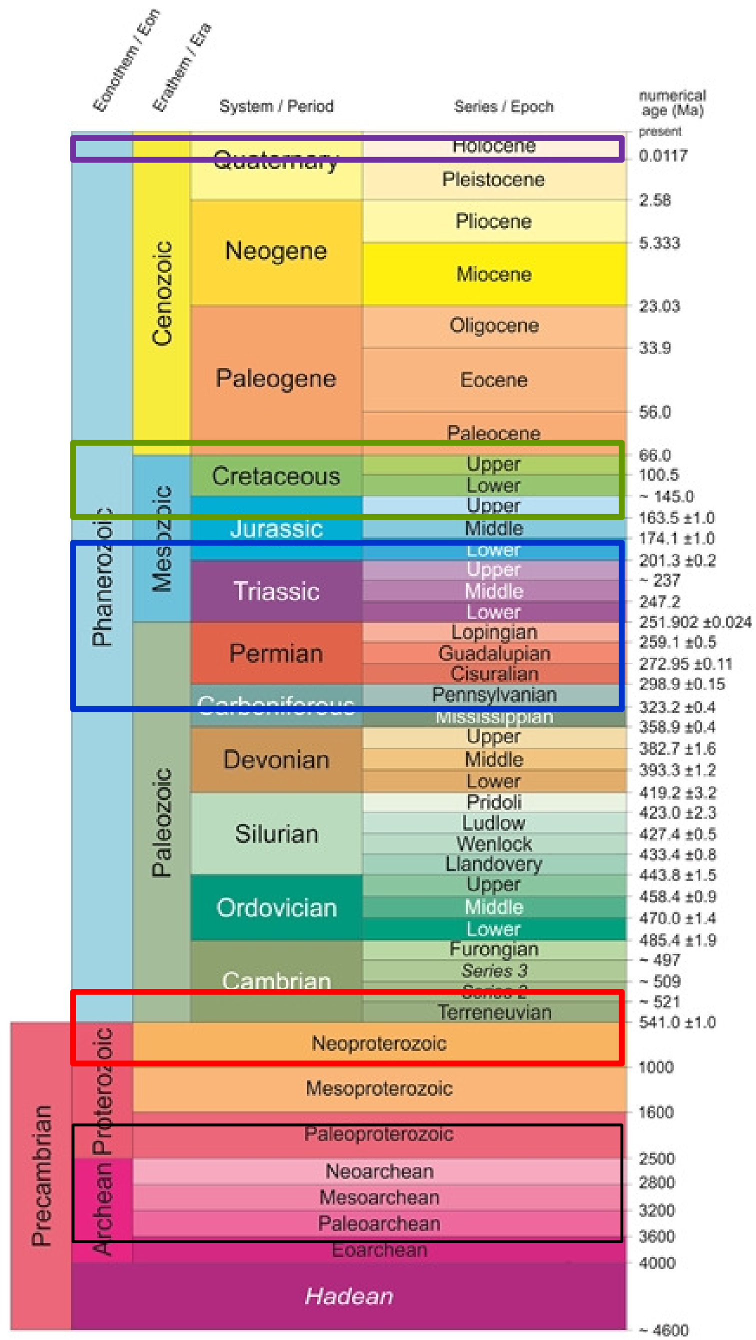




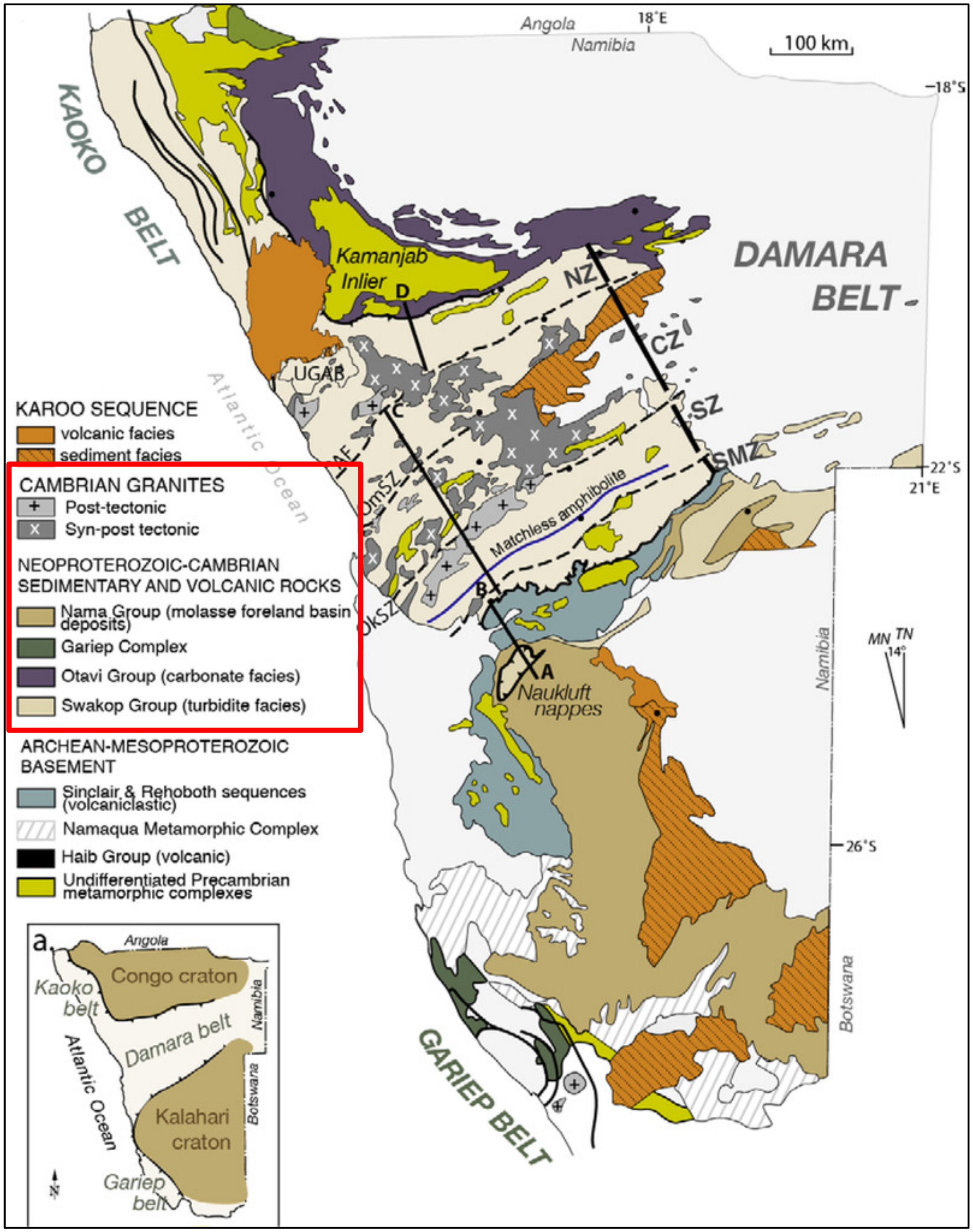
A few geological highlights

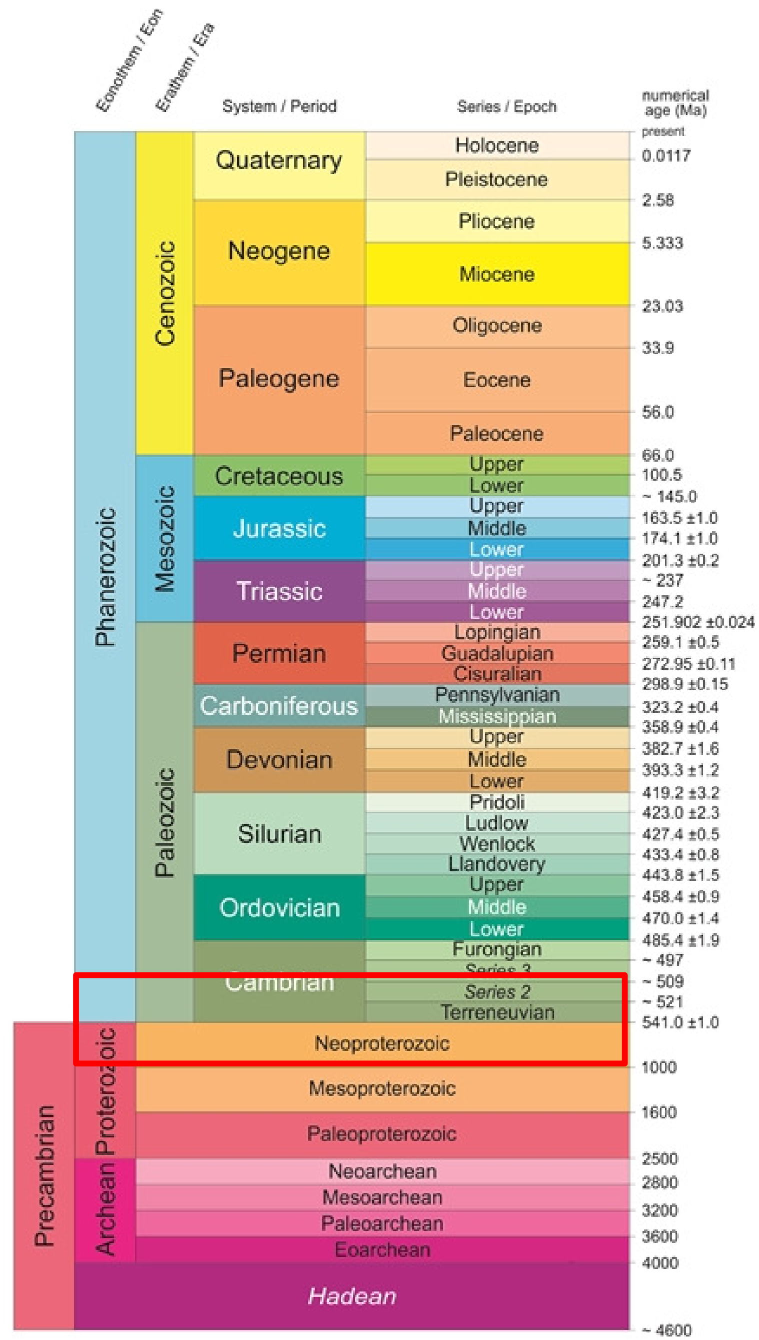


- ➢ The Congo & Kalahari cratons (3.6 – 2.0 bn years)
- ➢ **The Damara Belt & Nama Group – *ocean closure & formation of Gondwana***
- ➢ **The Karoo & offshore –*glaciation, forests & dinosaurs***
- ➢ **A hot spot trail & opening of the South Atlantic**
- ➢ Uplift from the late Cretaceous - alluvial & dune. Eocene rifting & phonolites> Miocene mammals & early apes
- ➢ **Today – *dunes & salt pans, canyons & meteorites***



Namibia – a quick history





Neoproterozoic & earliest Cambrian - the Damara Belt & Nama Group

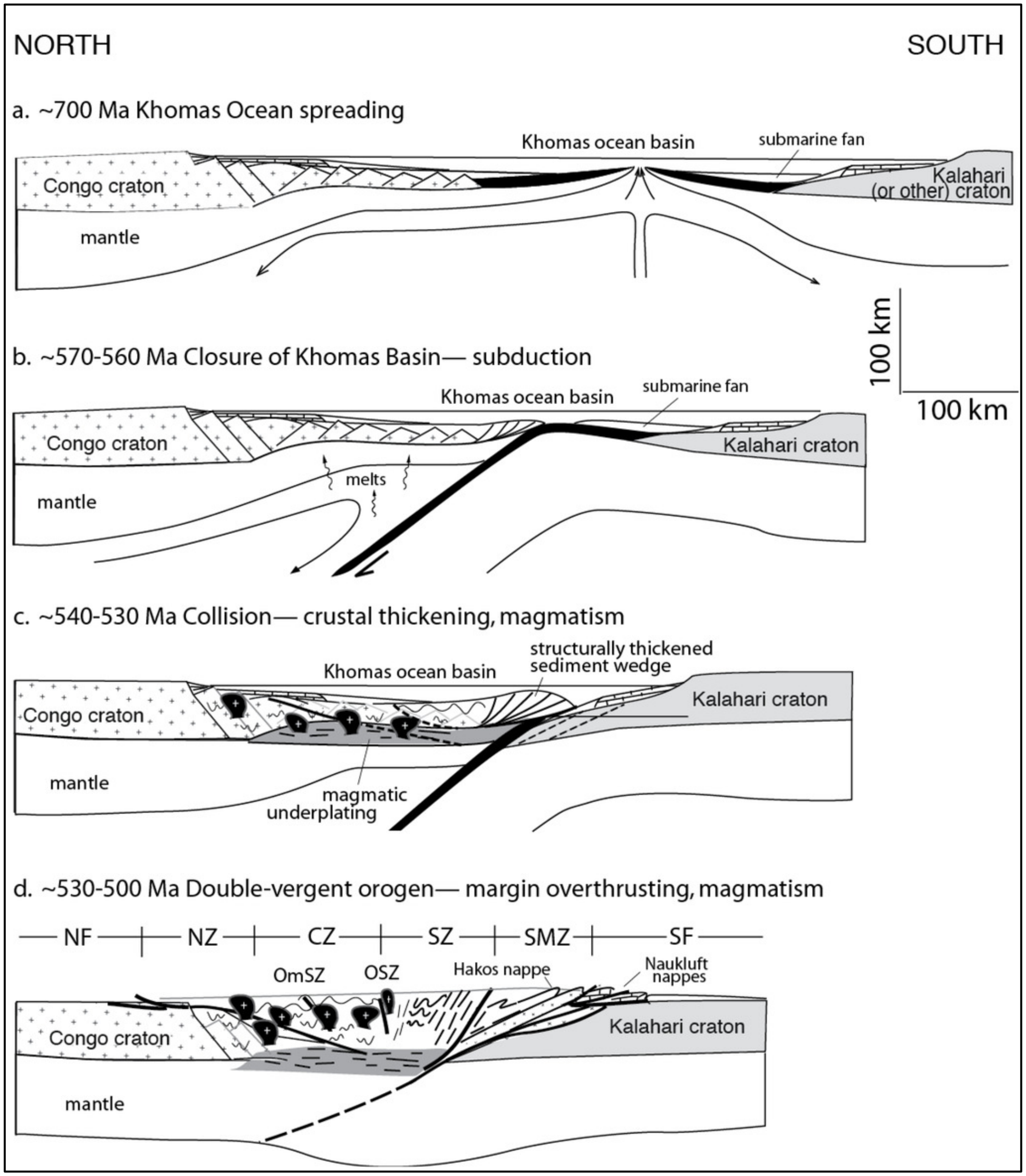
From Rodinia to Gondwana – the Damara Belt & the Pan-African Orogeny (the Neoproterozoic)

~ 780 Ma: early rifting

~740 Ma: the Khomas Ocean splits from the Rodinia Supercontinent - separating the Congo & Kalahari cratons

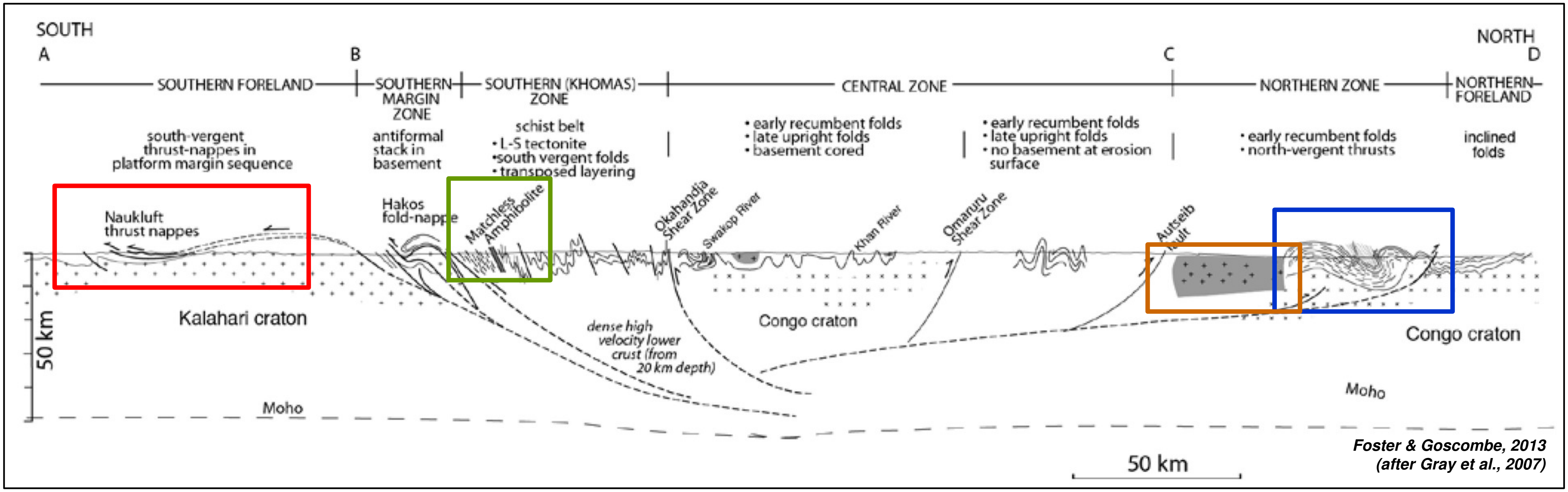
~ 570 Ma: convergence along a north-directed subduction zone below the Congo Craton

~530 to 500 Ma: orogenesis – ending ~ mid Cambrian



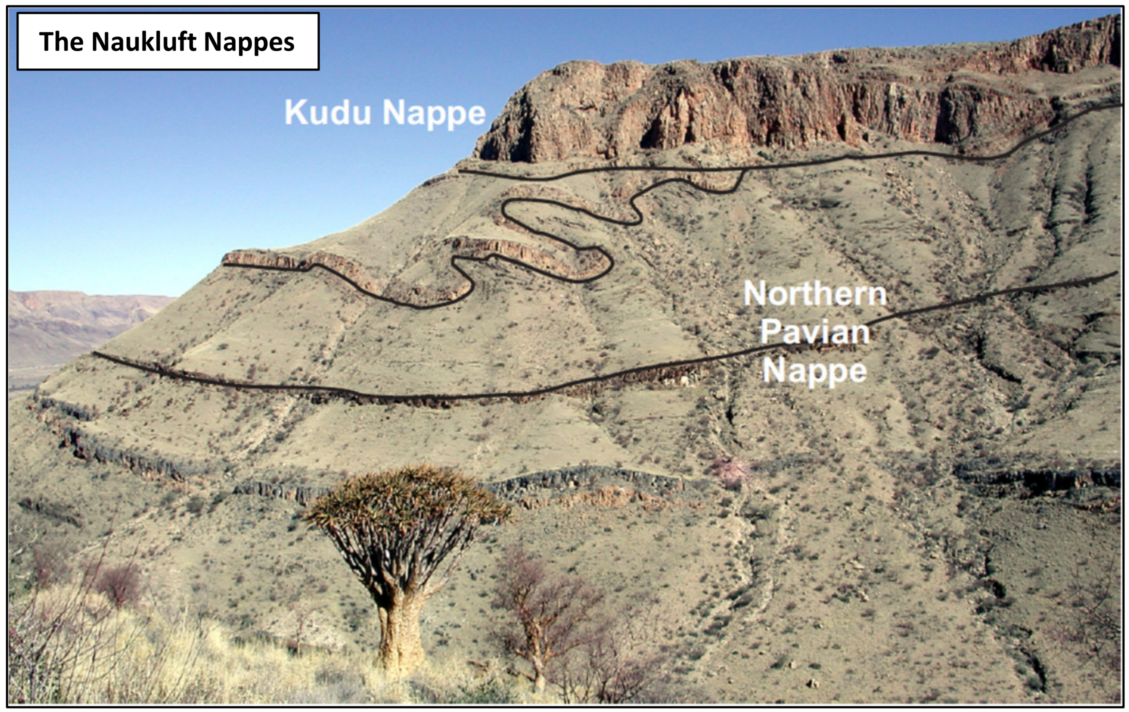
Foster & Goscombe, 2013
(after Barnes & Sawyer, 1980)

The Khomas Ocean & the Damara Belt



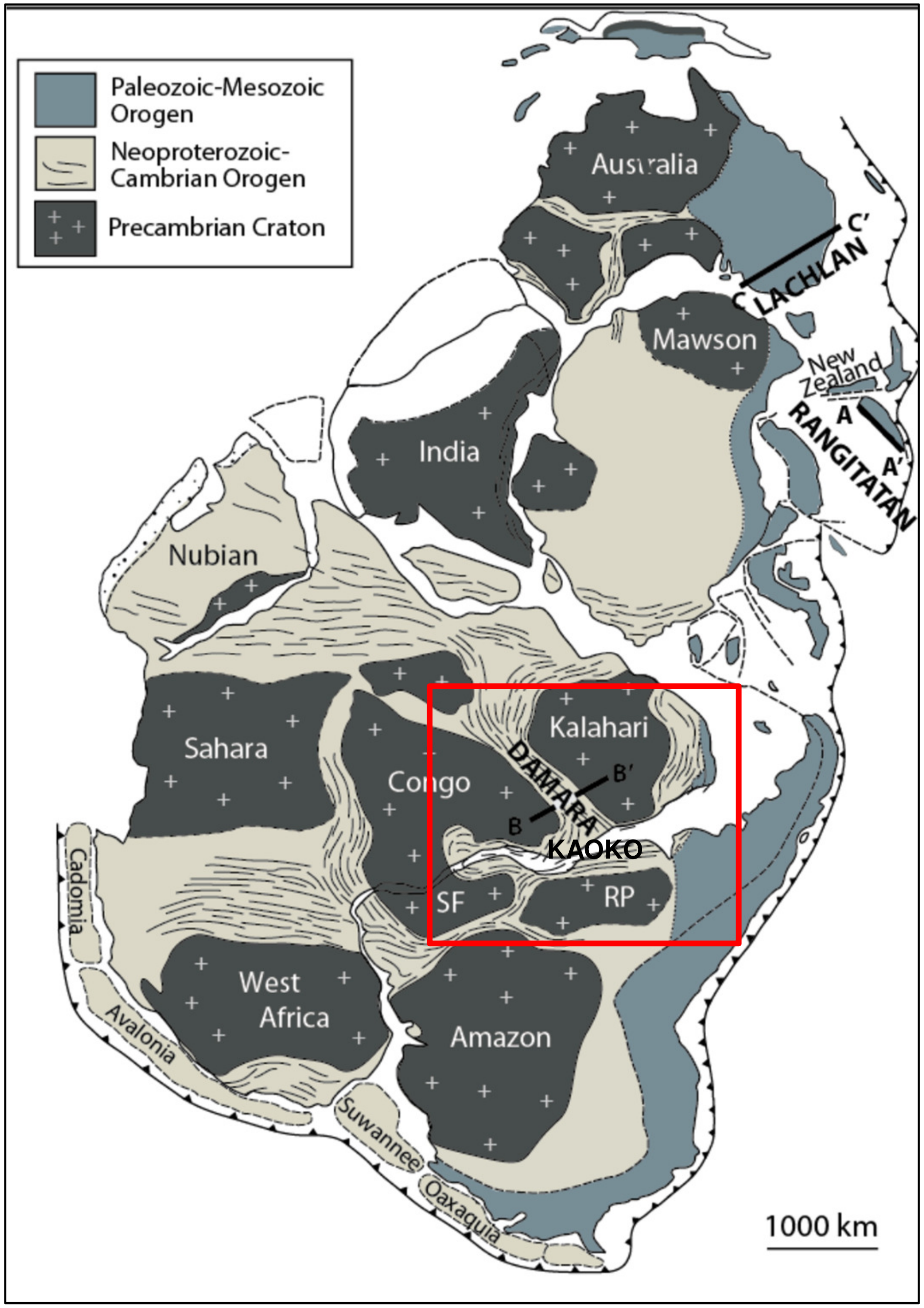
Foster & Goscombe, 2013
(after Gray et al., 2007)

- ➢ A thick carbonate platform on the Congo margin host stromatolites from ~ 740 Ma – below glacial sediments of the diamictites from the "Snowball Earth" glaciation (Cryogenian - ~ 710 Ma)
- ➢ Ediacaran fauna at 565 Ma – Kuibis Quartzite
- ➢ Large thrombolite / stromatolite reefs & earliest calcareous fossils from the late Ediacaran (547 Ma) – Upper Nama Group
- ➢ Matchless Belt ophiolite (amphibolite) – Khomas ocean crust obducted onto the Kalahari margin
- ➢ Naukluft Nappes over-thrust the Kalahari margin & Nama Group sediments – gravity glide lubricated by a "sole dolomite"
- ➢ Granite emplacement & pegmatites - Cambrian ~ 530-505 Ma



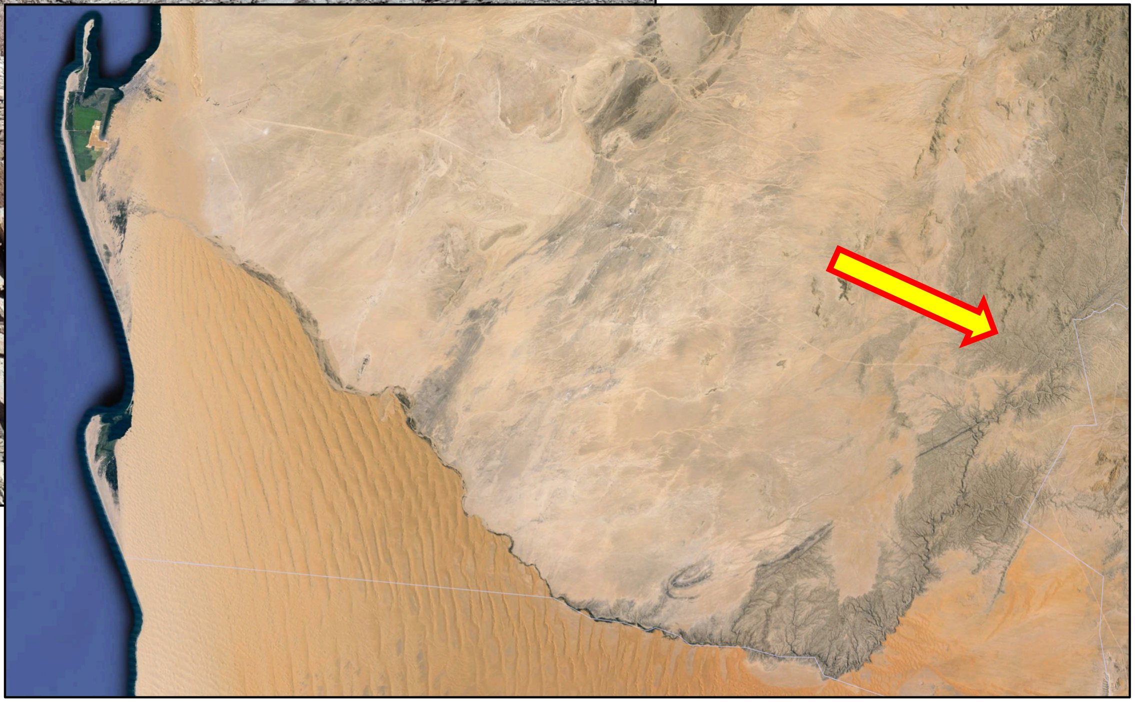
Namibia Geological Survey, 2017

The Damara Belt & Forelands



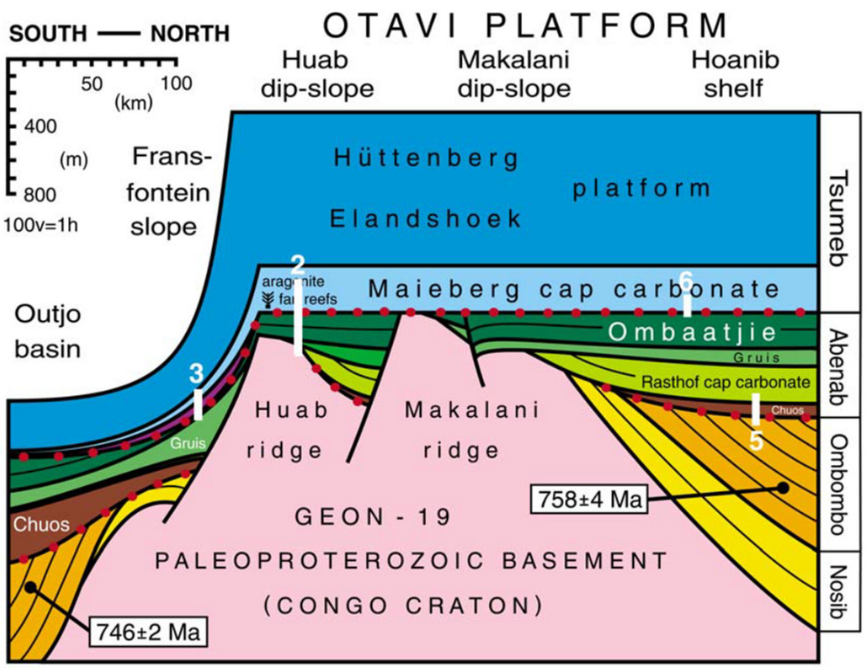
Foster & Goscombe, 2013

Consolidation of the Gondwana Supercontinent



Kuiseb Canyon – Damara schists

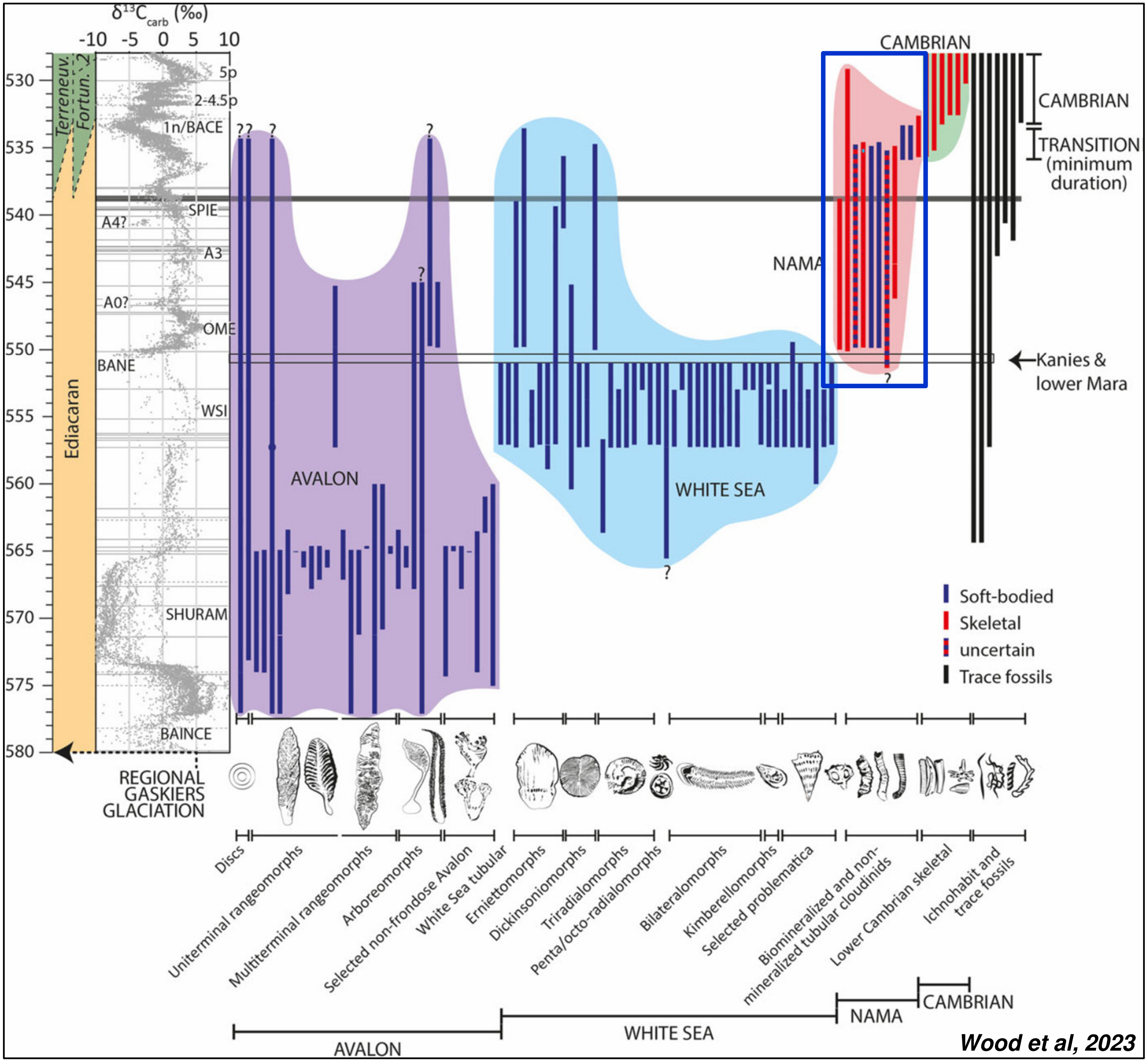
Photo: Sinclair Stammers



Hoffman, 2002

National Earth Science Museum, Windhoek

Otavi Group – carbonate platform & stromatolites (750-650 Ma)



Schwarzrand Subgroup (547.3 (+/- 0.3) Ma

Some of the earliest known organisms with a carbonate (aragonite) skeleton (*Namacalathus & Cloudina)* occur in late Ediacaran carbonate platform / thrombolite / stromatolite reefs of the upper Nama Group in the Zebra River & Tsaris Mountains

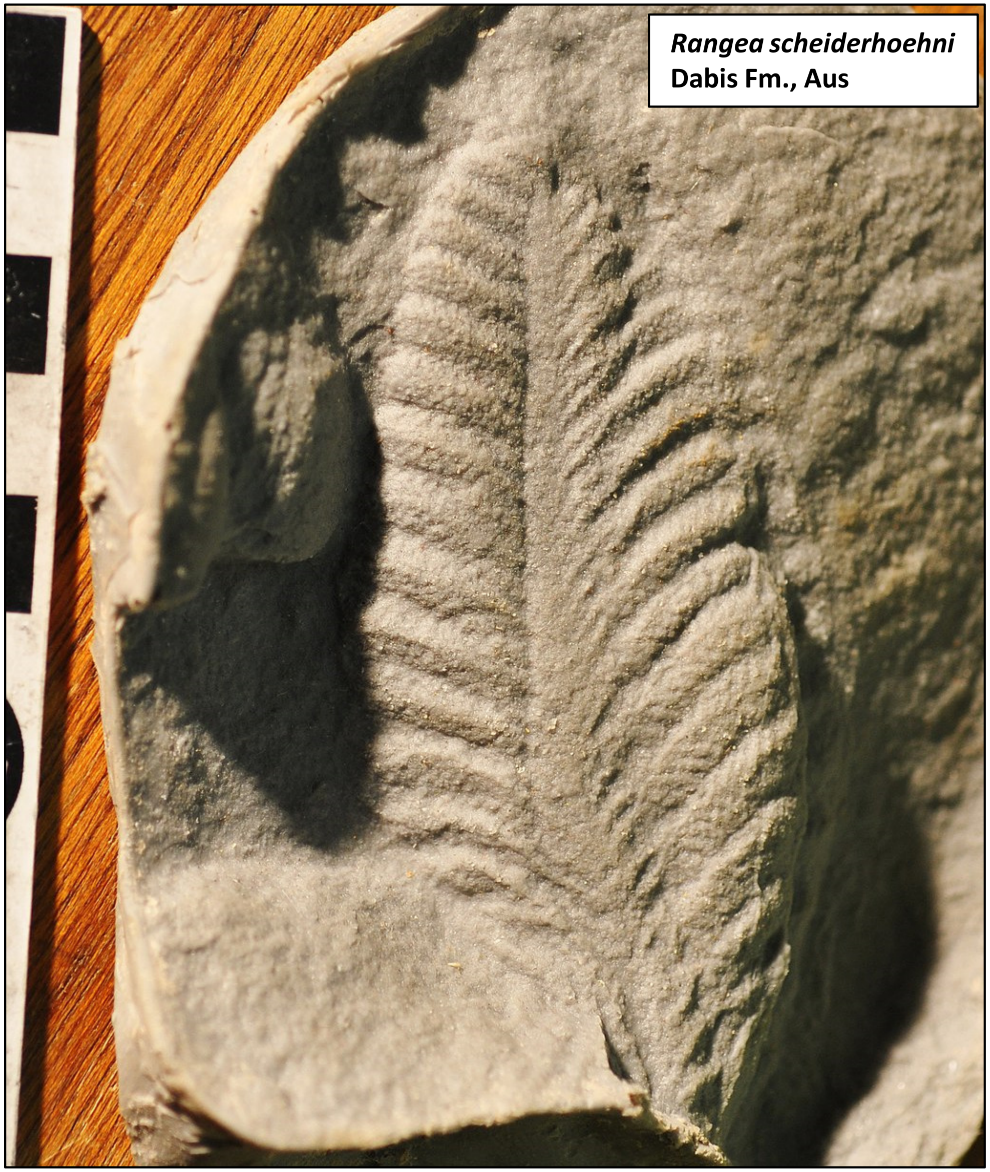
Kuibis Quartzite (565 Ma)

Ediacaran body fossils as sandstone casts in shallow marine sands - *Pteridium simplex* is abundant in the lower Nama Group

Nama Group - (Ediacaran & early Cambrian)

National Earth Science Museum, Windhoek

Nama Group - (Ediacaran & early Cambrian)



https://en.wikipedia.org/wiki/Rangea#/media/File:Rangea_scheiderhoehni_1.jpg

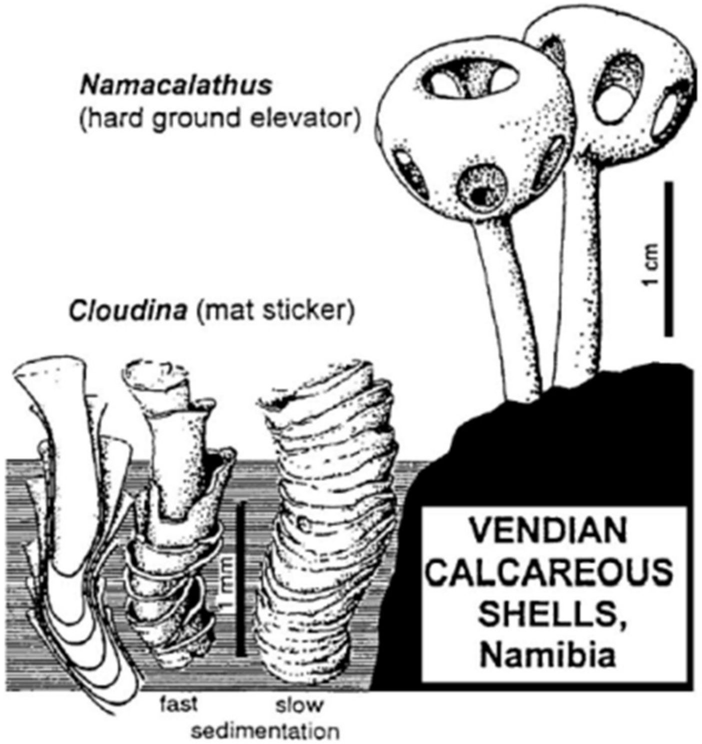
http://www.paleophilatelie.eu/description/stamps/namibia_2008.html

Lower Nama Group – Ediacaran fauna (c. 565 Ma)

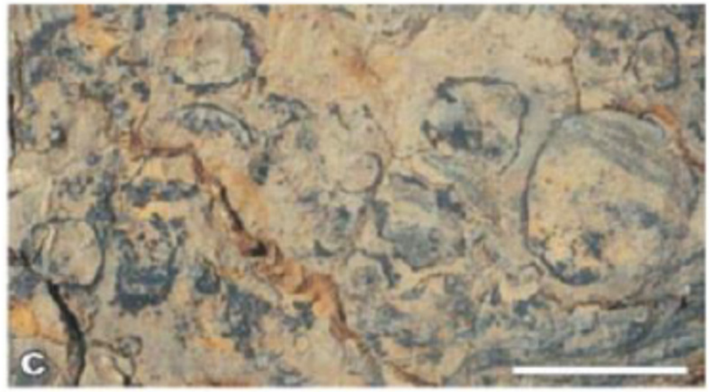
Leaning stromatolite columns at Zebra River. Picture by Rachel Wood.

Photos: Chris Rowan

U. Nama Group – thrombolite / stromatolite reefs (550-543 Ma)



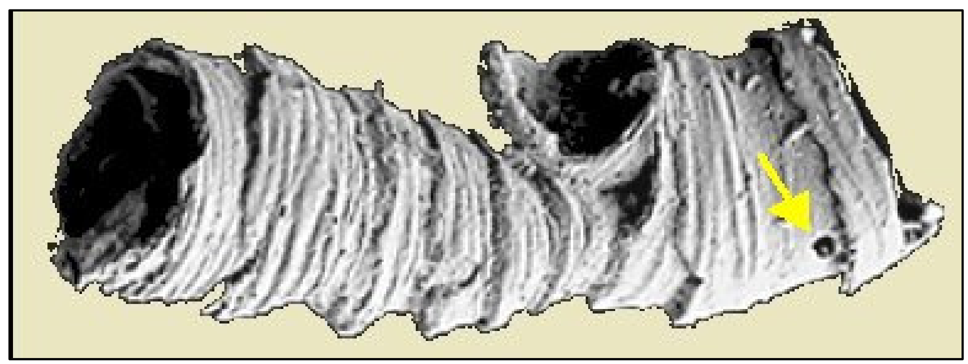
Namacalathus



Cloudina

Reef outcrop in the Upper Omkyk Member of the Nama Group, containing tubular white Cloudina hartmannae fossils. Cloudina is one of the earliest known animals to have built a calcified skeleton.

Cloudina



Upper Nama Group – earliest carbonate fossils (c. 547 Ma)

The Tsumeb Mine, on production from 1907 to 1996 recovered 1.7 million tonnes of copper, 2.8 million tonnes of lead & 900,000 tonnes of zinc, as well as germanium & other metals from rich ores

- For some time the largest lead producer in Africa

Neoproterozic (750-545 Ma): the Otavi Dolomite - up to 4,800 m thick - was deposited as a carbonate platform on the northern margin of the Khomas Ocean

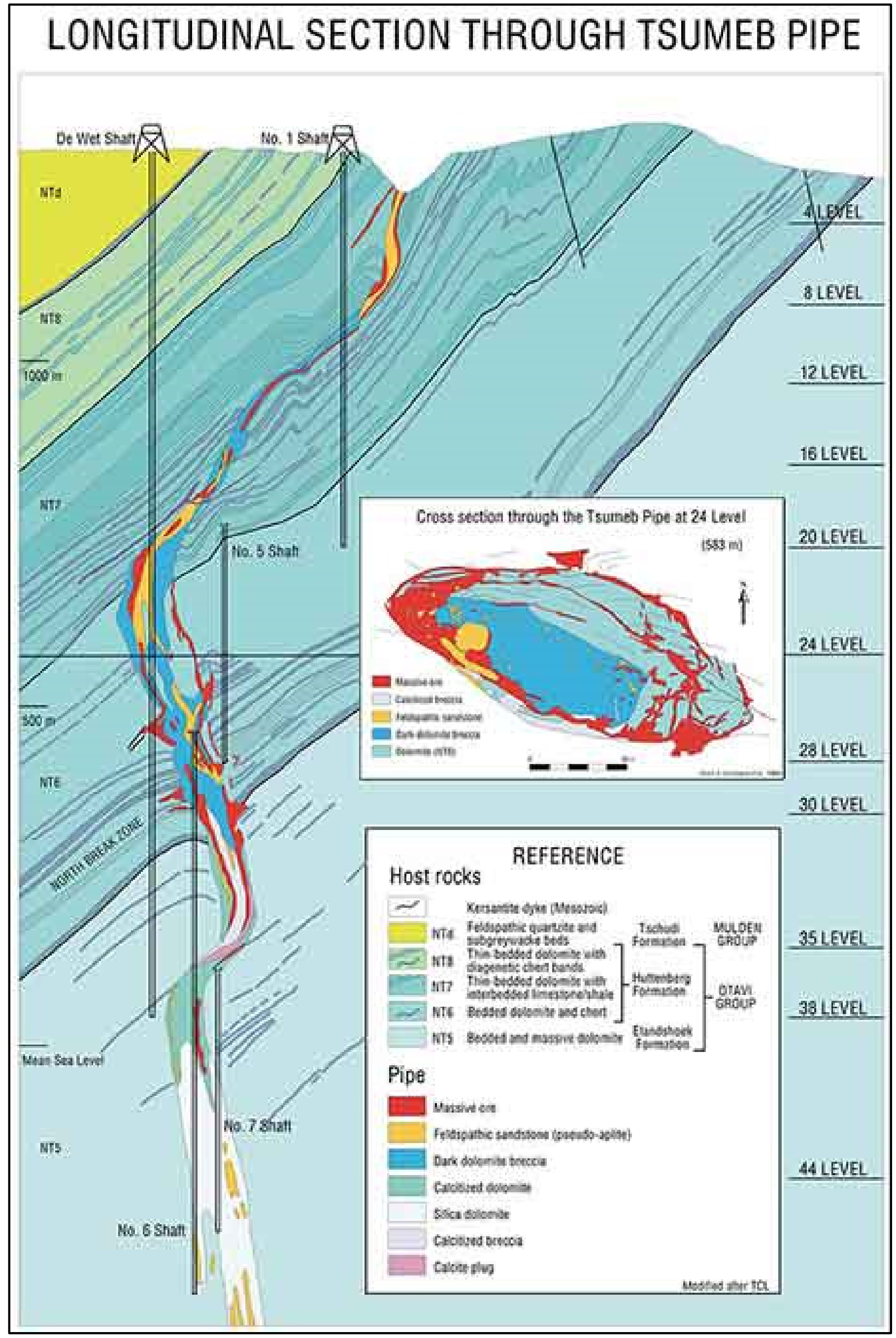
Uplift & karst development, with a vertical solution pipe, extending at least 1,500 m from the surface partially infilled by carbonate breccia & sand washed in from the surface

Hydrothermal mineralisation along the permeable pipe during the Damara orogeny emplaced a rich & complex poly-metallic sulphide ore body

Groundwater infiltration through cross-cutting fault zones oxidised the sulphide minerals on three zones

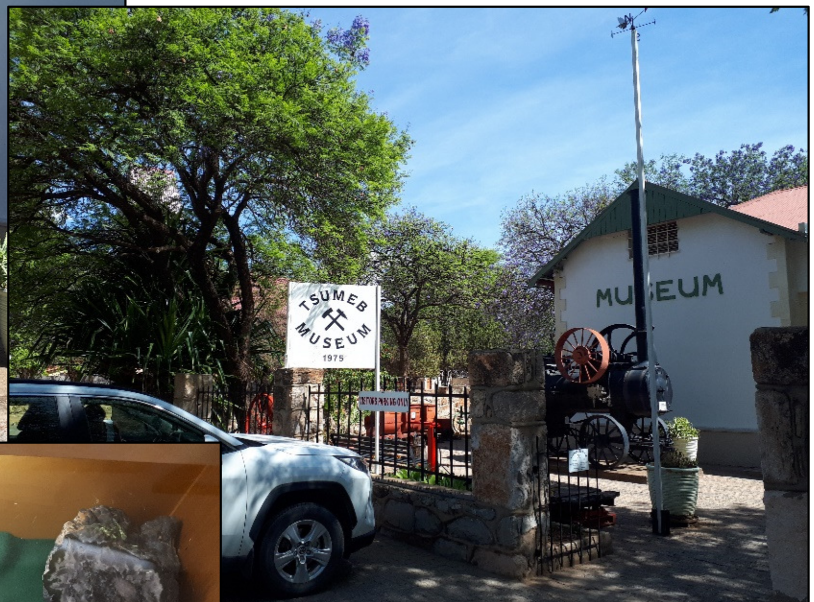
A combination of complex metal-rich solutions, interaction with the limestone & dolomite host rock & oxidation resulted in a rich 7 diverse mineral assemblage

Estimates vary, but approximately 337 mineral species, including 72 type minerals



After Lombaard et al., 1986 from the original sketch by P. G. Soehnge

The Tsumeb Pipe & Mine

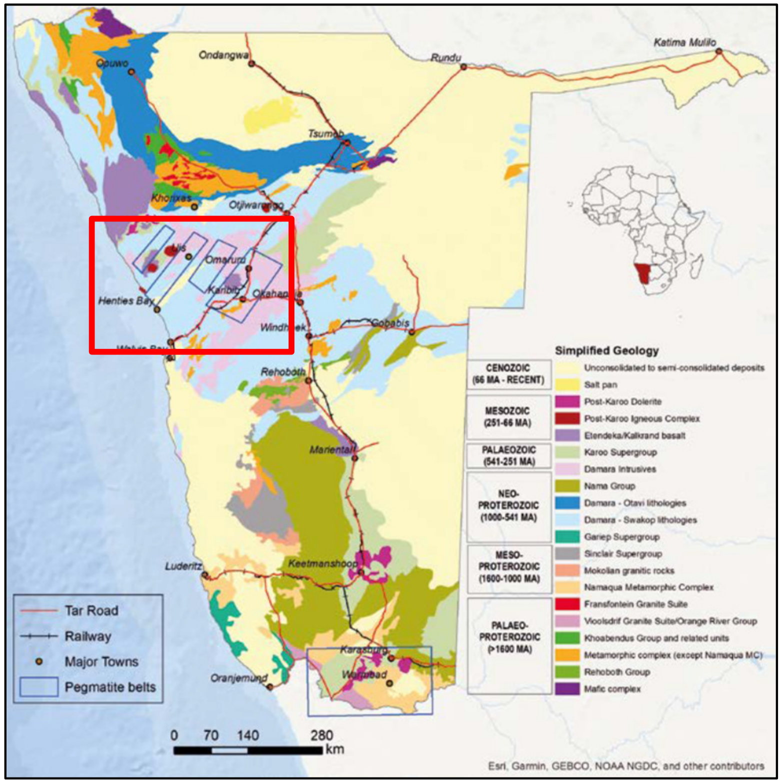


Tsumeb Museum

Petalite - Rubicon pegmatite

Lepidolite - Rubicon pegmatite

BGR Bundesanstalt für Geowissenschaften und Rohstoffe

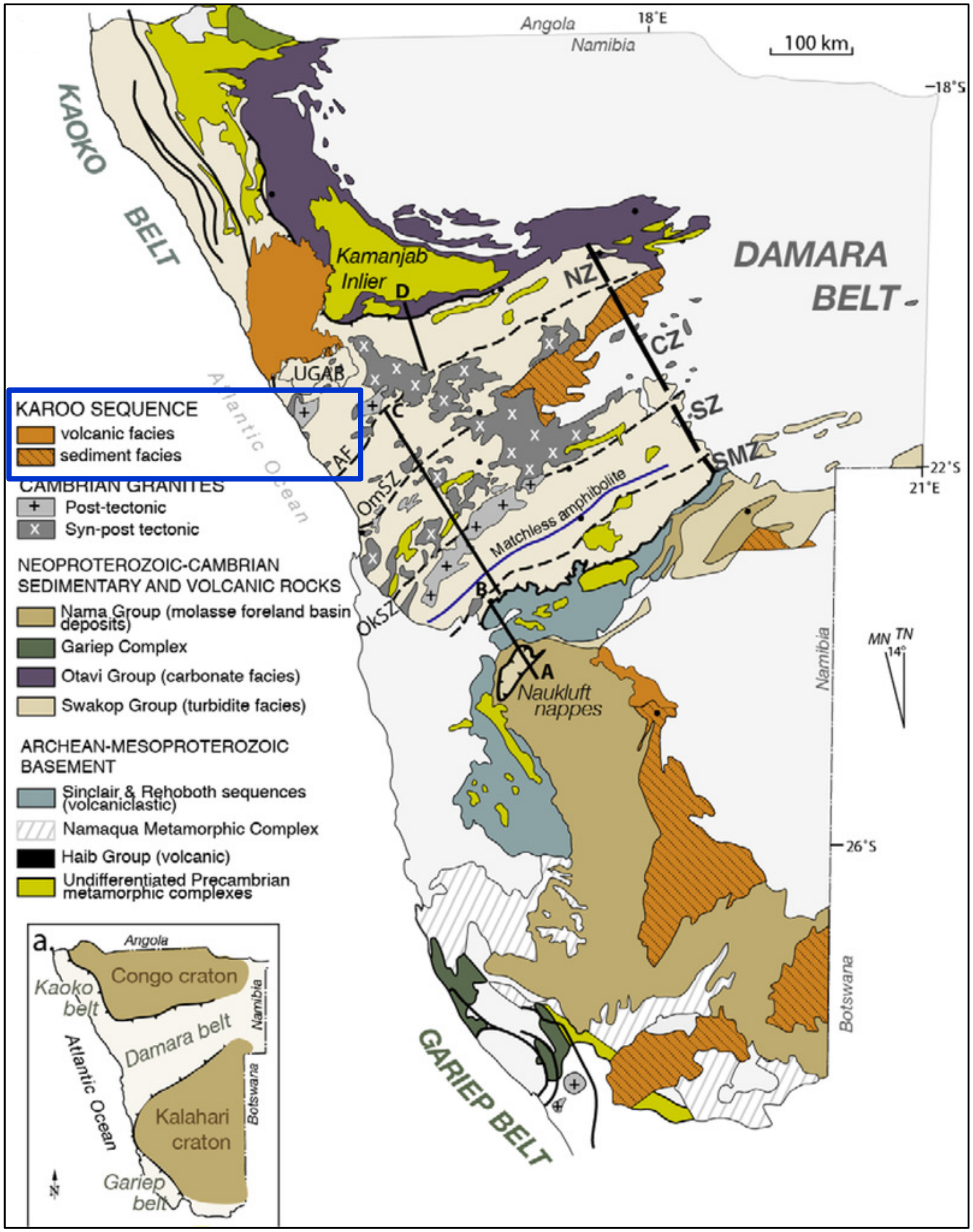


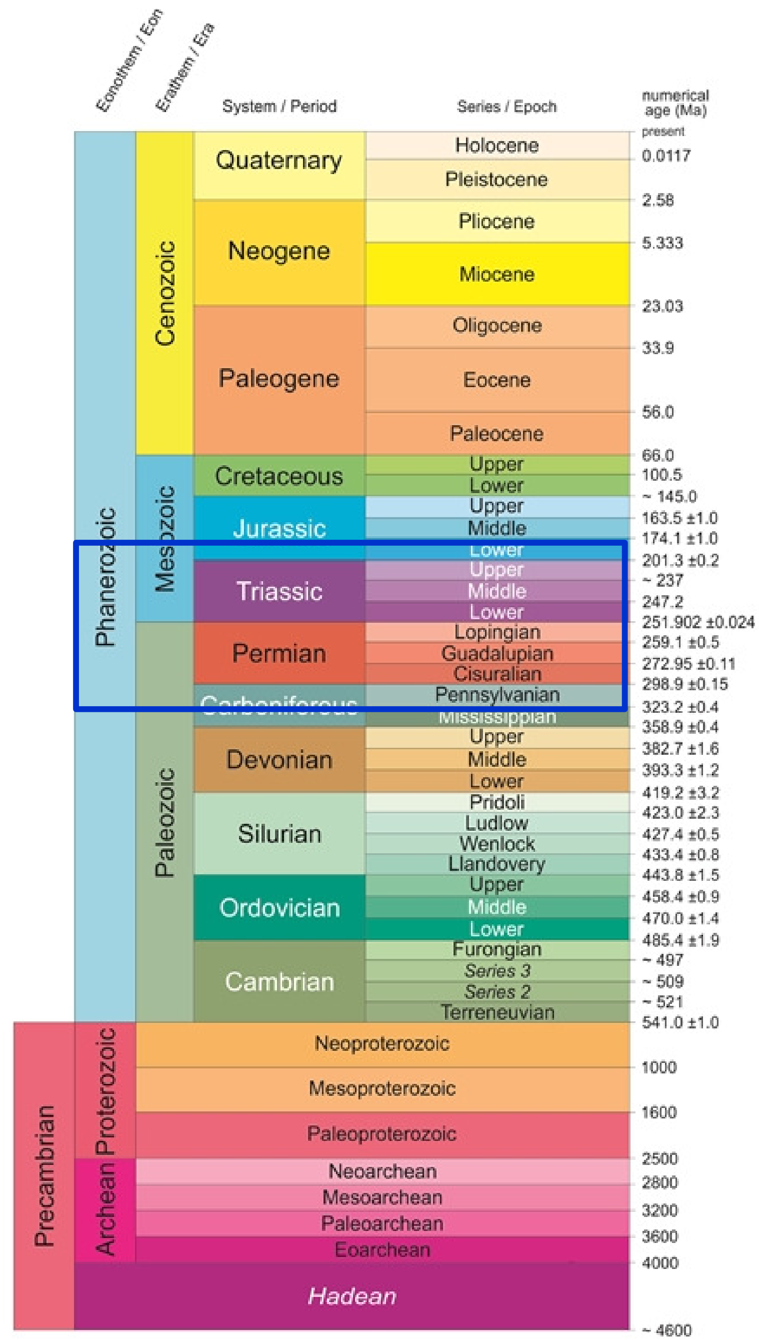
Post-orogenic granites in the western Damara Belt host pegmatites hosting lithium-rich minerals (lepidolite & petalite)

- Active exploration & early production in the Uis & Omarurur areas NW of Windhoek
- Possible $1 bn / year potential production

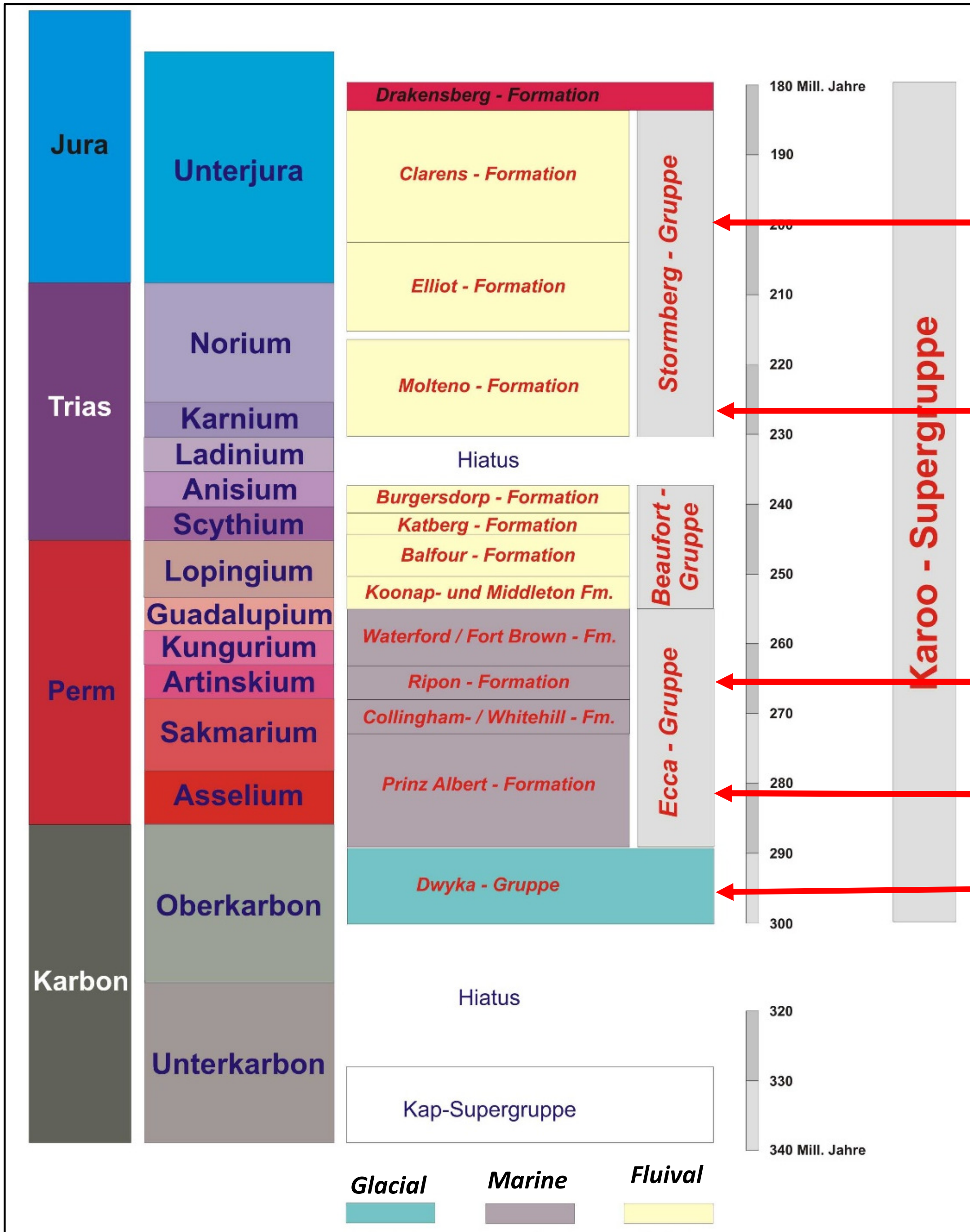
Uis tin mine – under redevelopment for lithium-bearing pegmatites

Cambrian granite & lithium production

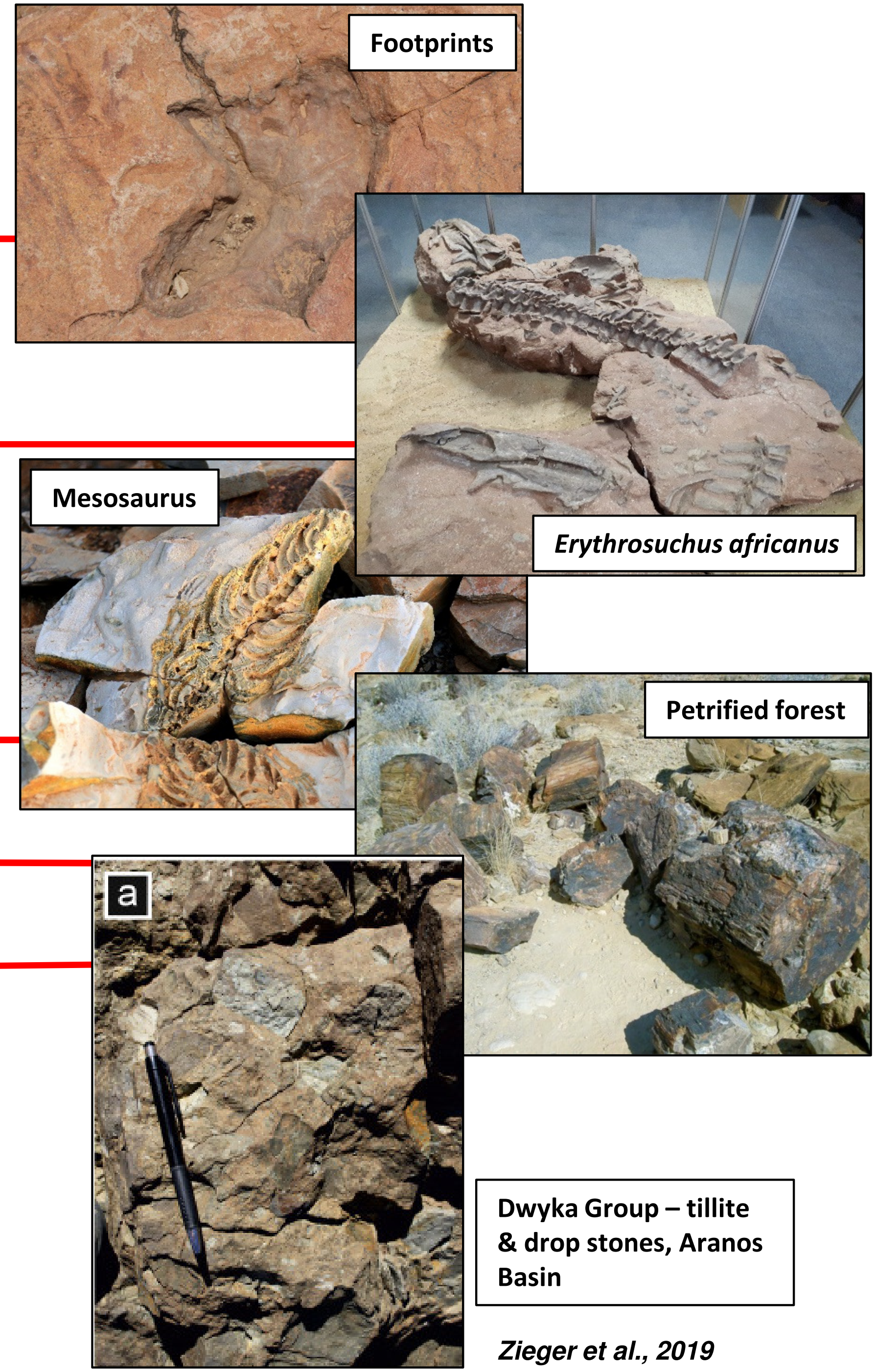




Late Carboniferous to early Jurassic- the Karoo Supergroup



O. Catuneanu, H. Wopfner, P.G. Eriksson, B. Cairncross, B.S. Rubidge, R.M.H. Smith, P.J. Hancox:
The Karoo basins of south-central Africa. in: Journal of African Earth Sciences 43, 2005

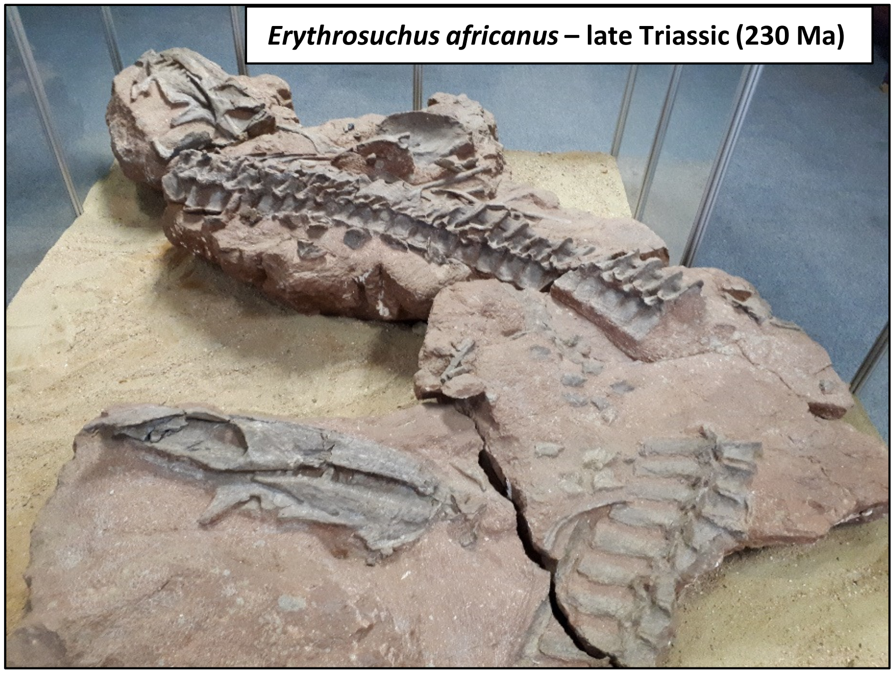


Dwyka Group – tillite & drop stones, Aranos Basin

Zieger et al., 2019

The Karoo Supergroup

Petrified Forest, Khorixas – early Permian (280 Ma)

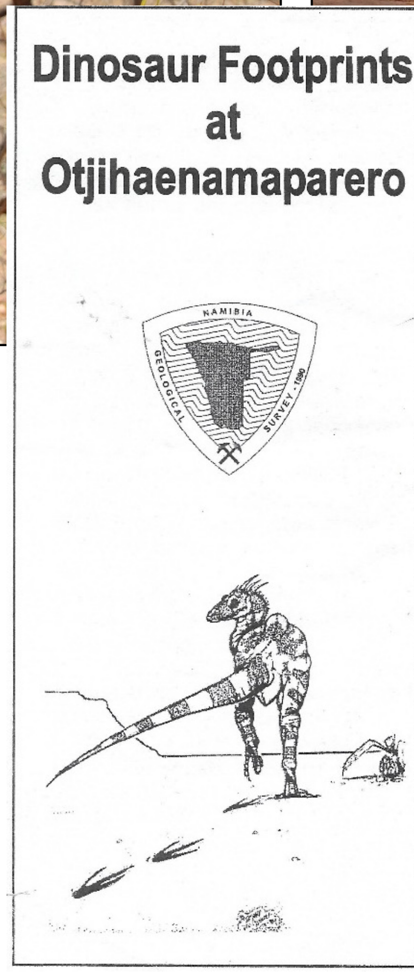


Erythrosuchus africanus – late Triassic (230 Ma)

https://gondwana-collection.com/blog/how-can-a-forest-in-namibia-become-petrified

Albert, 2015

The Karoo – Permo-Triassic



<u>Otjihhaenamaparero Farm</u>
Dinosaur Tracks National Monument

Etjo Sandstone (early Jurassic ~ 200 Ma). Semi-arid grading to arid desert including aeolian dune sandstones & inter-dune siltstones

Tracks of bipedal theropod dinosaurs; possibly including the medium-sized Kayentapus

Approximately 350 prints, including the longest known dinosaur trackway in Africa

The Karoo (Etjo Sandstone) – Lower Jurassic dinosaur footprints

The Karoo (Etjo Sandstone) – Lower Jurassic dinosaur footprints

https://prehistoric-wiki.fandom.com/wiki/Kayentapus

Kayentapus (?)

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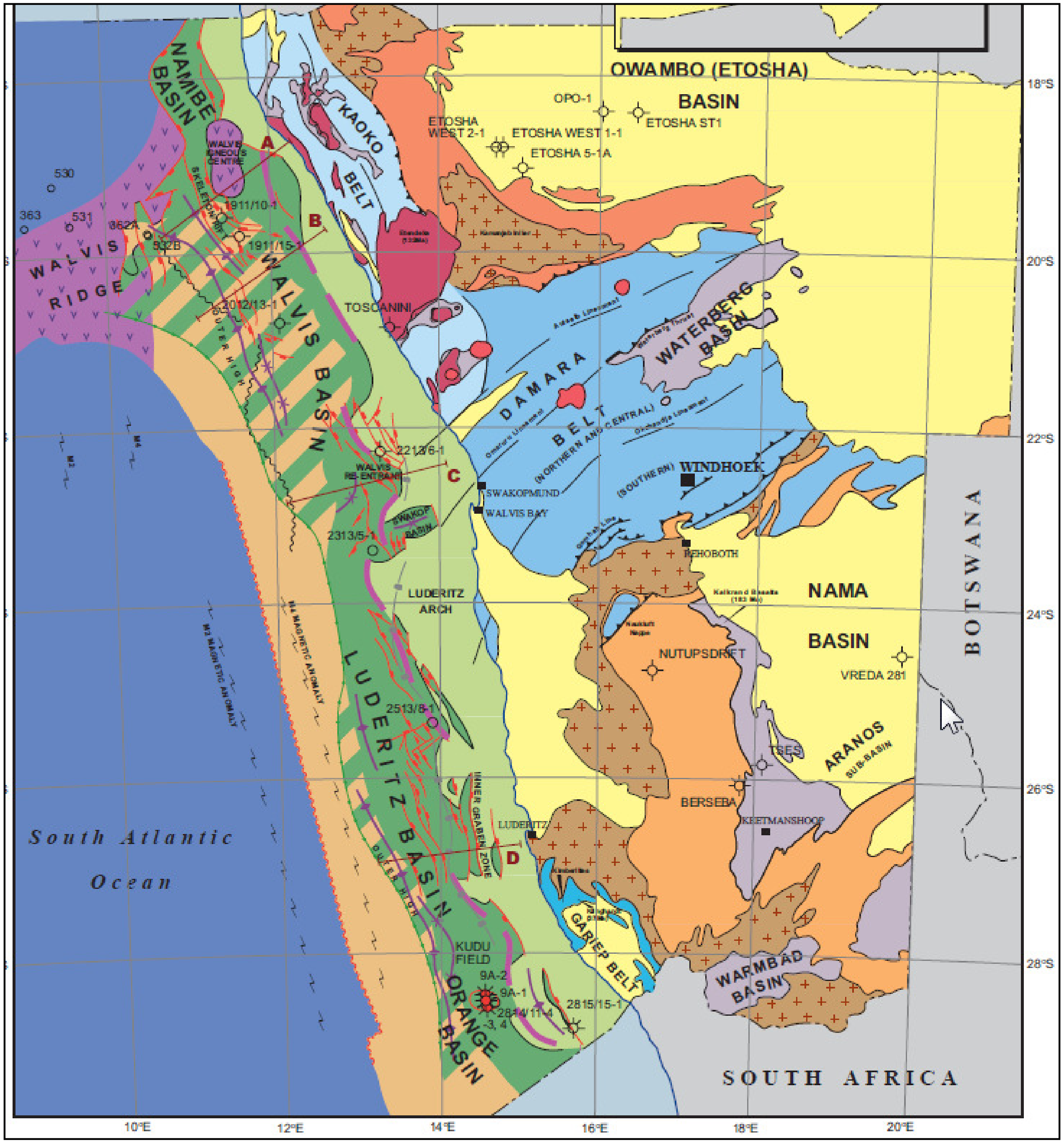
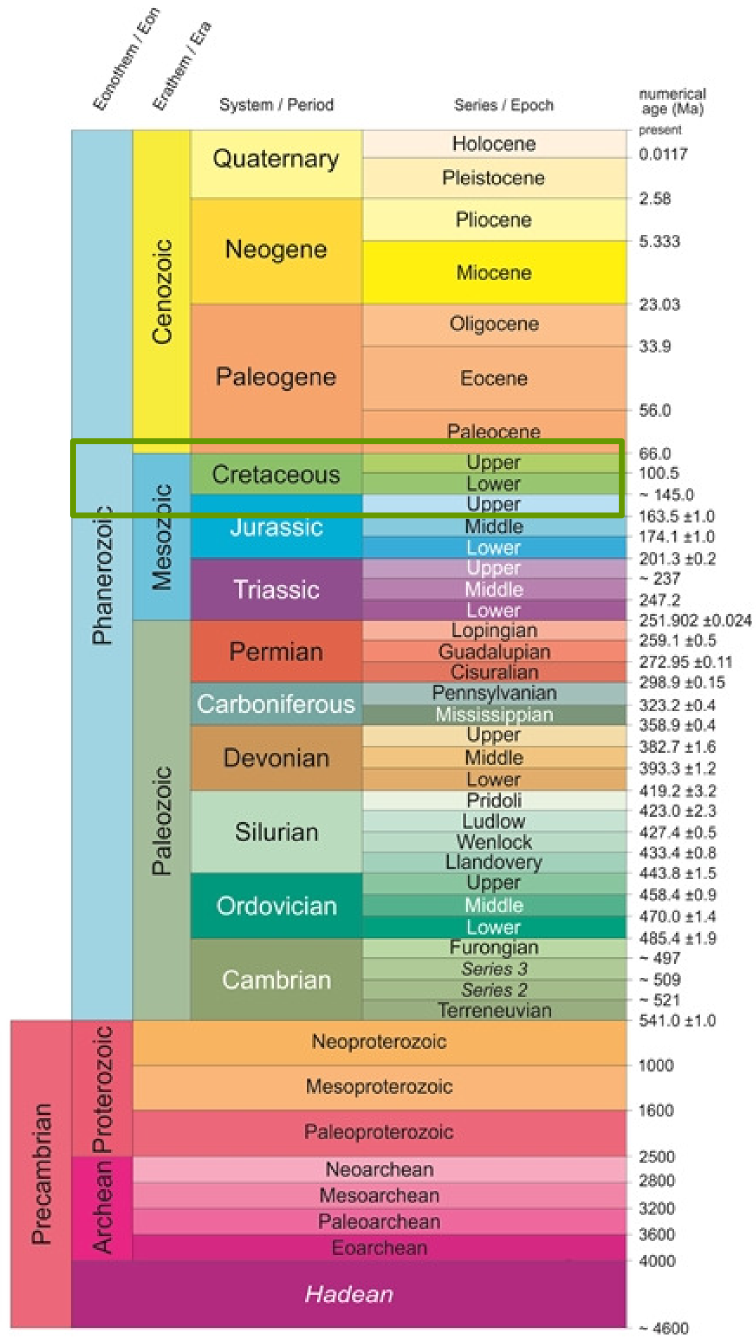
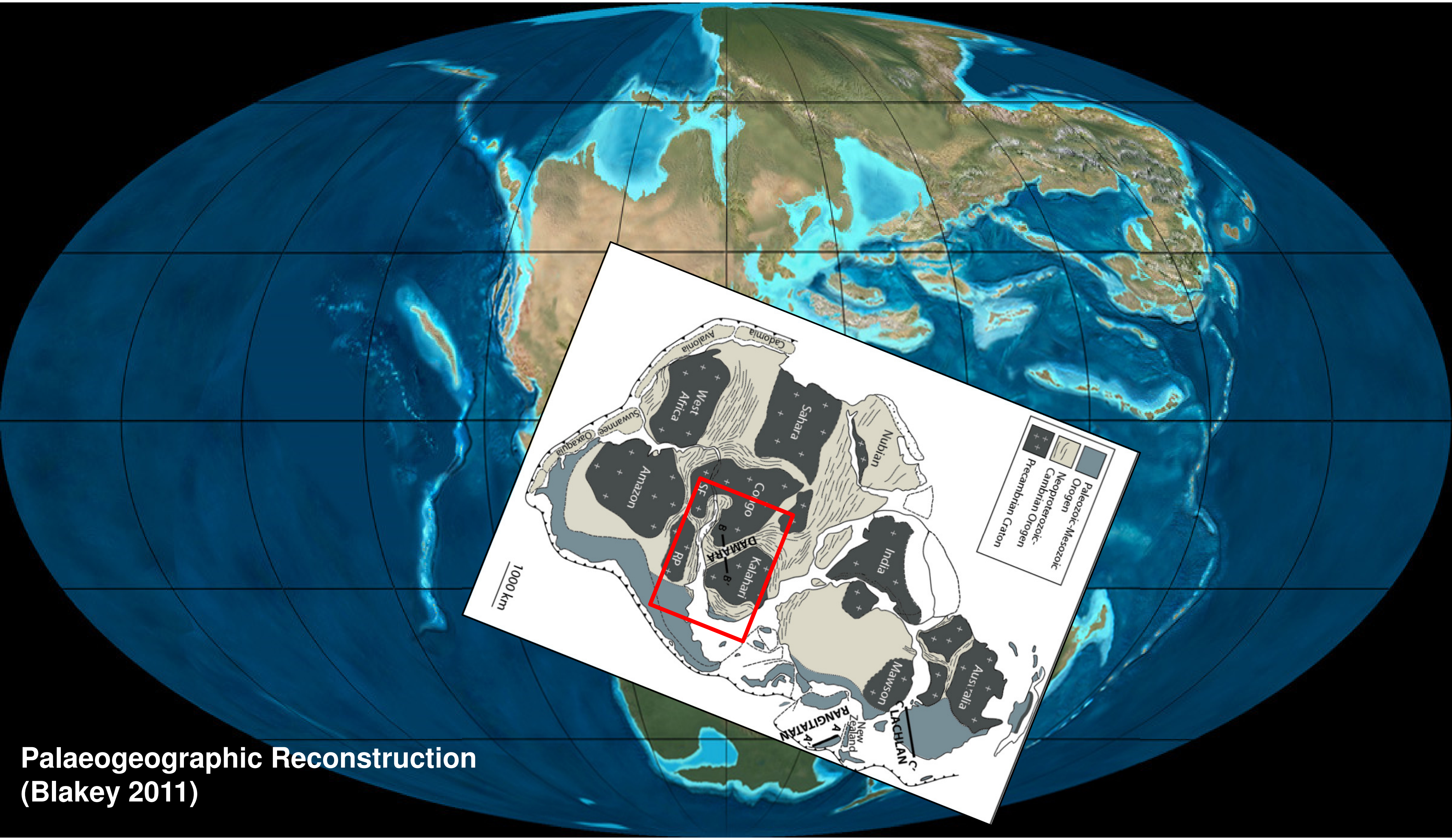
Massospondylus (Etjo Sandstone – early Jurassic)

Typical!

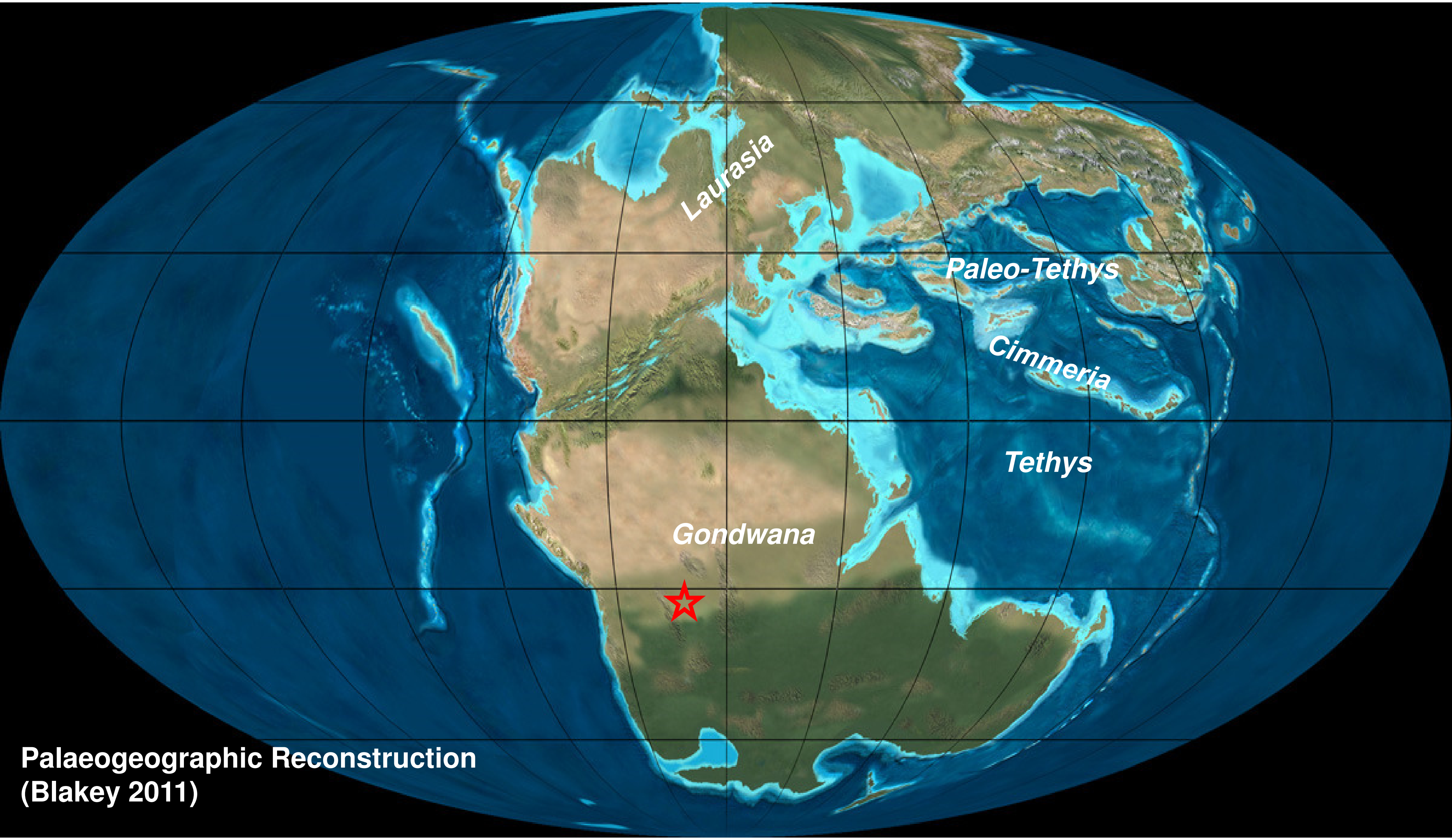




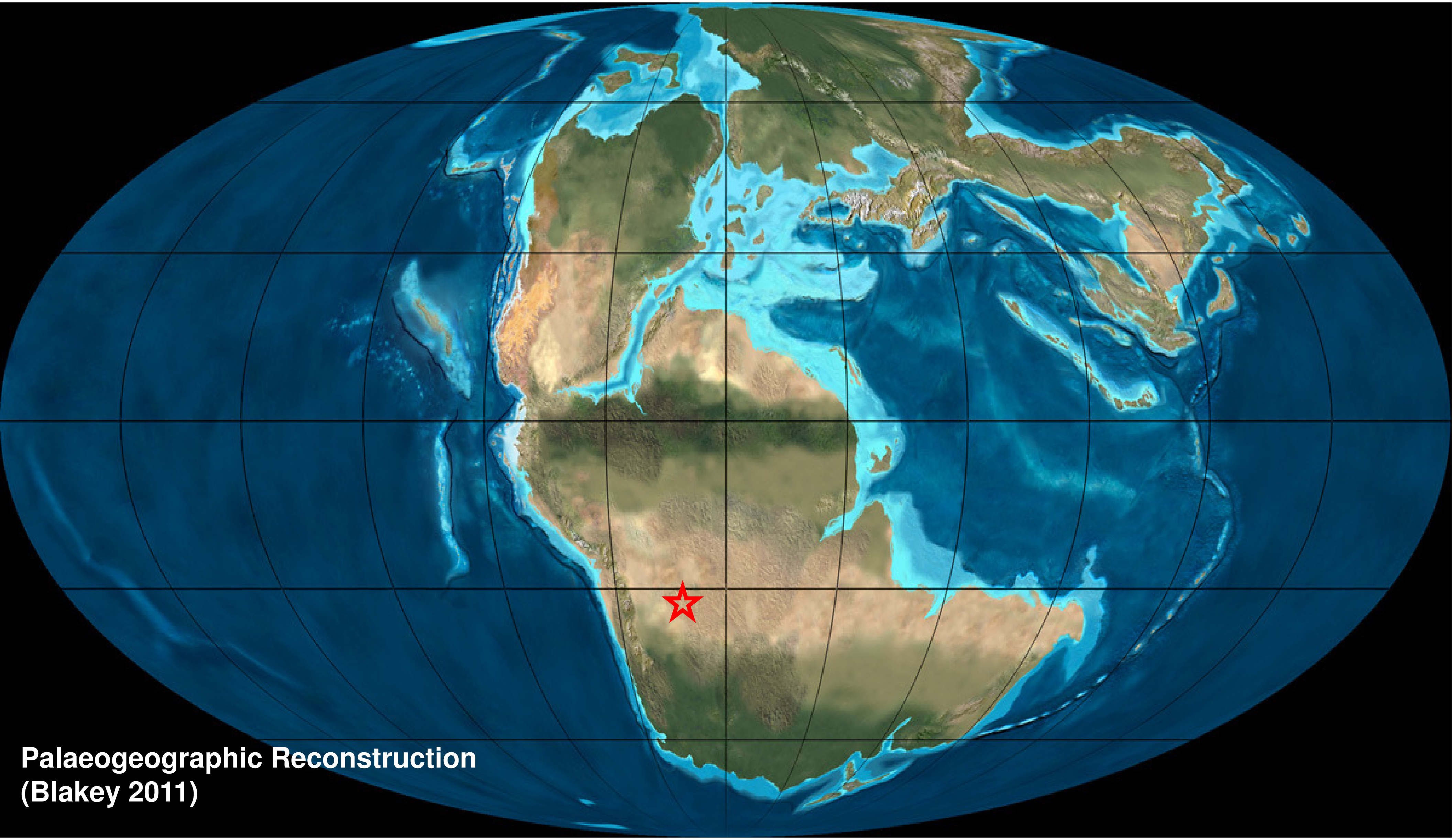
Cretaceous – opening of the South Atlantic



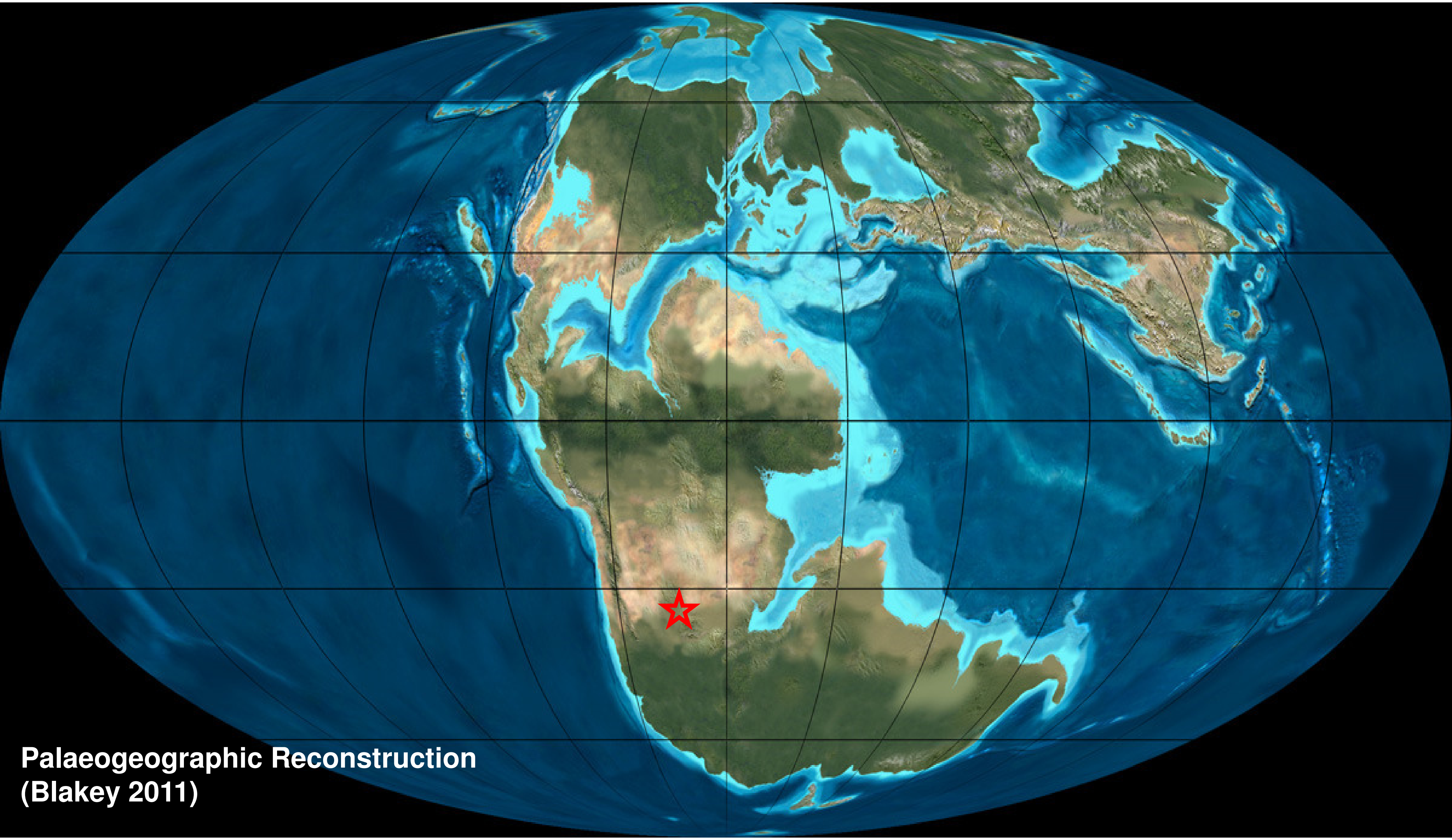
Lower Triassic – 220Ma



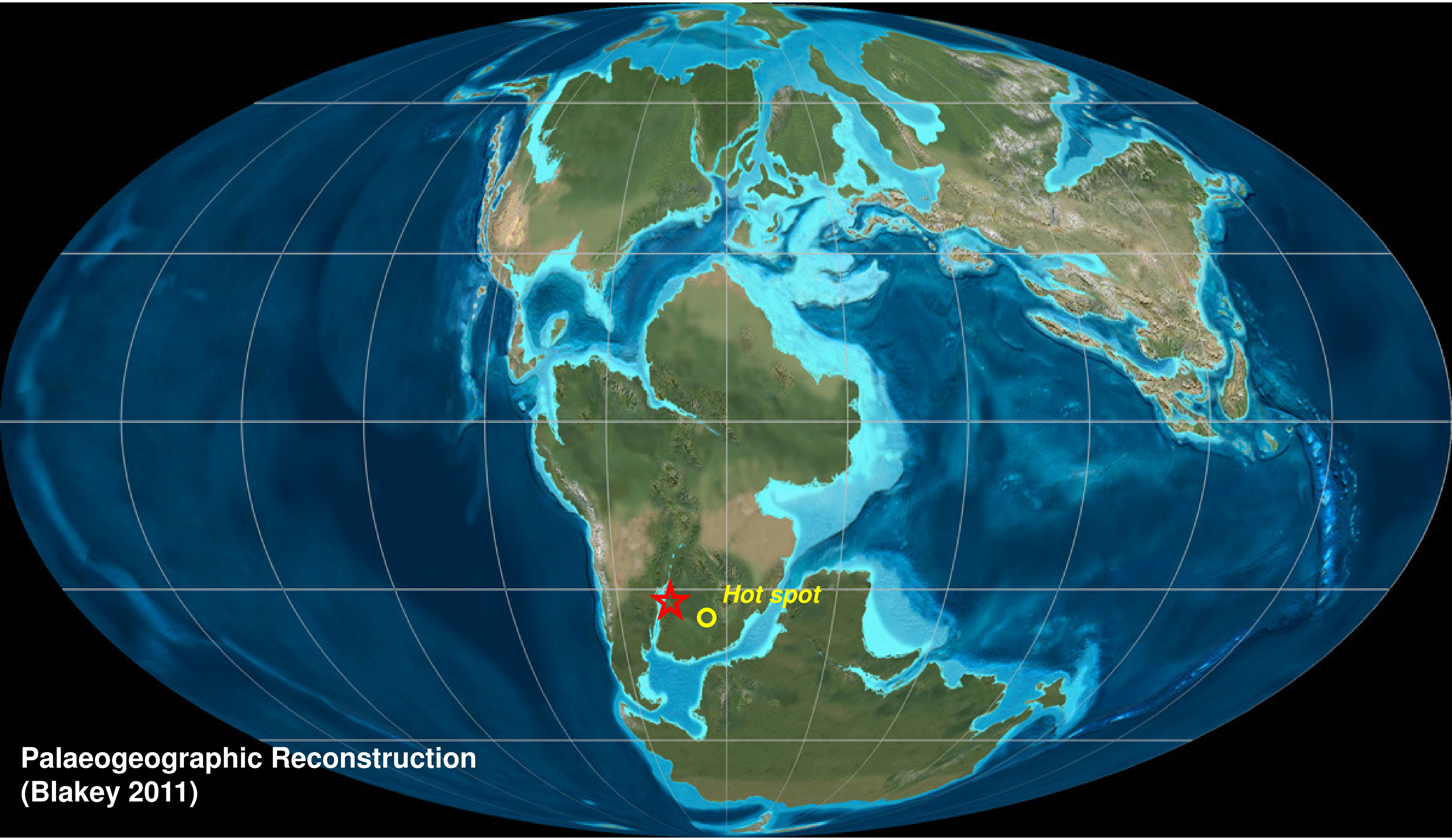
Lower Triassic – 220Ma



Early Jurassic – 200 Ma



Middle Jurassic – 170 Ma



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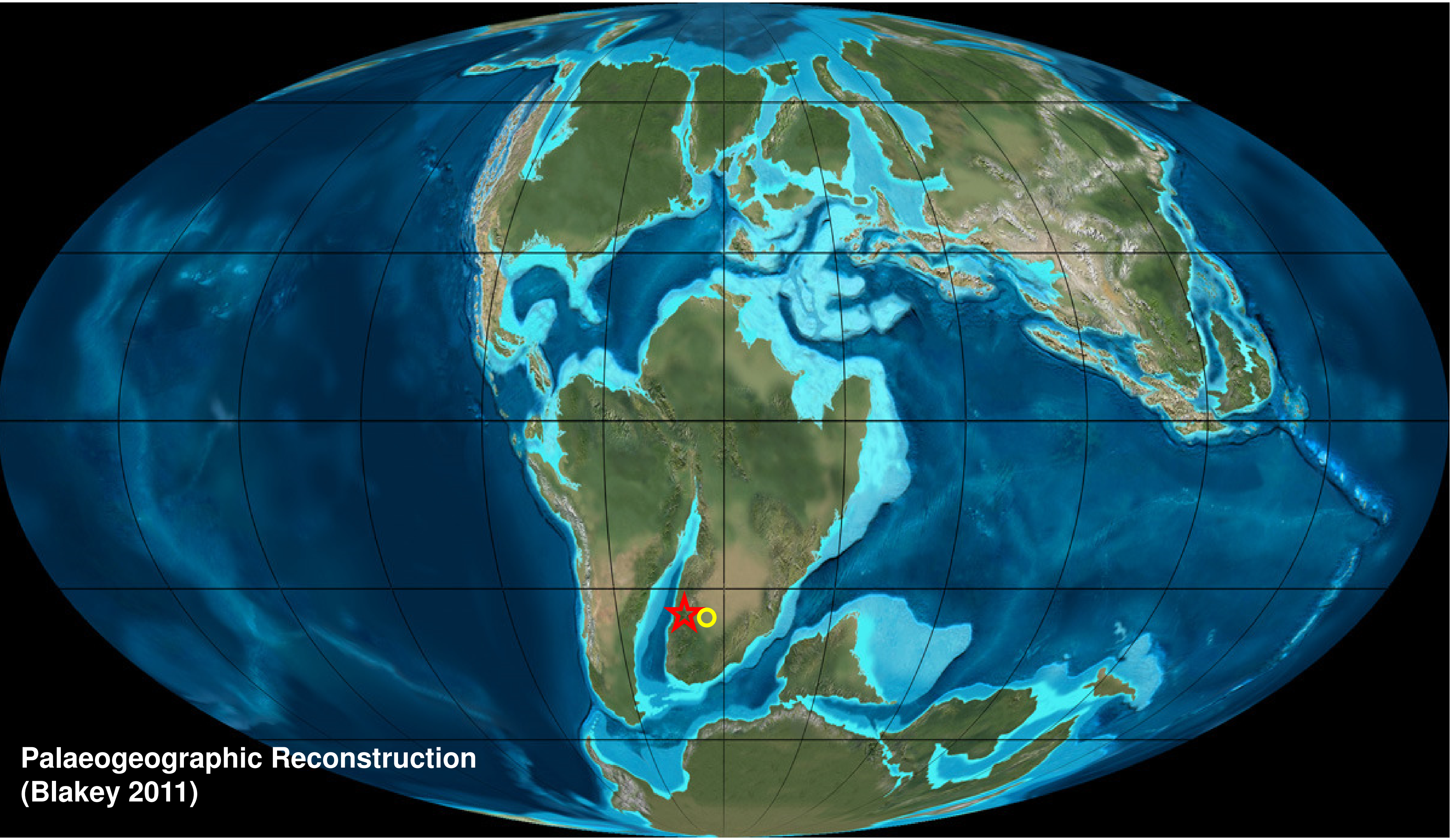
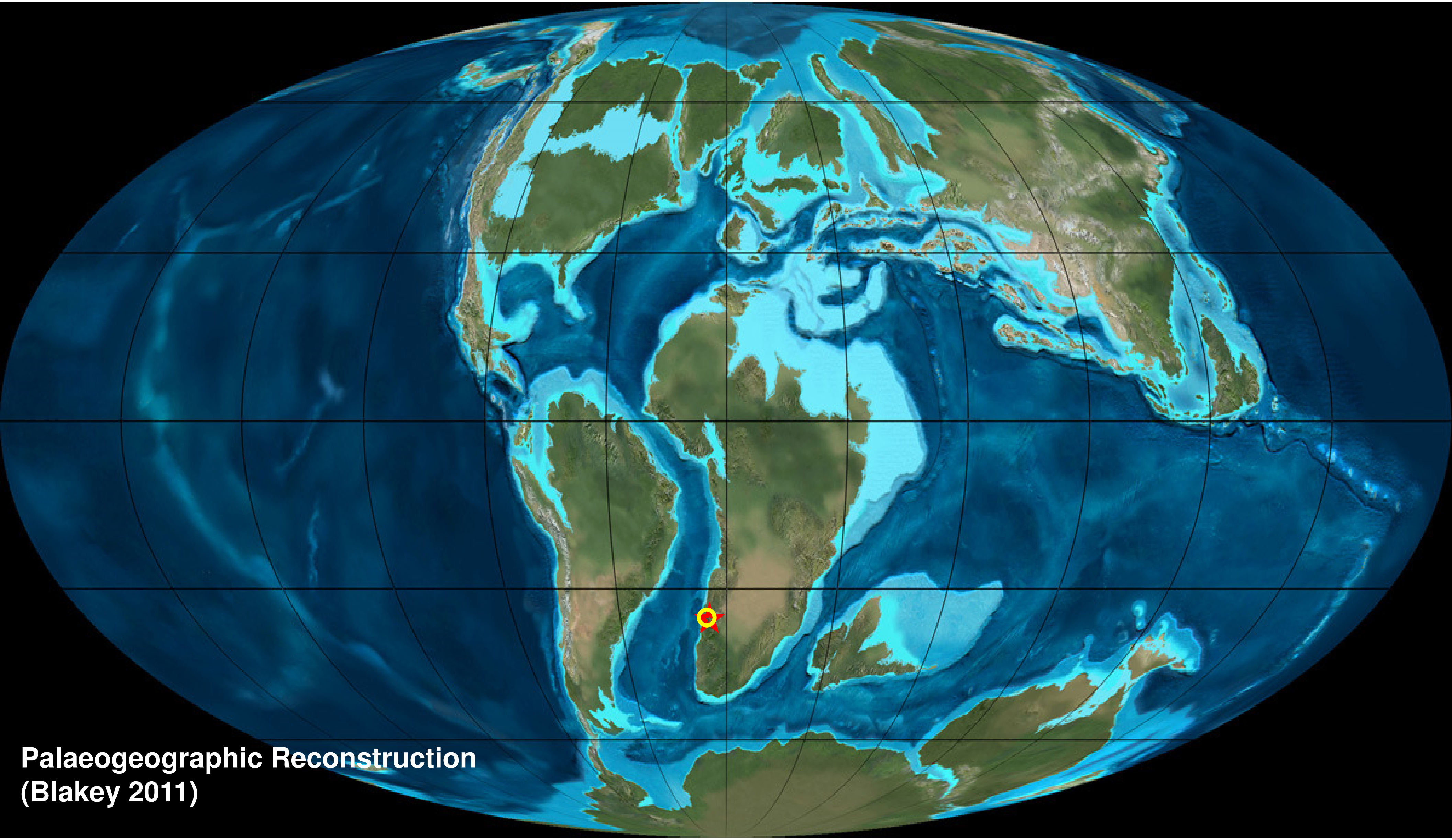
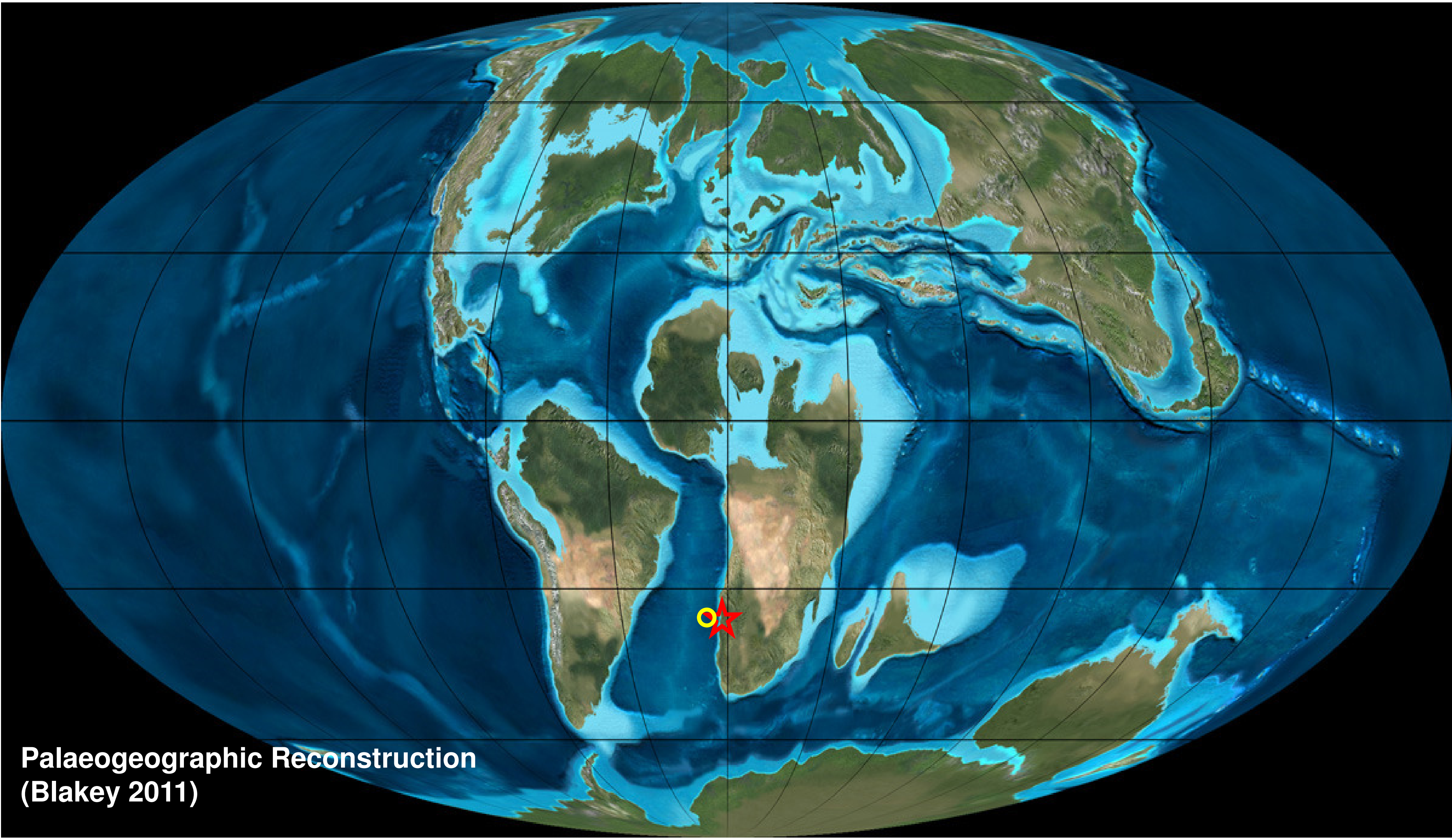
Late Jurassic – 150 Ma



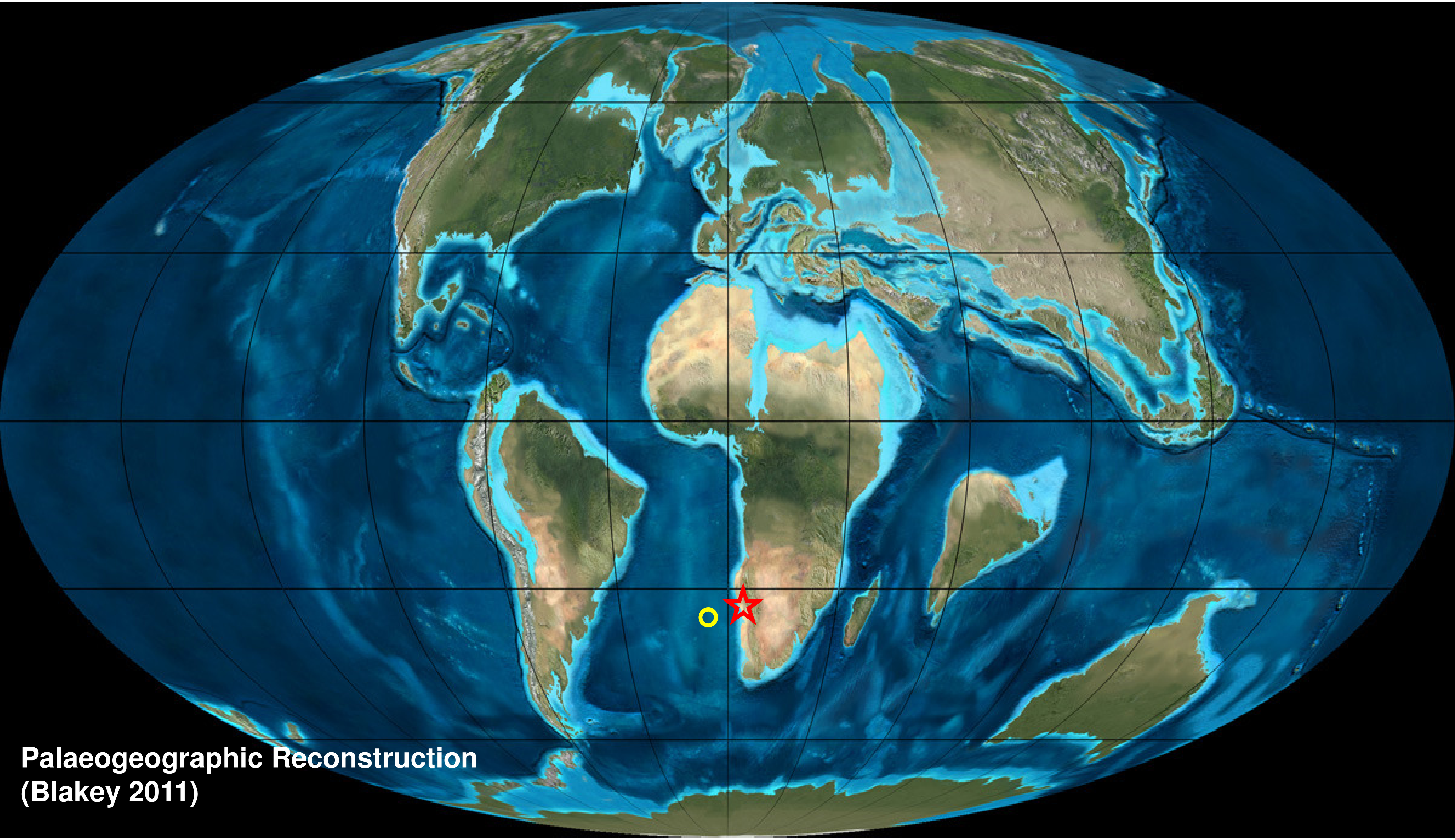
Early Cretaceous – 120 Ma



Mid Cretaceous – 105 Ma



Late Cretaceous – 90 Ma



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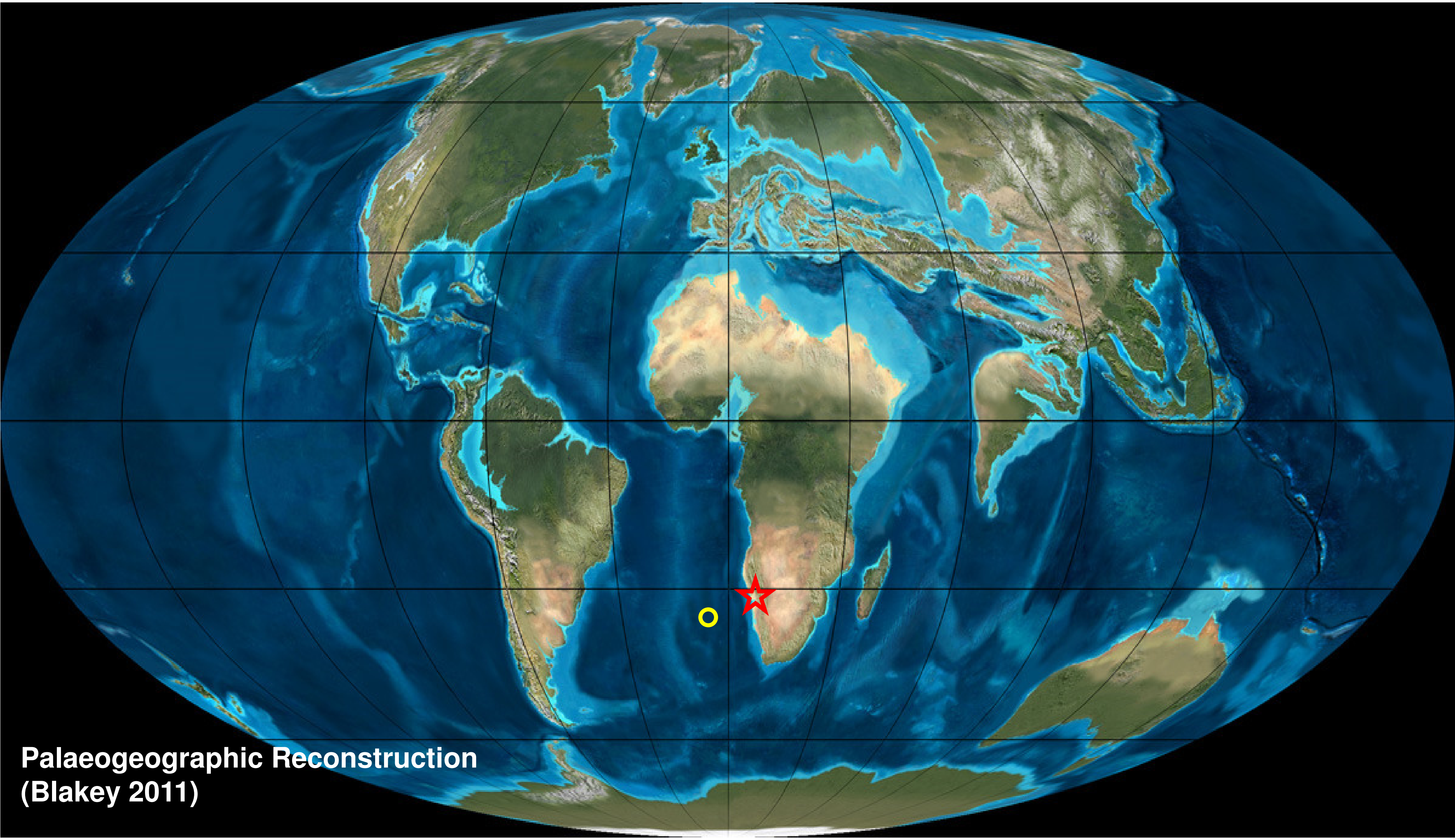
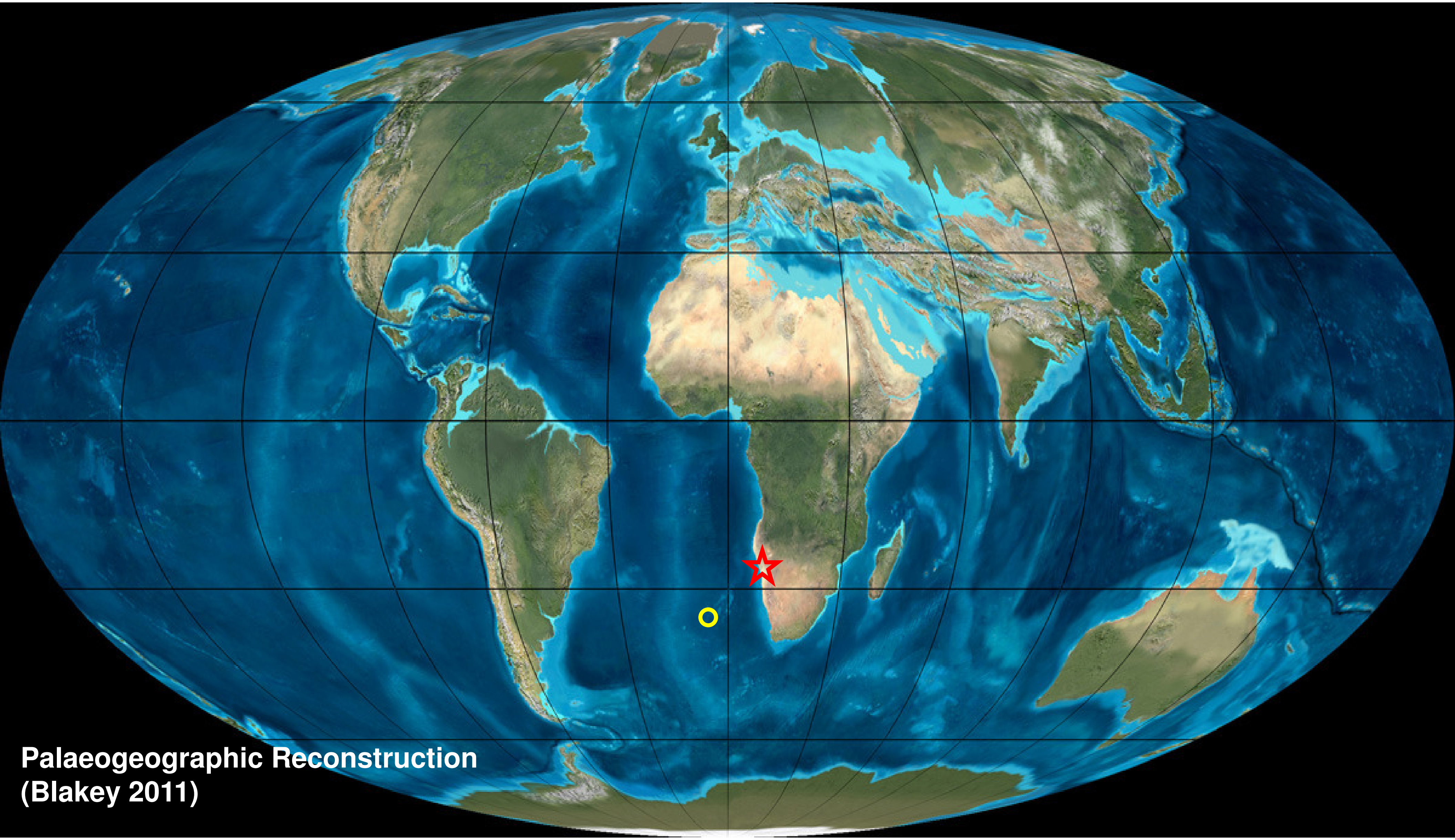
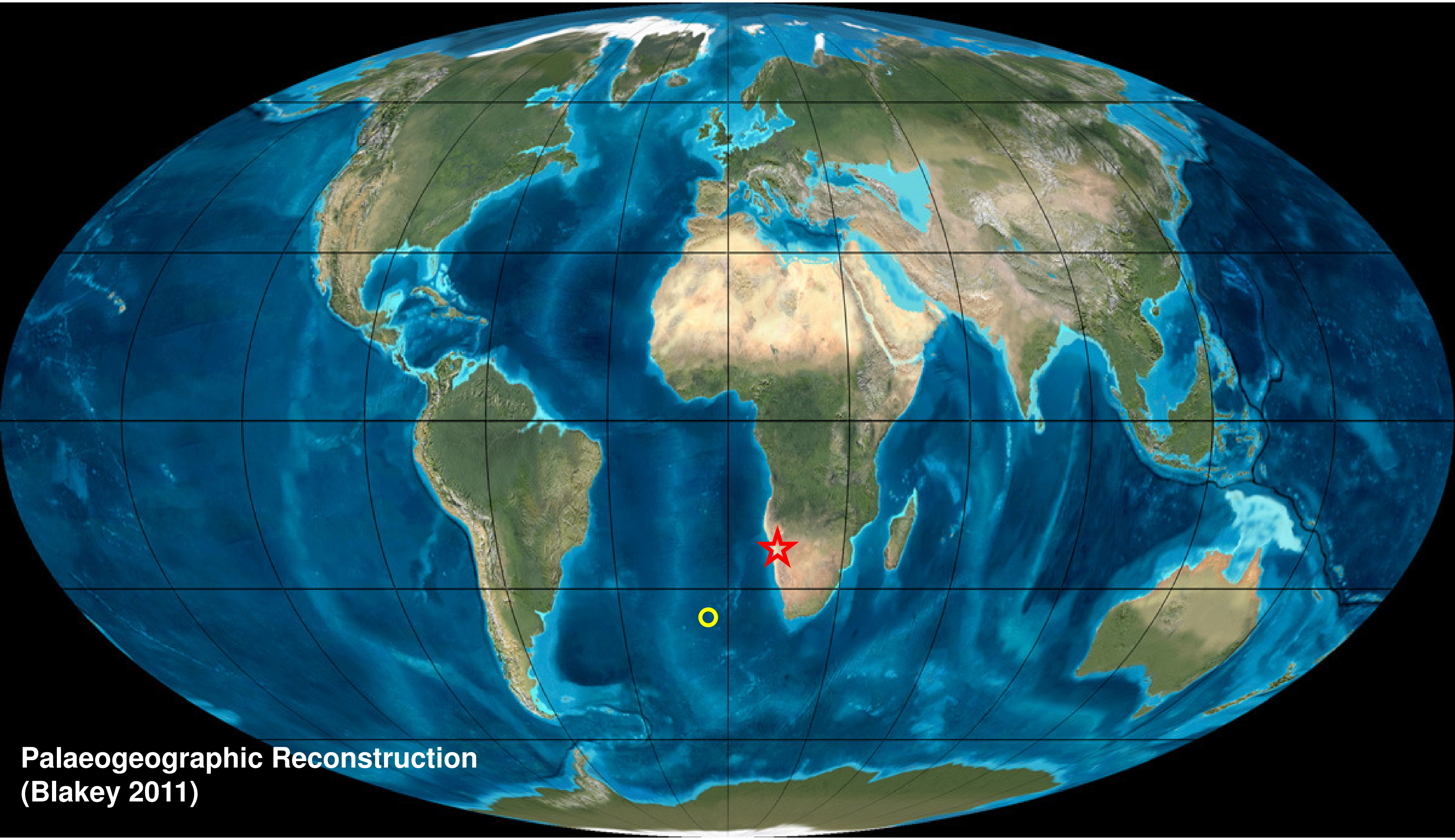
Cretaceous – Tertiary boundary – 65 Ma



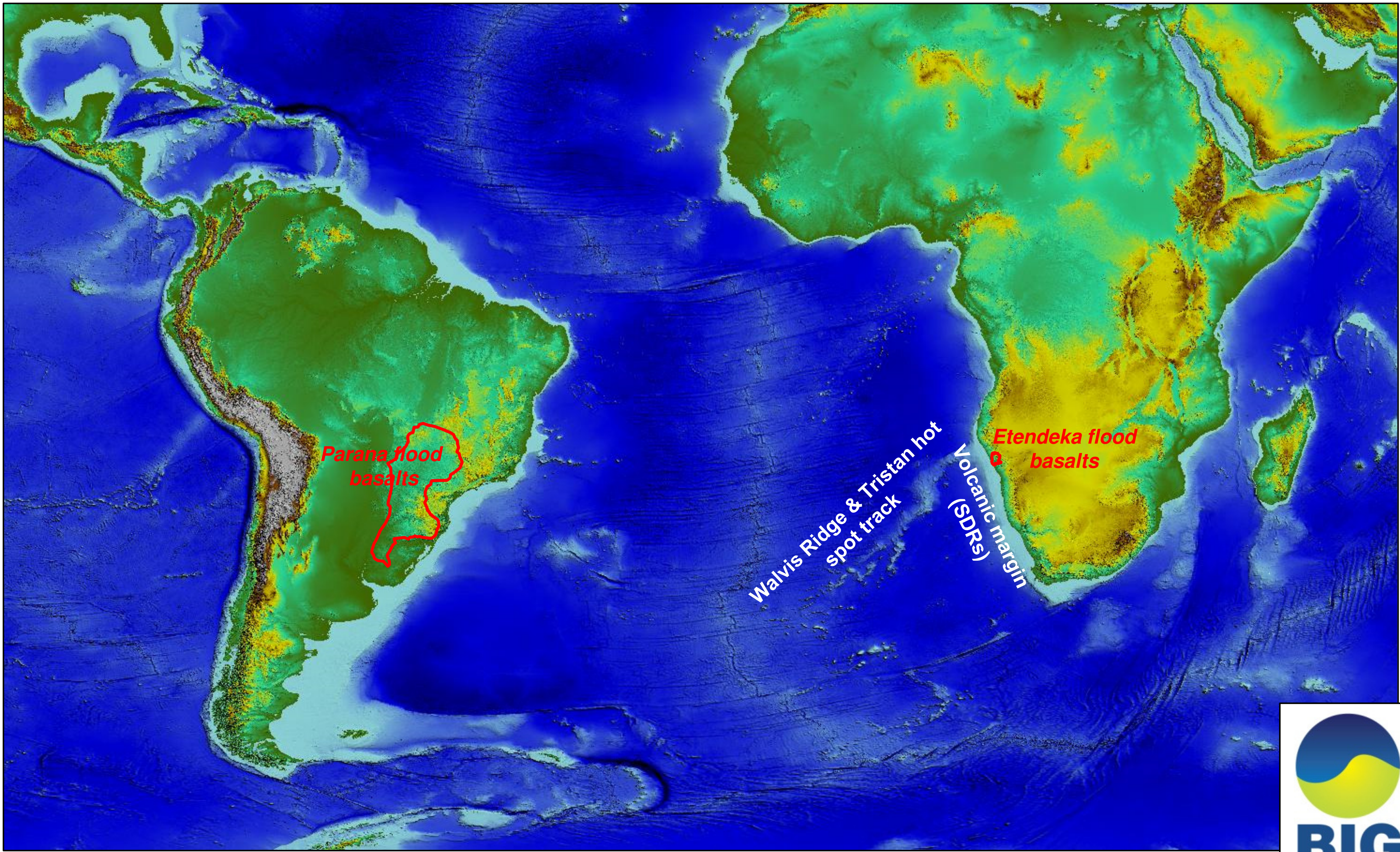
Eocene – 50 Ma



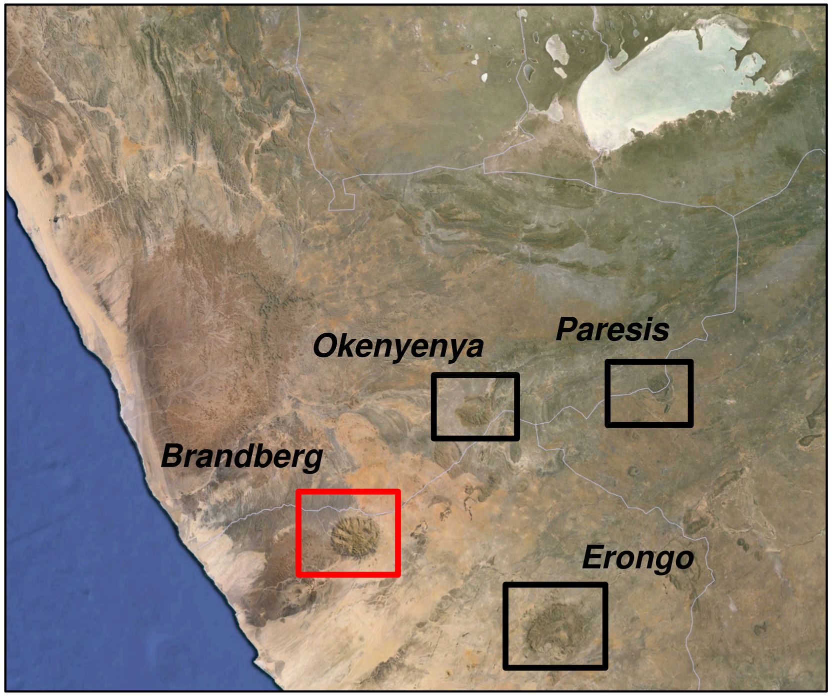
Miocene – 35 Ma



Miocene – 20 Ma



South Atlantic – early Cretaceous volcanism



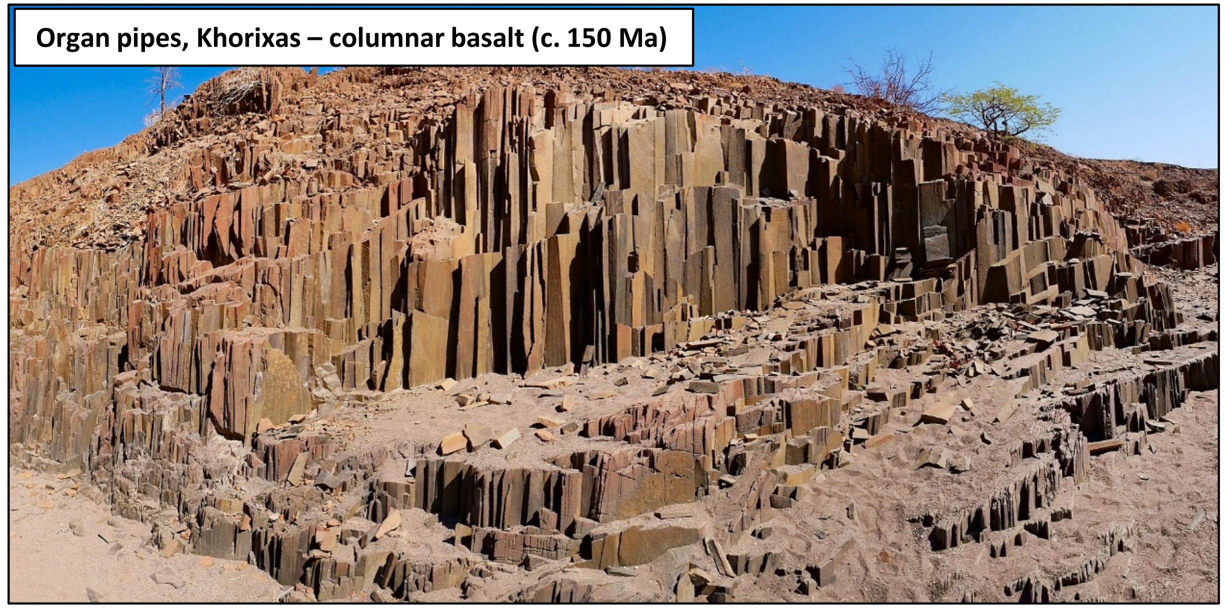
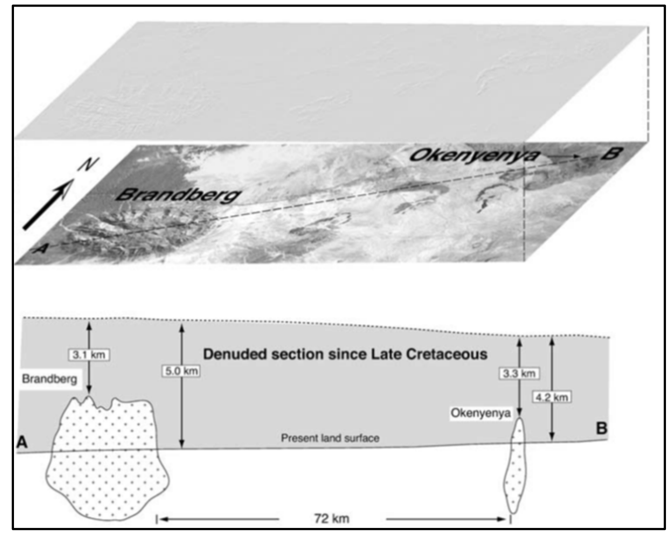


Photo: Daniel Craft



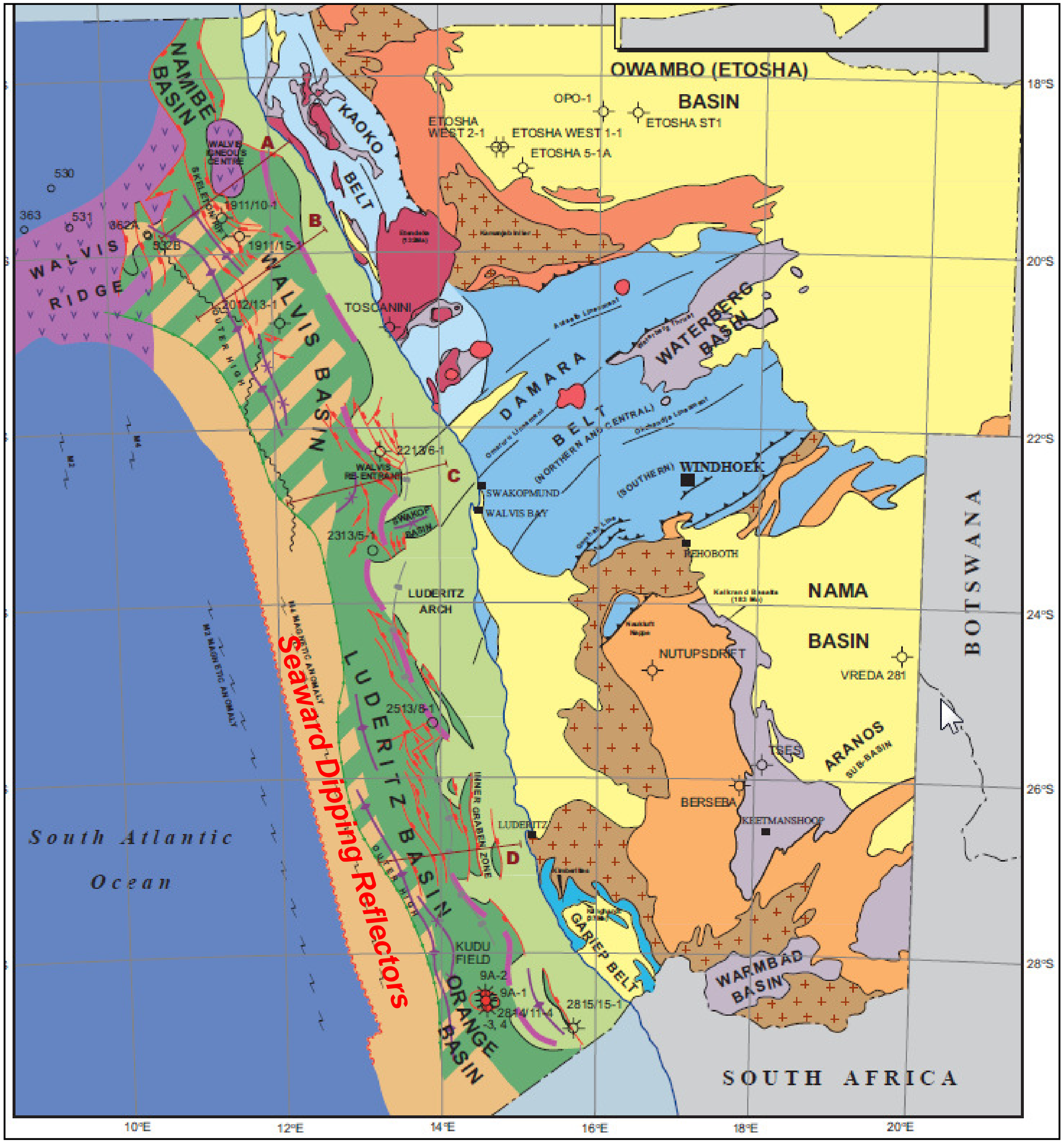
Raab et al., 2005

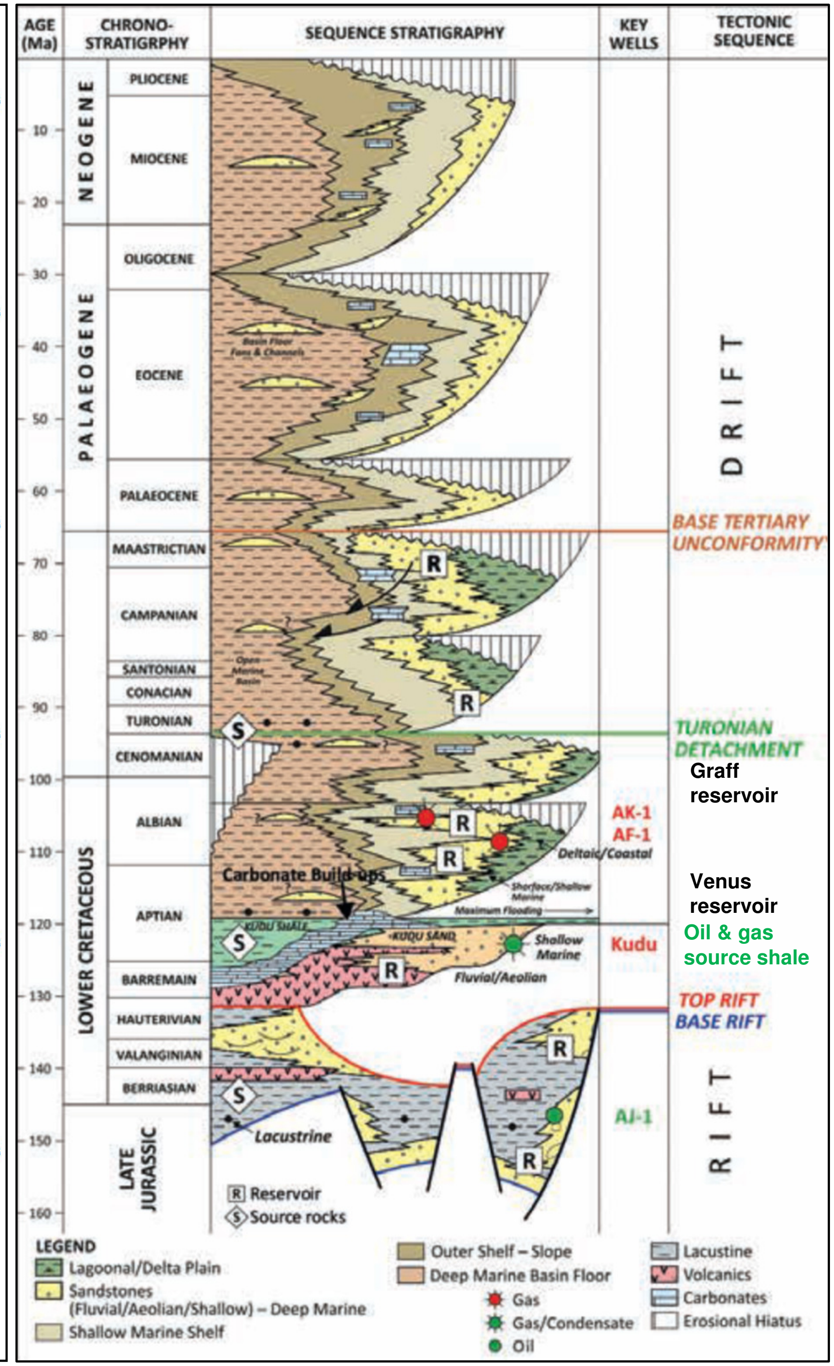
Late Jurassic & early Cretaceous volcanism

Initial extension in the South Atlantic & development of a mantle hot spot during the late Jurassic & early Cretaceous was marked onshore by the intrusion of dolerite sills, dykes & basaltic volcanism and several alkaline intrusions

- **Etendeka Magmatic Province** (NW Namibia) c. 1,000 m tholeiitic basalt, basaltic andesites locally interbedded with aeolian sands directly related to the Parana volcanics in SE Brazil & Uruguay (Valanginian – early Hauterivian - 136-131 Ma)
    - And massive volcanics along the Atlantic margin
- The **Brandberg granite pluton** was emplaced in the early Cretaceous (Hauterivian - 132-130 Ma) by partial melting of the granitic Congo Craton by basaltic magmas
- *Apatite fission track data indicates approximately 5 km of uplift during late Cretaceous (85-60 Ma)*

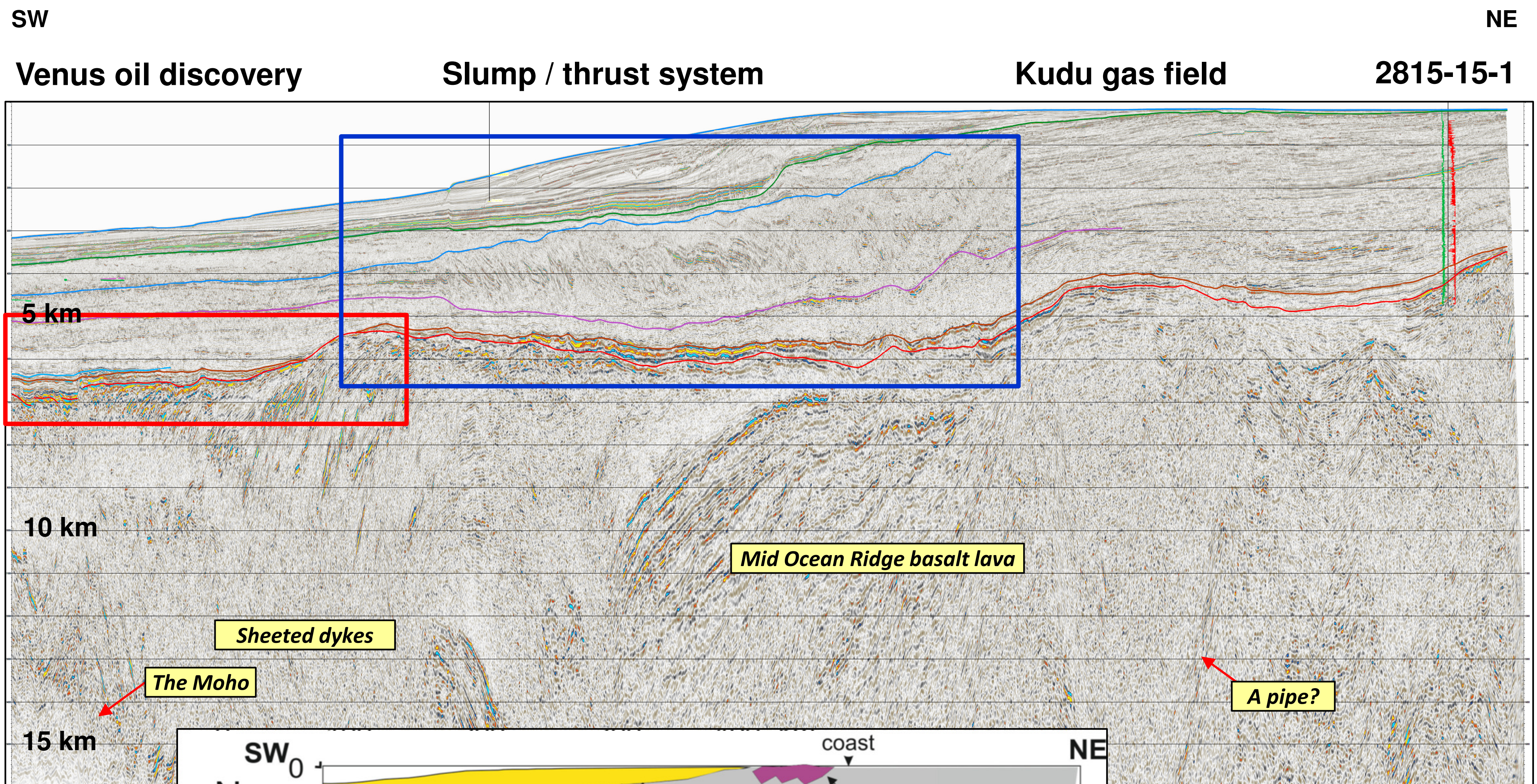
Early Cretaceous rifting, a mantle plume & the Brandberg Massif

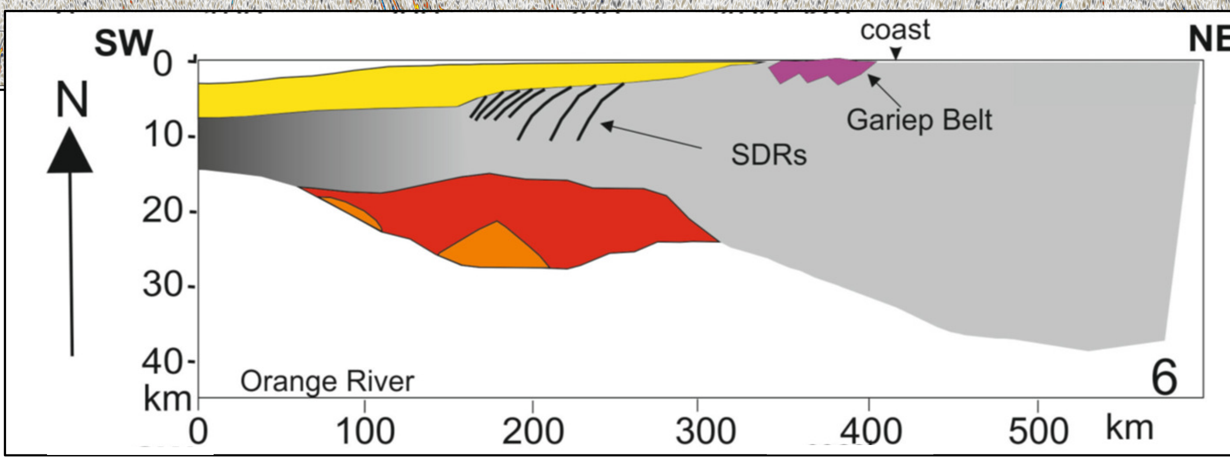




HRT, 2011

Namibian Atlantic margin – structure & stratigraphy

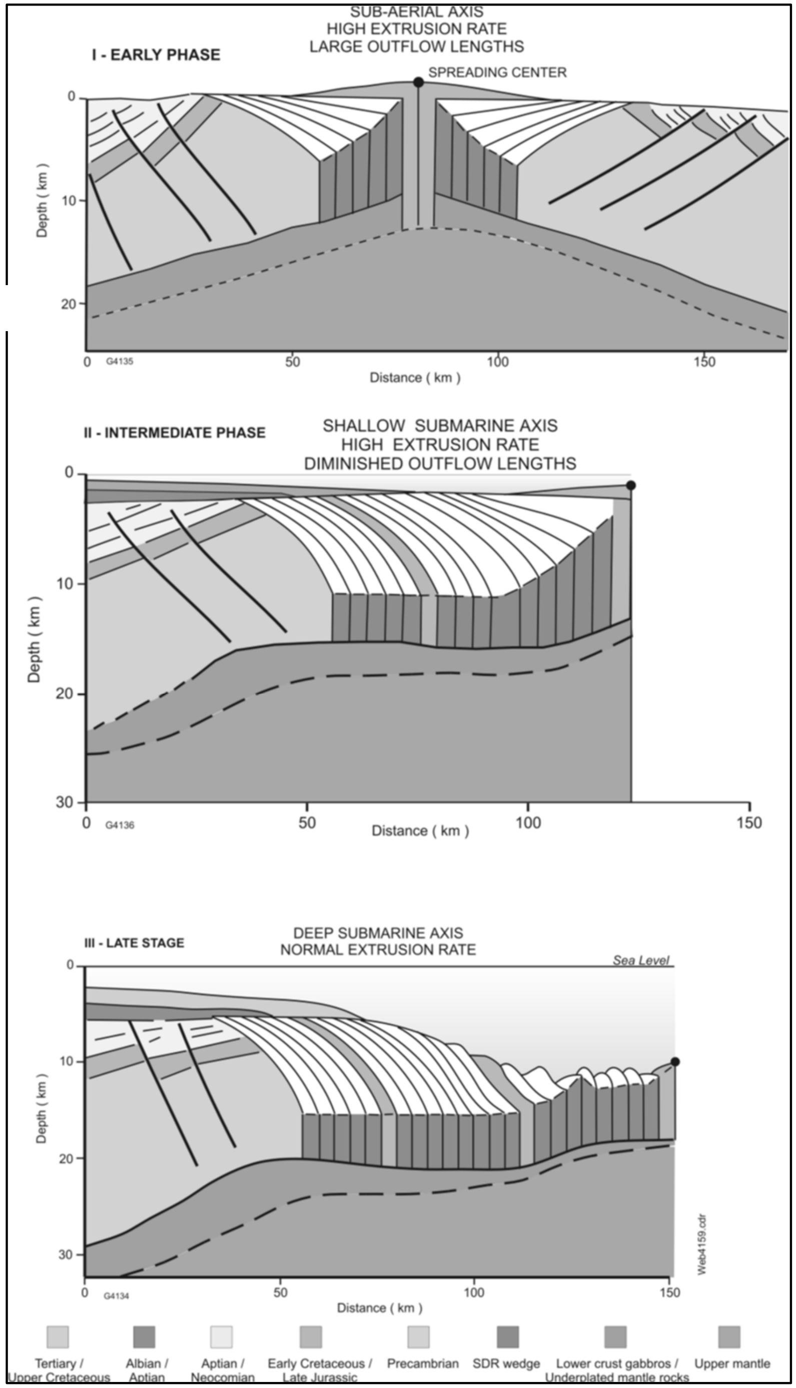




Becker et al., 2014

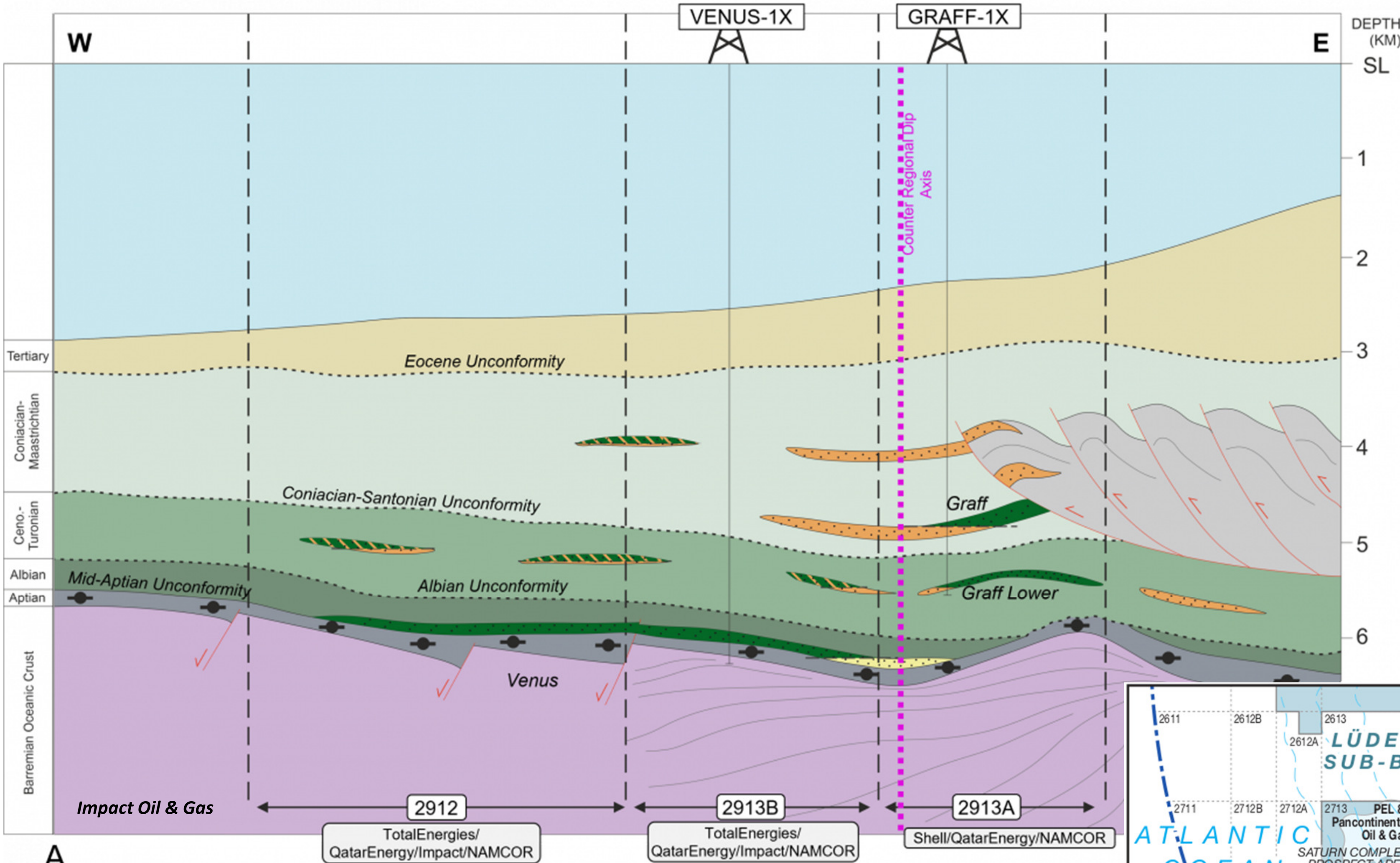
Early Cretaceous volcanism offshore
Strong extension along the Namibian Atlantic margin during the latest Jurassic & Neocomian with massive extrusive volcanics & sheeted dykes south of the Walvis Ridge

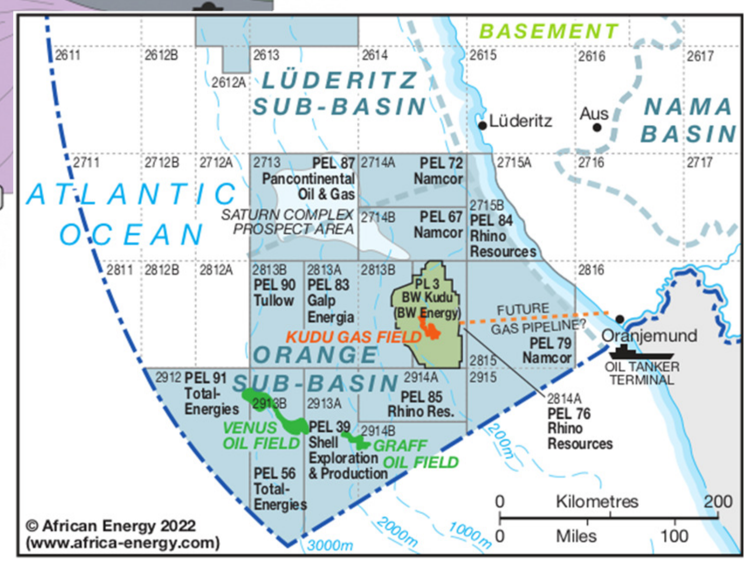
Neocomian rifting & SDRs (Orange River Basin)



Mohriak et al., 2015

FYI - development of a volcanic passive margin



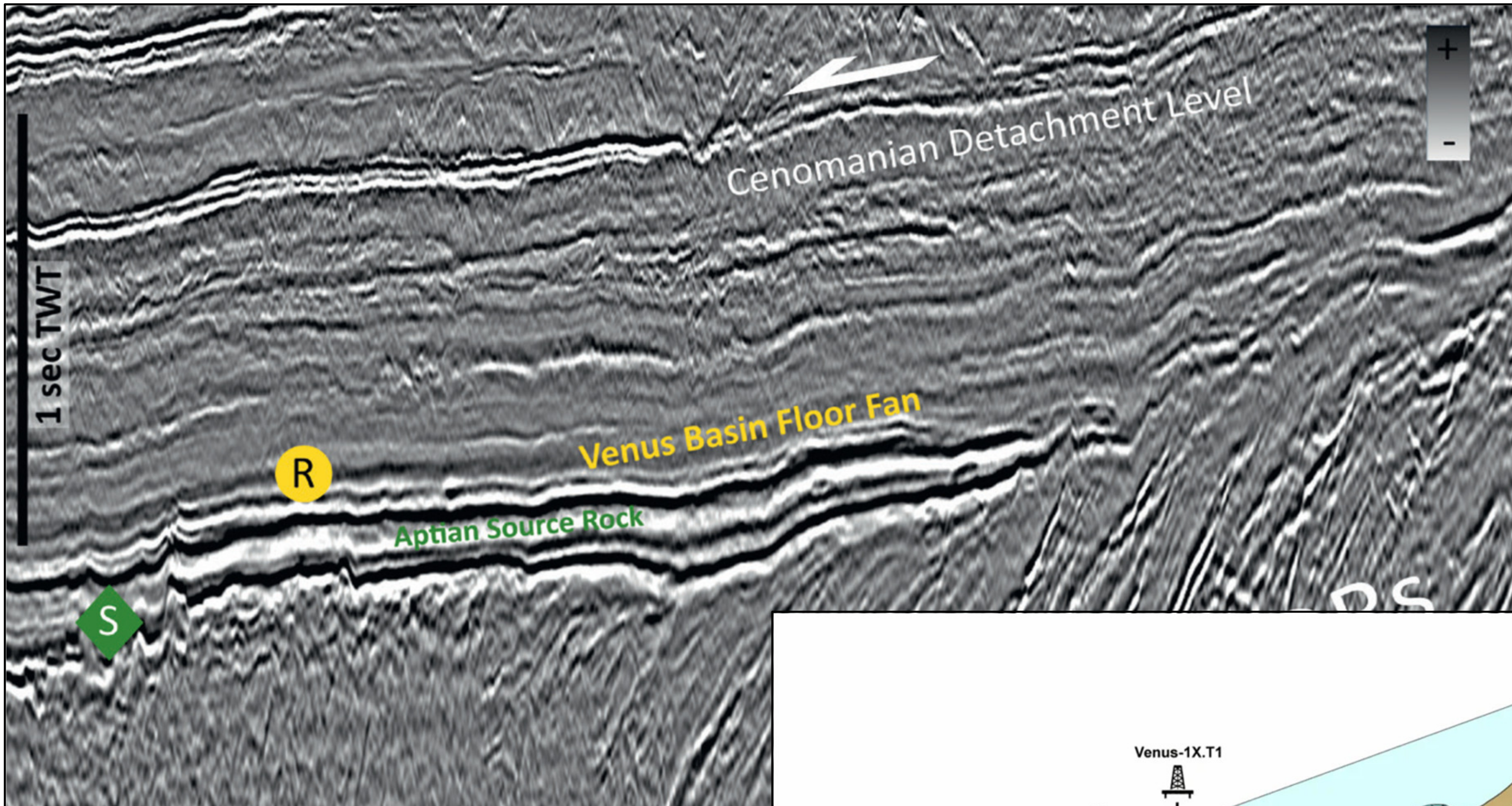


Oil & gas in Namibia

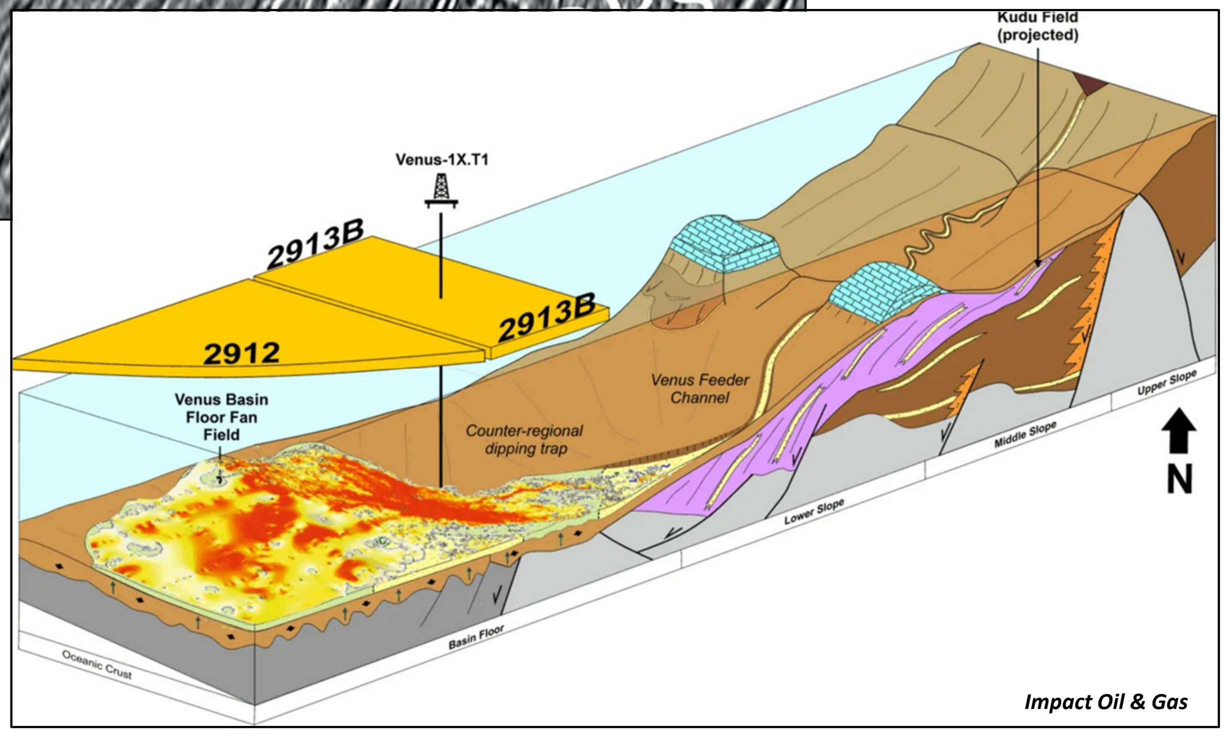
Exploration in the Atlantic basins of Namibia proved all of the components needed for oil (source rock, reservoir rock & a trap), but with only one gas discovery (Kudu) until 2021 / 2022

- ***Venus & Graff in the Orange Basin are amongst the largest oil discoveries made worldwide in recent years***
- ***Several recent discoveries have been made in water depths of 1,000 to 3,000 metres, with exploration drilling continuing today***

Offshore oil & gas



PGS



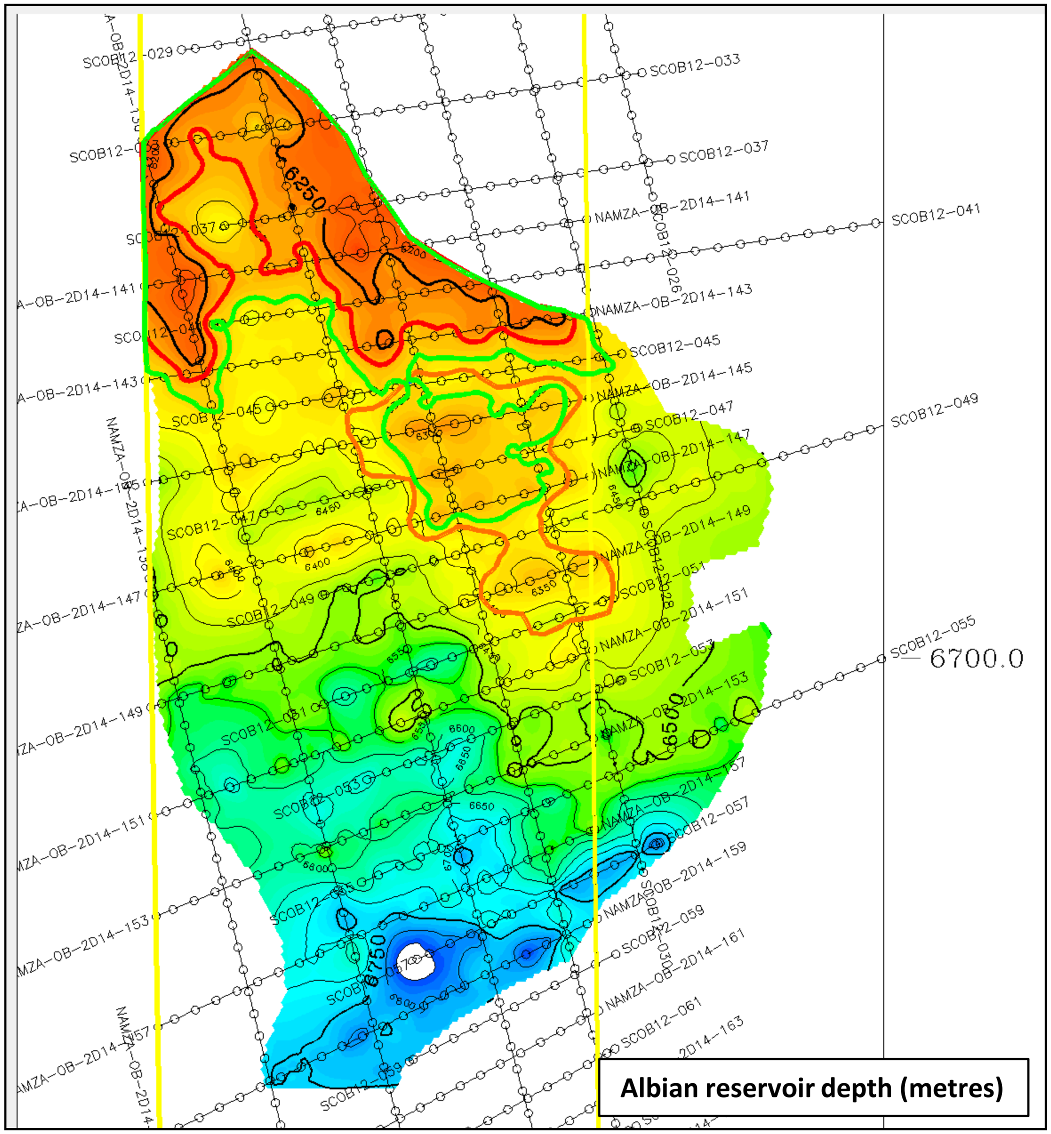
Impact Oil & Gas

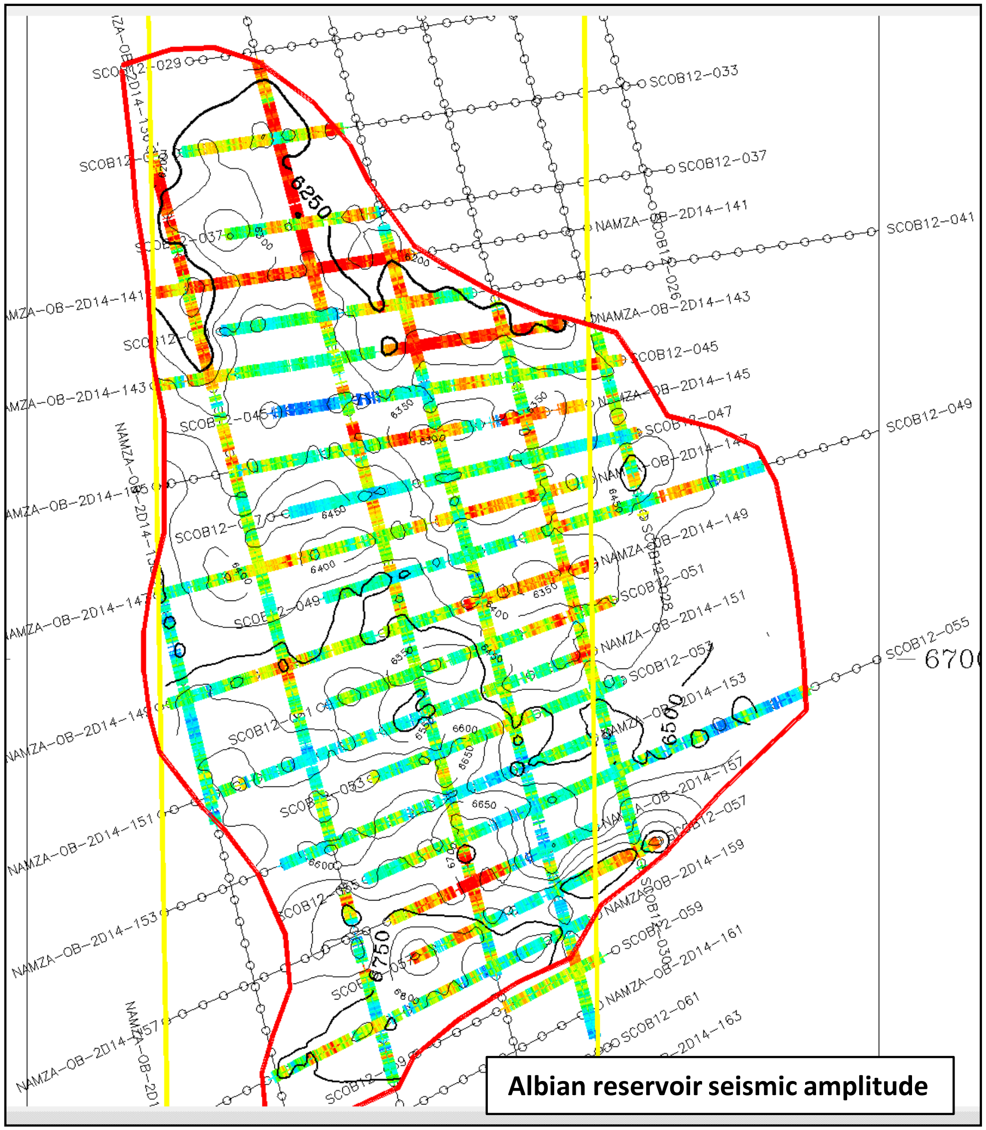
The Venus oil discovery (TotalEnergies, 2022)

Lower Cretaceous (Albian) turbidite sandstones, deposited in deep-water, with sands sourced from the east provide the reservoir

- ***Oil sourced from underlying thick organic rich black shales***
- ***Oil in Albian reservoir changes the reflection strength on seismic – direct indication of oil***
- ***Estimated 3 to 10 billion barrels***
- ***Water depth 2,500 – 3,000 metres***

The Venus oil discovery

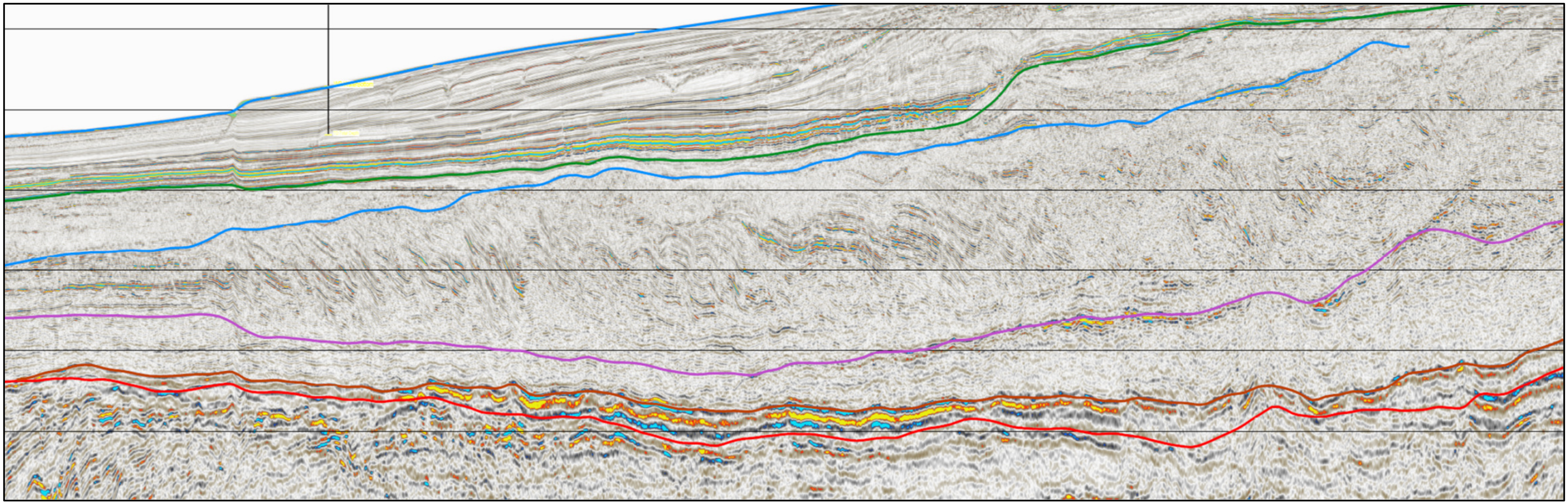


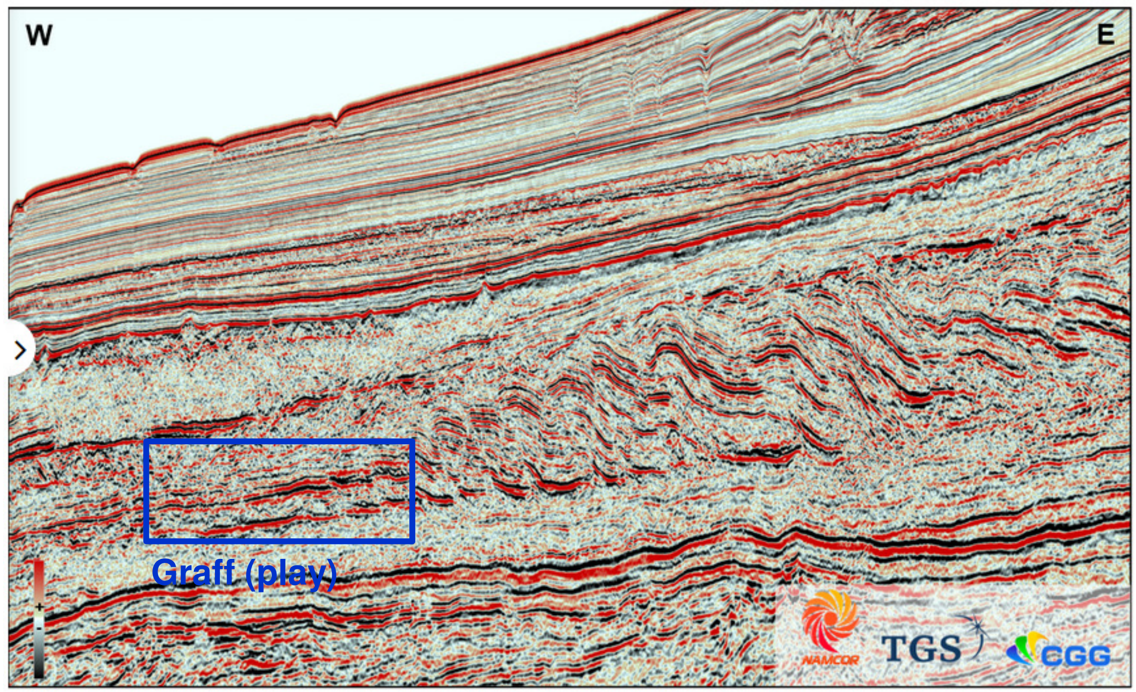


Original interpretation & identification of the Venus prospect from 2D seismic – Dave Rhodes for Impact Oil & Gas – 2014

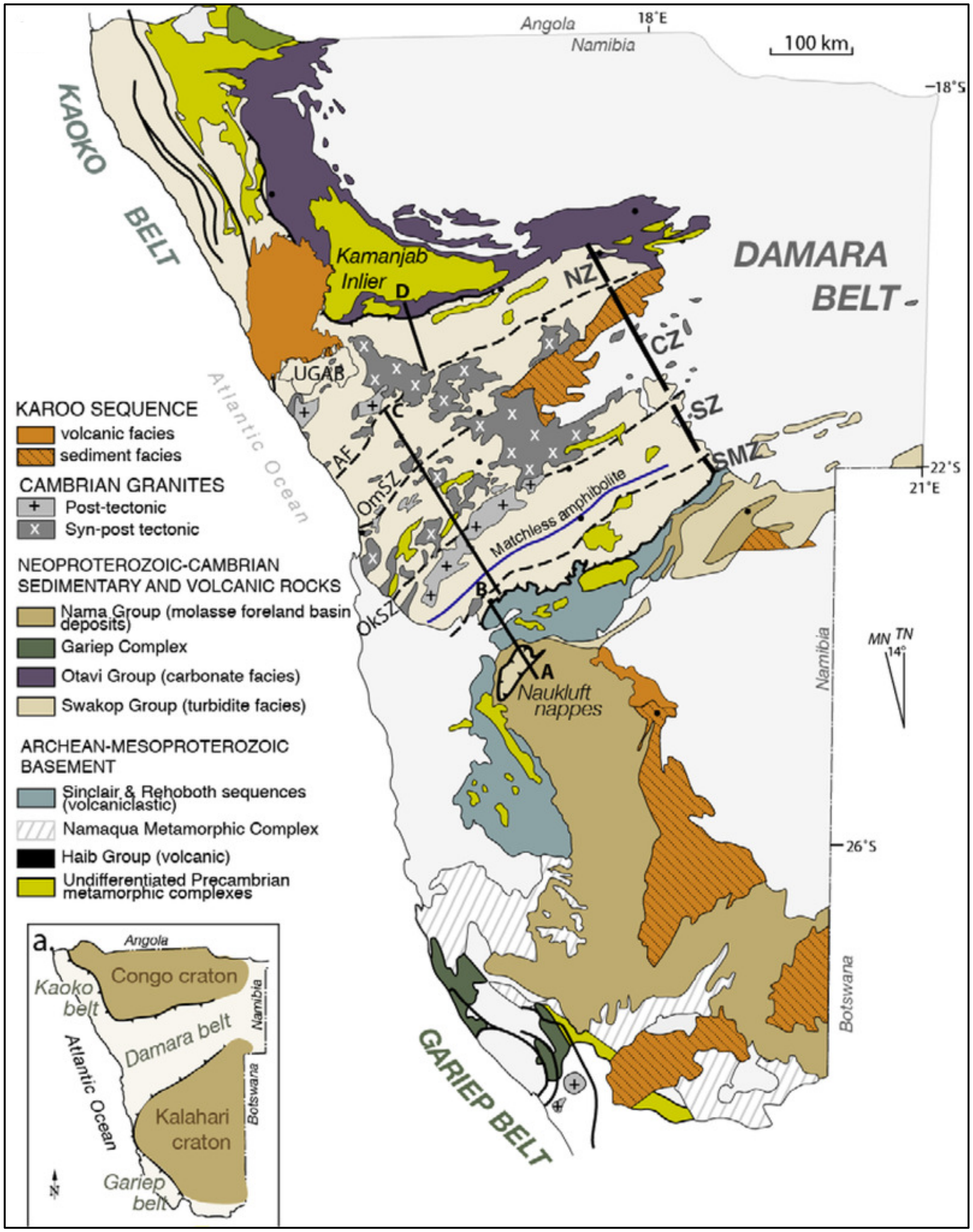
- **It took three years (& 3D seismic) to bring Total in as operator**
  - **Water depth & reservoir presence / oil maturity were the main issues**
- **Discovery well finally drilled in early 2022 – just following Shells' Graff-1 discovery (the first in Namibia)**

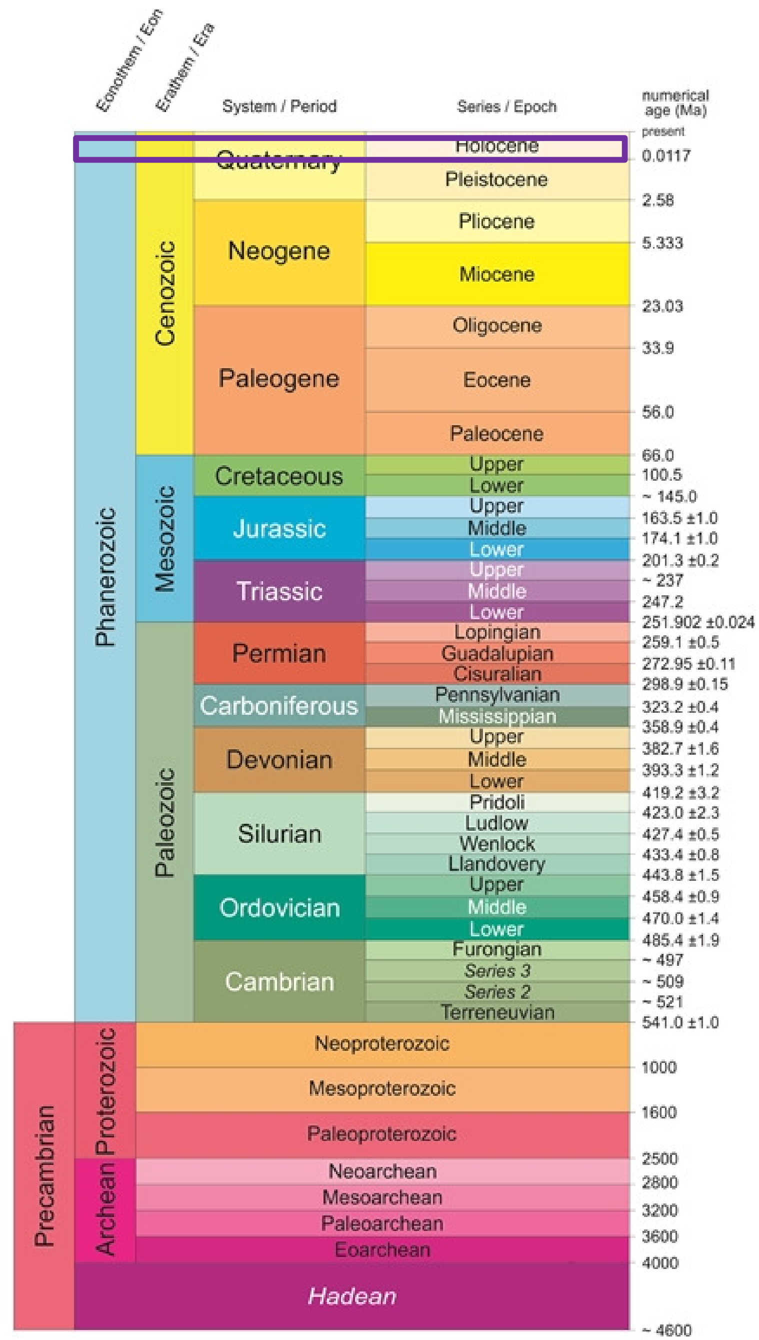
The Venus oil discovery





Upper Cretaceous – deltas with deep-water slumping & thrusting


Angola
Namibia
18°E
100 km
-18°S
KAOKO BELT
DAMARA BELT
Kamanjab Inlier
NZ
CZ
SZ
SMZ
UGAB
AF
OmSZ
OkSZ
Matchless amphibolite
Atlantic Ocean
-22°S
21°E
Naukluft nappes
Namibia
Botswana
MN TN
14°
-26°S
GARIEP BELT
KAROO SEQUENCE
volcanic facies
sediment facies
CAMBRIAN GRANITES
Post-tectonic
Syn-post tectonic
NEOPROTEROZOIC-CAMBRIAN SEDIMENTARY AND VOLCANIC ROCKS
Nama Group (molasse foreland basin deposits)
Gariep Complex
Otavi Group (carbonate facies)
Swakop Group (turbidite facies)
ARCHEAN-MESOPROTEROZOIC BASEMENT
Sinclair & Rehoboth sequences (volcaniclastic)
Namaqua Metamorphic Complex
Haib Group (volcanic)
Undifferentiated Precambrian metamorphic complexes
a.
Angola
Congo craton
Kaoko belt
Damara belt
Namibia
Atlantic Ocean
Kalahari craton
Botswana
Gariep belt


Eonothem / Eon
Erathem / Era
System / Period
Series / Epoch
numerical age (Ma)
present
Quaternary
Holocene
0.0117
Pleistocene
2.58
Neogene
Pliocene
5.333
Miocene
23.03
Paleogene
Oligocene
33.9
Eocene
56.0
Paleocene
66.0
Cenozoic
Cretaceous
Upper
100.5
Lower
~ 145.0
Jurassic
Upper
163.5 ±1.0
Middle
174.1 ±1.0
Lower
201.3 ±0.2
Triassic
Upper
~ 237
Middle
247.2
Lower
251.902 ±0.024
Mesozoic
Permian
Lopingian
259.1 ±0.5
Guadalupian
272.95 ±0.11
Cisuralian
298.9 ±0.15
Carboniferous
Pennsylvanian
323.2 ±0.4
Mississippian
358.9 ±0.4
Devonian
Upper
382.7 ±1.6
Middle
393.3 ±1.2
Lower
419.2 ±3.2
Silurian
Pridoli
423.0 ±2.3
Ludlow
427.4 ±0.5
Wenlock
433.4 ±0.8
Llandovery
443.8 ±1.5
Ordovician
Upper
458.4 ±0.9
Middle
470.0 ±1.4
Lower
485.4 ±1.9
Cambrian
Furongian
~ 497
Series 3
~ 509
Series 2
~ 521
Terreneuvian
541.0 ±1.0
Paleozoic
Phanerozoic
Neoproterozoic
1000
Mesoproterozoic
1600
Paleoproterozoic
2500
Proterozoic
Neoarchean
2800
Mesoarchean
3200
Paleoarchean
3600
Eoarchean
4000
Archean
Hadean
~ 4600
Precambrian

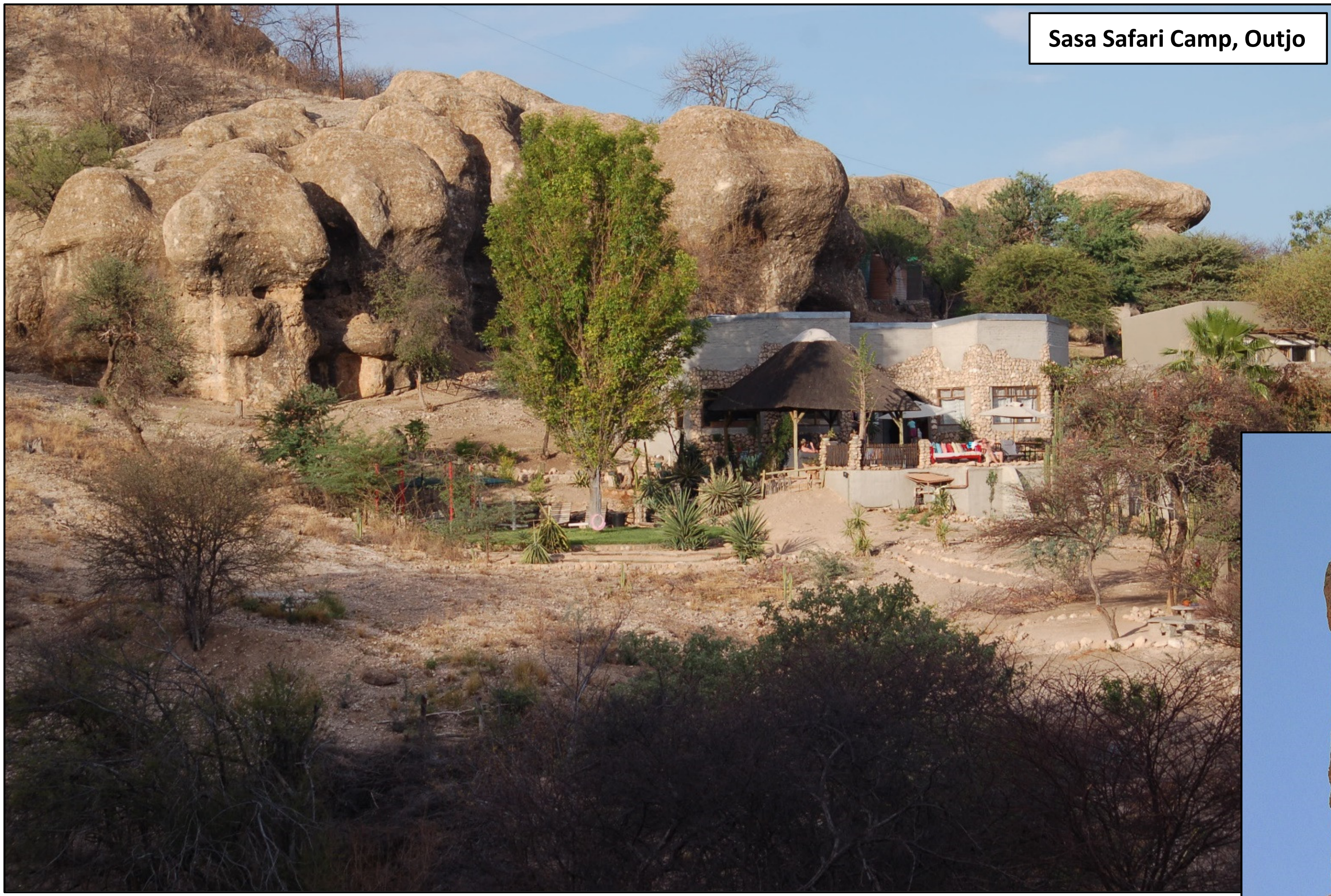
….. & today

Uplift of southern Africa began at c. 180 Ma (early Jurassic) due to an underlying mantle plume

Late Cretaceous (Santonian) uplift from ~ 85 Ma, resulting from a change in plate vector; ~ 5 km of uplift at Brandberg 85-60 Ma

Late phase of uplift at ~ 20 Ma defies the modern escarpment

The Great Escarpment



Erosion

Soussusvlei dunes

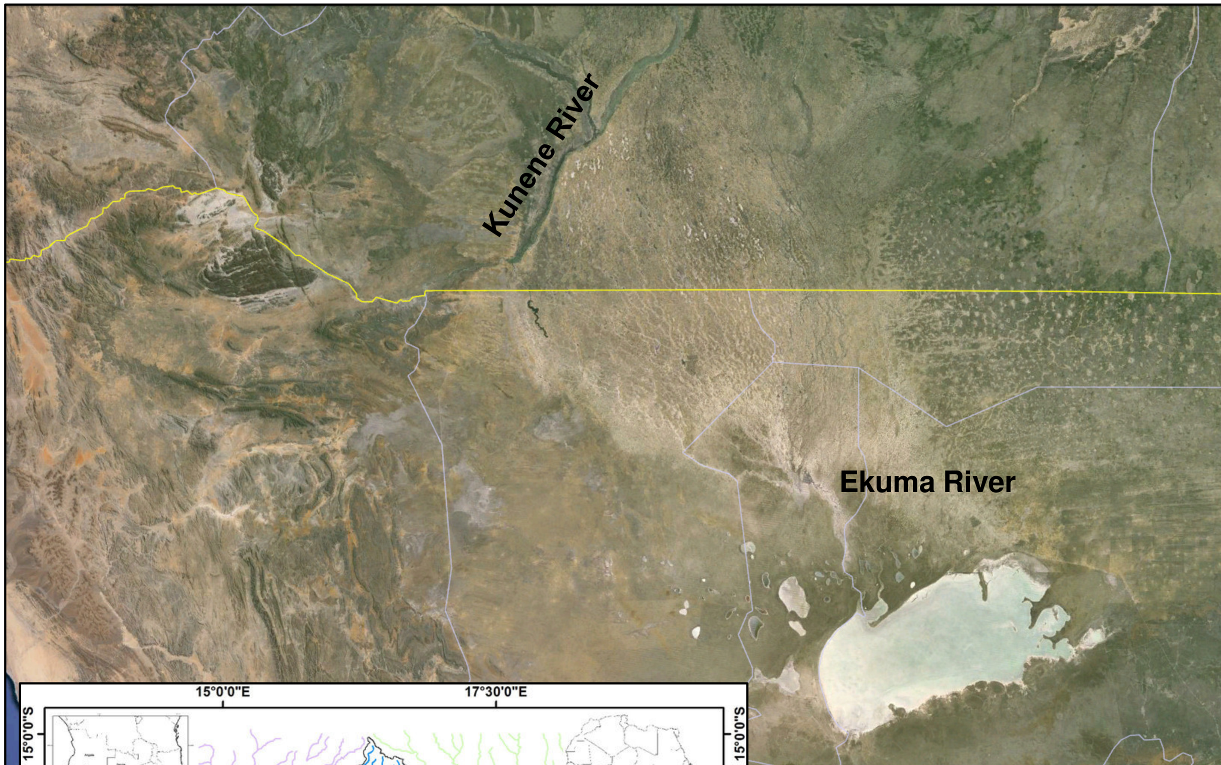
Big Daddy – 325 m!

BEAGLE GEOSCIENCE
Guiding your company on its voyage of discovery

Dunes on the move

An oasis – before the river changed course!

Deadvlei

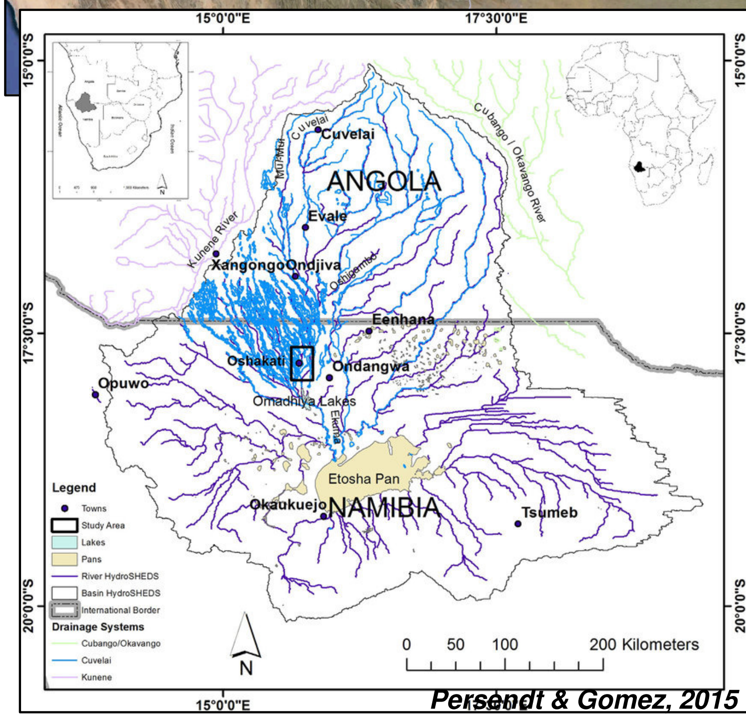


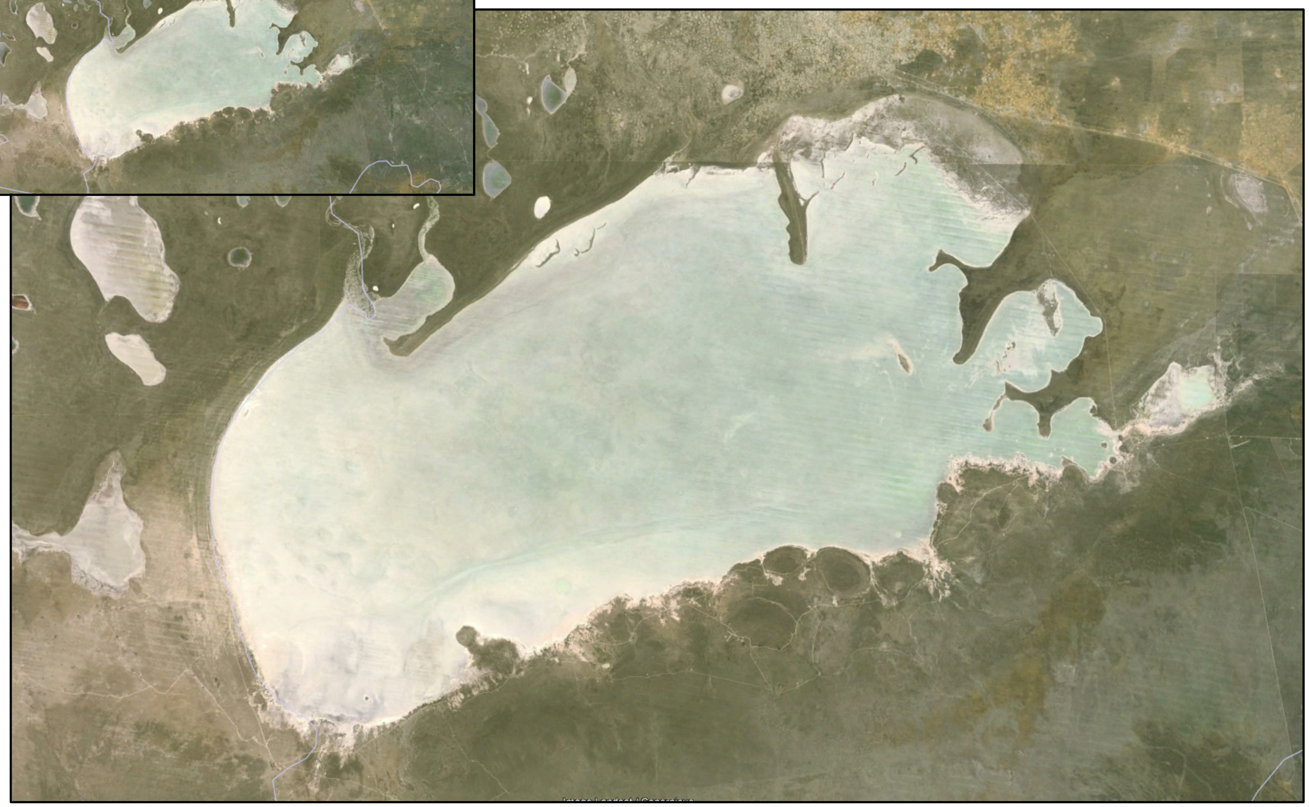
The largest salt pan in Africa

- 130 km x 50 km
- 4,800 km^2

Originally fed by the Kunene River before tectonic uplift caused the river to change course

Etosha is still fed by several, relatively small seasonal rivers, especially the Ekuma River, draining south from Angola





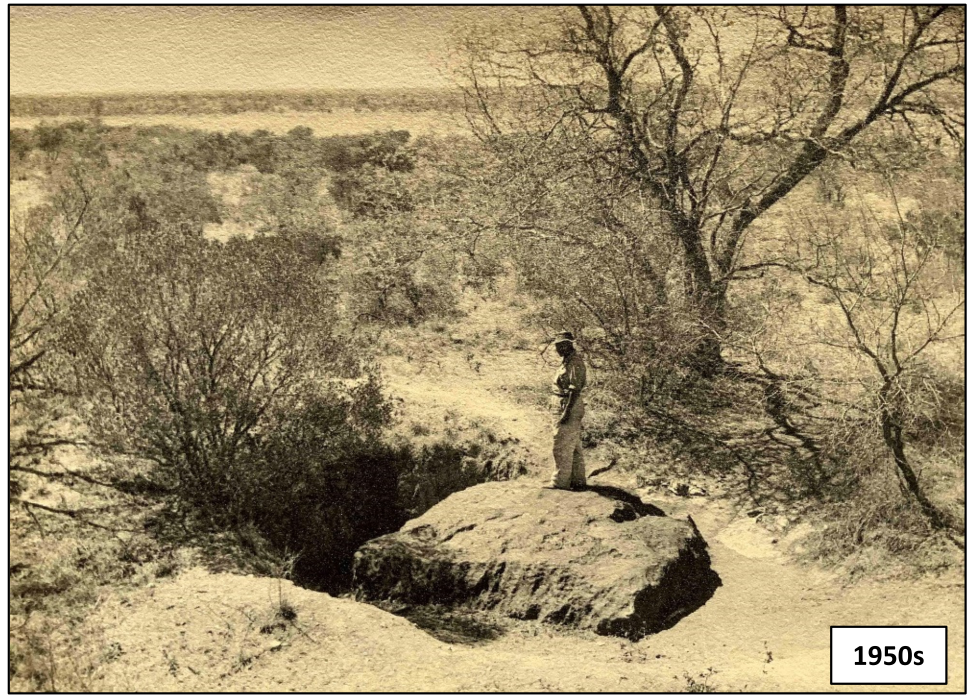
Etosha – salt pan & National Park

https://commons.wikimedia.org/wiki/User:Alchemist-hp

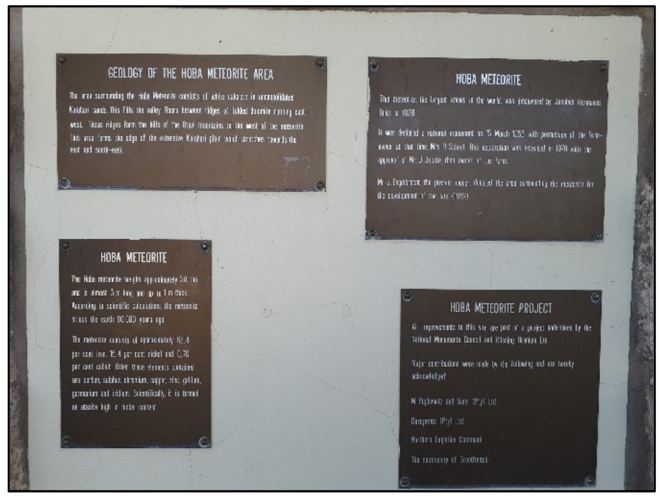
Etosha salt pan

Hoba – the world's largest meteorite


Geo-vandalism


1950s

Tsumeb Museum



- Discovered 1920
- Approximate weight 64 tonnes
- A nickel / iron meteorite (iron 82.4%, nickel 16.4%)
- Believed to have fallen ~ 80,000 years ago

Hoba

National Earth Science Museum, Windhoek

Gibeon meteorite strew field

- 77 pieces (so far) of up to 506 kg from a parent body of ~ 15 tonnes
- Similar iron-nickel meteorite to Hoba (not related!)
- Worlds largest strew field (390 x 120 km)

Roter Kamm impact crater

- 2.5 km in diameter & 130 m deep
- Impact breccias & shocked quartz
- Impact estimated at 4.8 Ma (Pliocene)
- No debris discovered – suggesting the meterorite evaporated on impact

https://en.wikipedia.org/wiki/Roter_Kamm_crater #/media/File:Roter_Kamm_Bird's_Eye_View.jpg

Gibeon meteorite fall & the Roter Kamm crater

A few pretties ……

Birds ....

Seals ……..

& the rest (Etosha National Park)

Customary rhino shot