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The Perth basin, Australia, and the Karroo Corridor, Madagascar – similarities and possible hydrocarbon implications.

An example of parallel margins (as opposed to much more widely recognised conjugate margins).

Reeves et al (2016) GS Sp Pub 431

JANUARY 2018

Talk outline

1. Initial comparison and palaeogeography
2. Madagascar and Perth Basin overviews
3. Stratigraphic comparison
4. Structural comparison
5. Delta C13, source rocks, and HCs
6. Recent discoveries, Perth Basin
7. Conclusions; learnings.

Comparison between Karroo Corridor and Perth Basin.

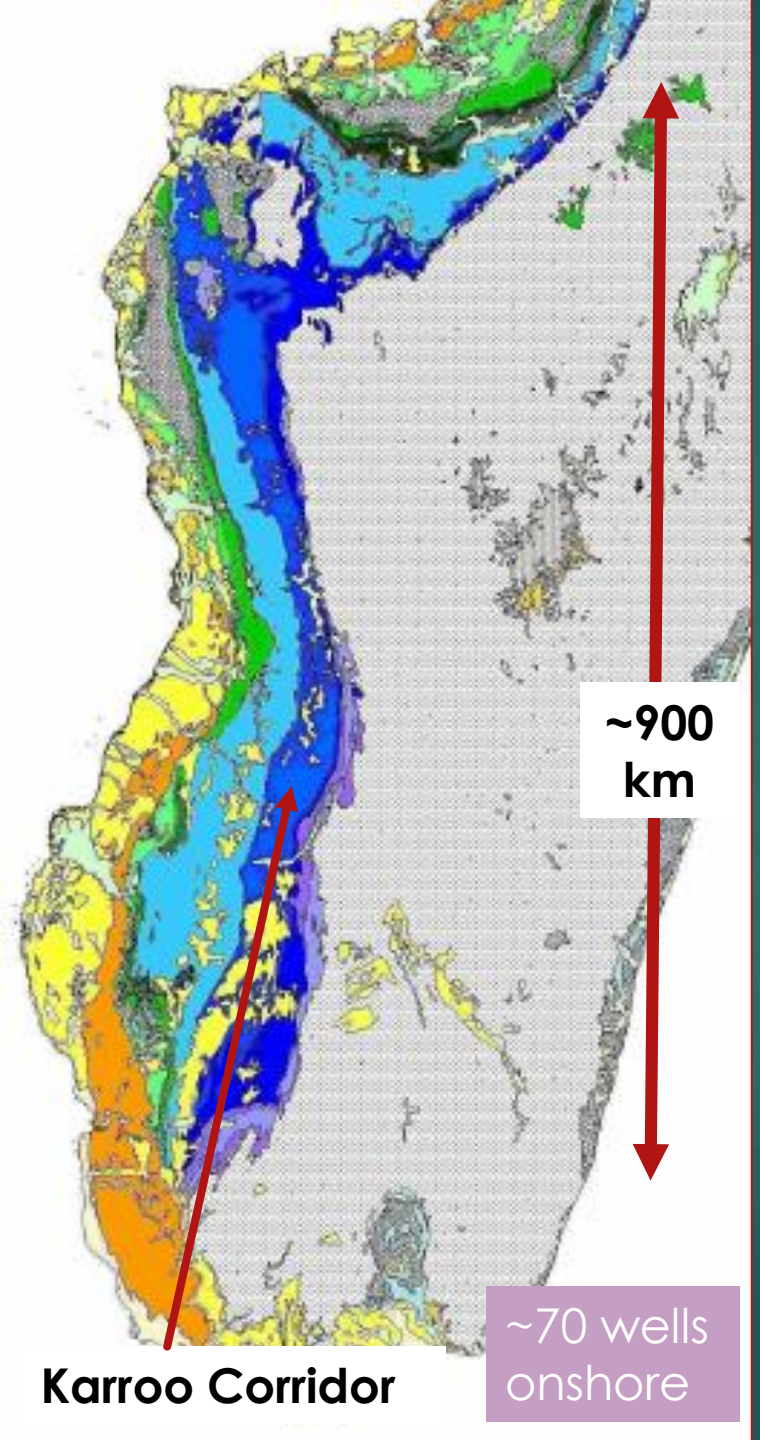
Both basins have an inboard abortive Permian rift adjacent to Bmt on the east, and a Jurassic rift basin outboard, which proceeds to SFS.

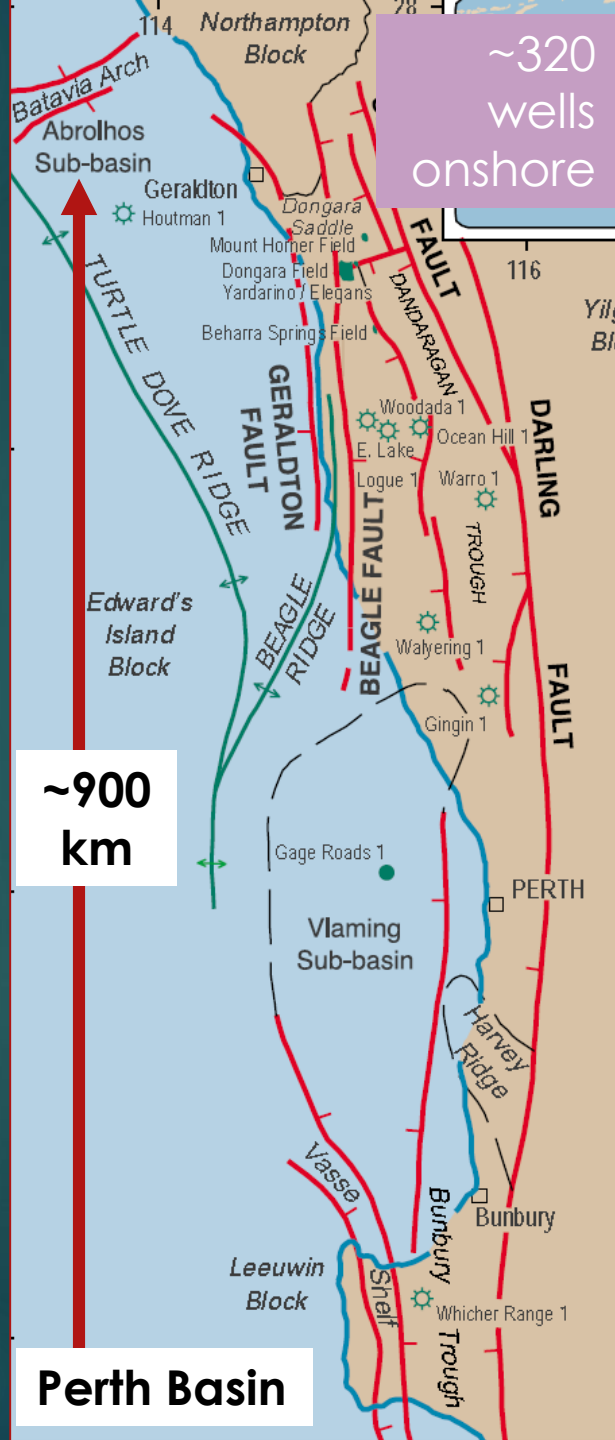
Both basins have a rich Lower Triassic oil-prone source rock and a Lwr-Mid Permian gas (oil) prone coal sequence.

Both basins have Mid-Late Permian sandstone reservoirs (oil and gas).

The N. Karroo Corridor is heavily oil-bitumen prone (~22 BBOIIP: dom Tr resvrs).
The S. Karroo Corridor is ? gas (oil) prone.

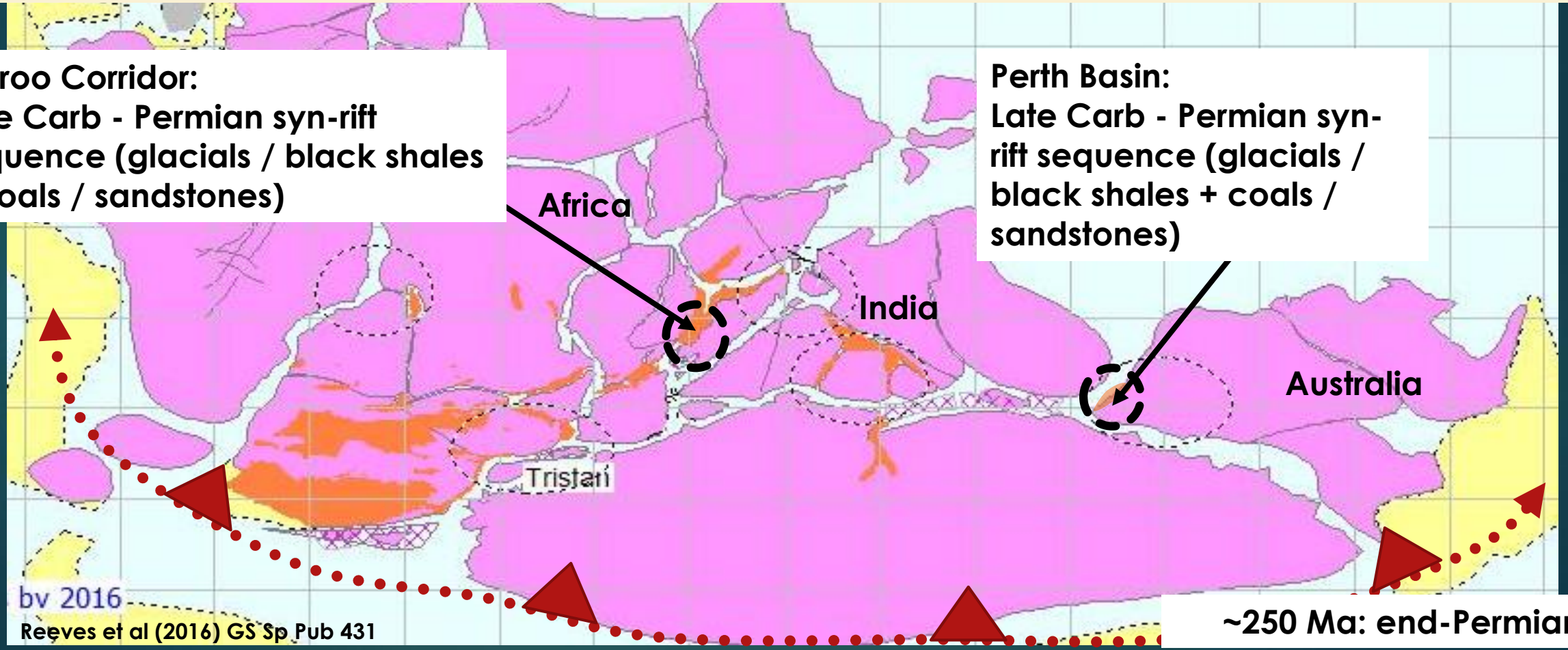
The N. Perth basin is heavily gas prone (~2 tcf + 39 mmbo: dominantly P resvrs).
S. Perth basin has 1 non-comm discovery.





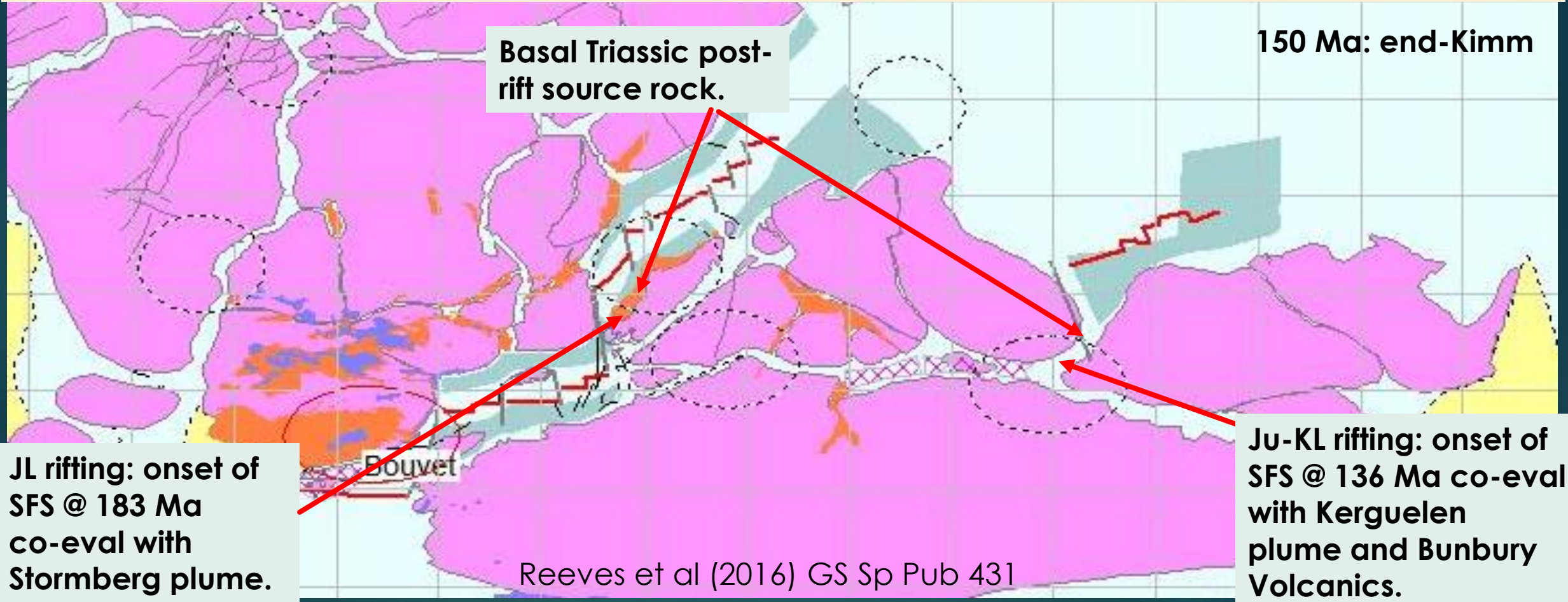
Perth and Morondava basins: palaeogeography (end-Permian).

Both lie at roughly the same palaeo-latitude; both lie at the end of a narrow seaward-opening gulf. Karroo rifts trend ~NE-wards away from the orogenic S. margin of Gondwana (Cape Fold Belt and equivalents), towards the free face of Palaeo-Tethys.



Perth and Morondava basins: palaeogeographic comparison (JJ)

Jurassic rifts aligned with, but outboard of, the earlier P-C (Karroo) rifts. Jurassic rifting in Madagascar was earlier than in W. Australia (Early Jurassic vs Late Jurassic-Early Cretaceous)



Reeves et al (2016) GS Sp Pub 431

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Madagascar Overview

Permo-Carb Karroo rifting (abortive)

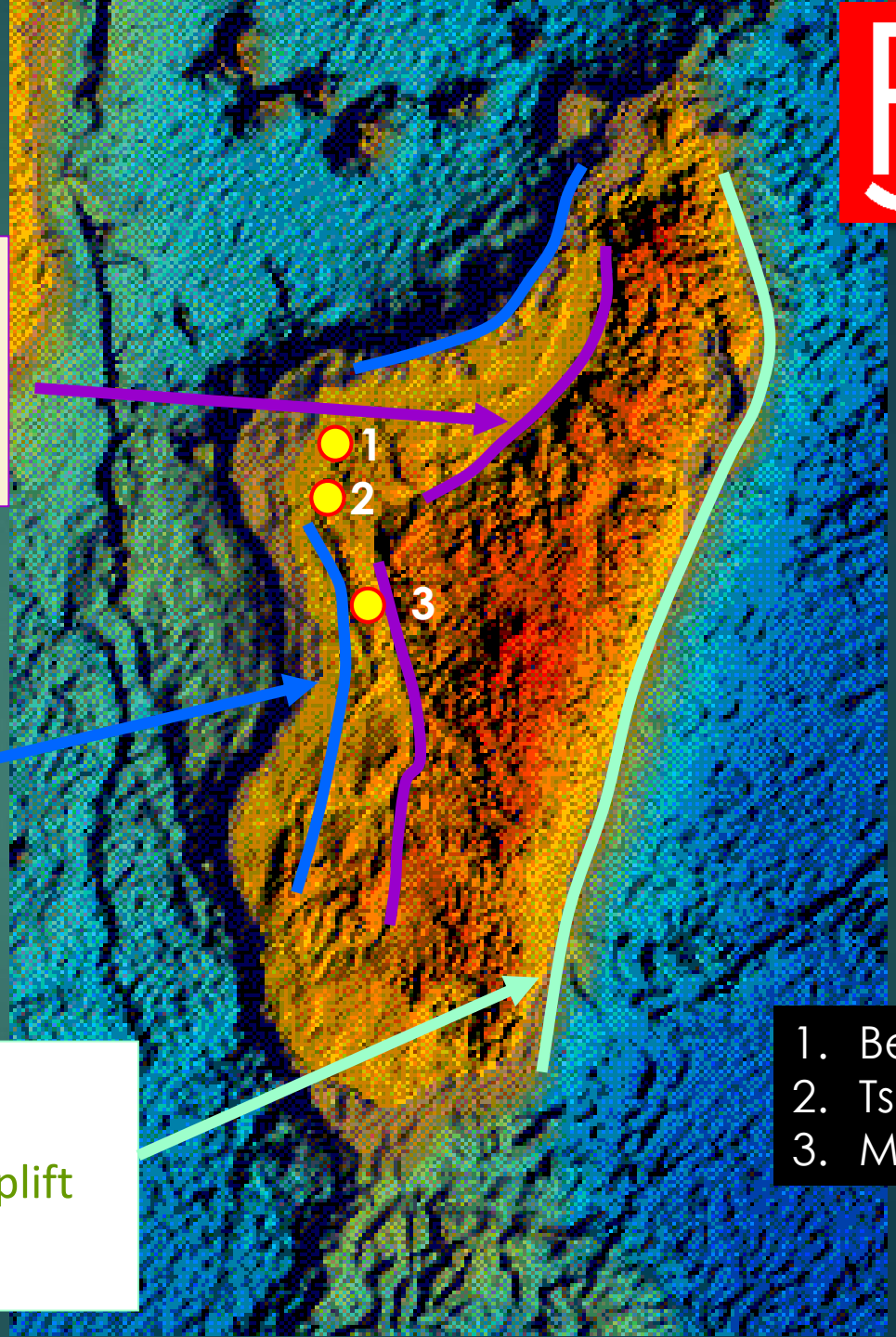
- tillites; coal
- remote from eventual line of separation

Lower Jurassic rifting

- evaporites (N); source rocks
- adjacent to eventual line of separation (W, E Gondwana)

Late Cretaceous (~ Turonian) rifting

- no apparent antecedents; widespread volcanism and uplift
- Wernicke style – only footwall remains.



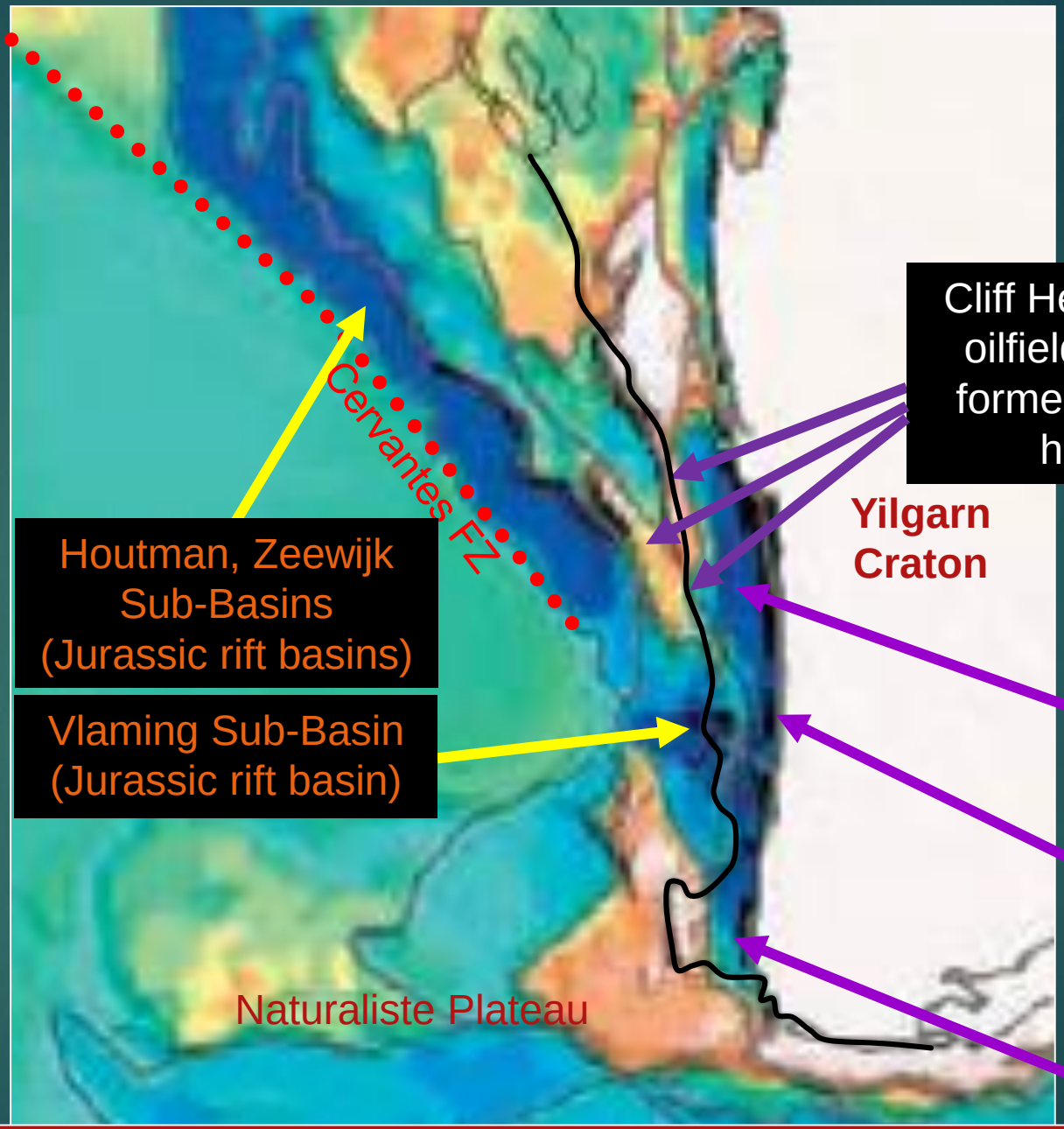
1. Beronono
2. Tsimiroro
3. Manandaza

Perth Basin overview

Cliff Head oilfield: discovered 2001 on Beagle Horst. Large NNW-trending fault/dip closure to E of major Geraldton fault. URR ~25 mmbo. Oil is waxy, high PP, 32*API, v low GOR.

Dongara gas/oilfield: discovered 1965 on Permian horst. GIIP=0.5 tcf, STOIIP= 105 mmbo

A/a end-2015, the basin has 9 producing fields, all in the north.



Cliff Head Xanadu,and Hovea oilfields; Dongara O/G field: formed on inverted Permian half-graben / horsts

Yilgarn Craton

Denderagan Trough (Permian rift basin) 50-60 km wide

Darling Fault

Bunbury Trough

Both have N-S elongate Permian rift basin in East, ~50 - 60 km wide, adjacent to Basement, with Jurassic rift basin outboard. Both Morondava and the Perth Basins characterised by oblique J-K extension

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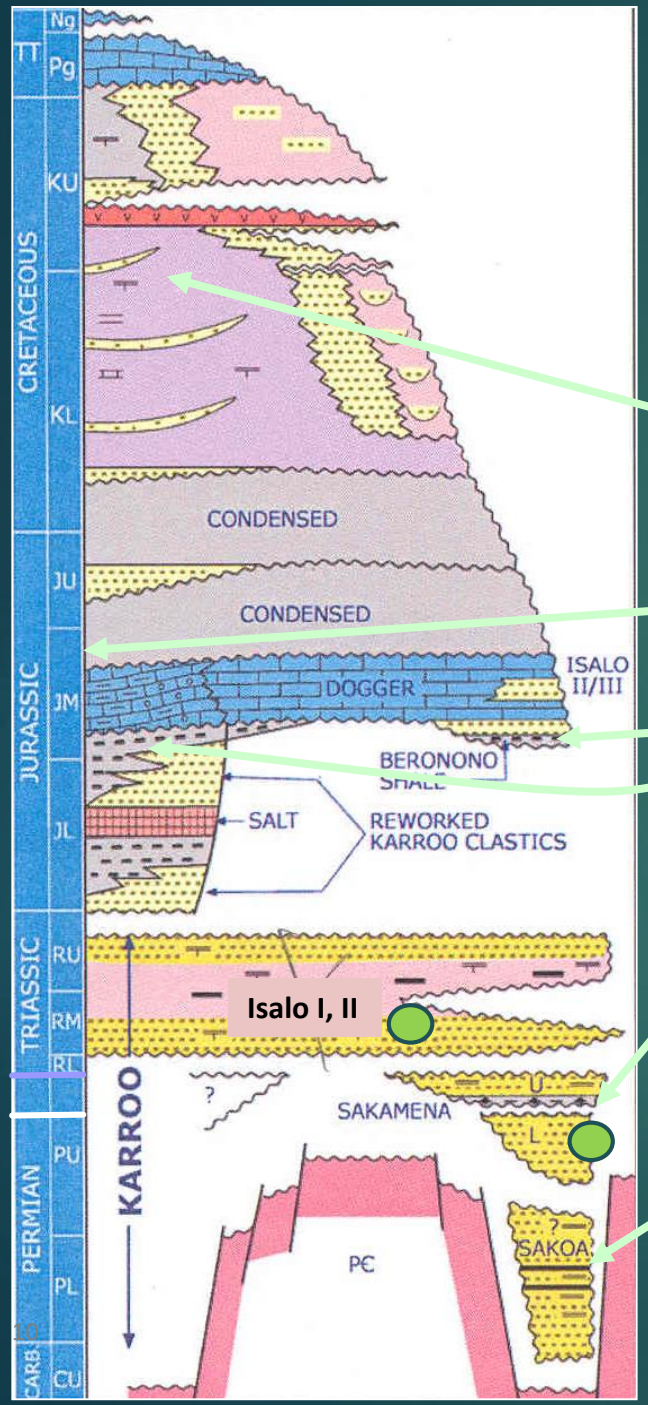
Morondava Basin: stratigraphy



Km-Ku anoxic event SR – none reported.

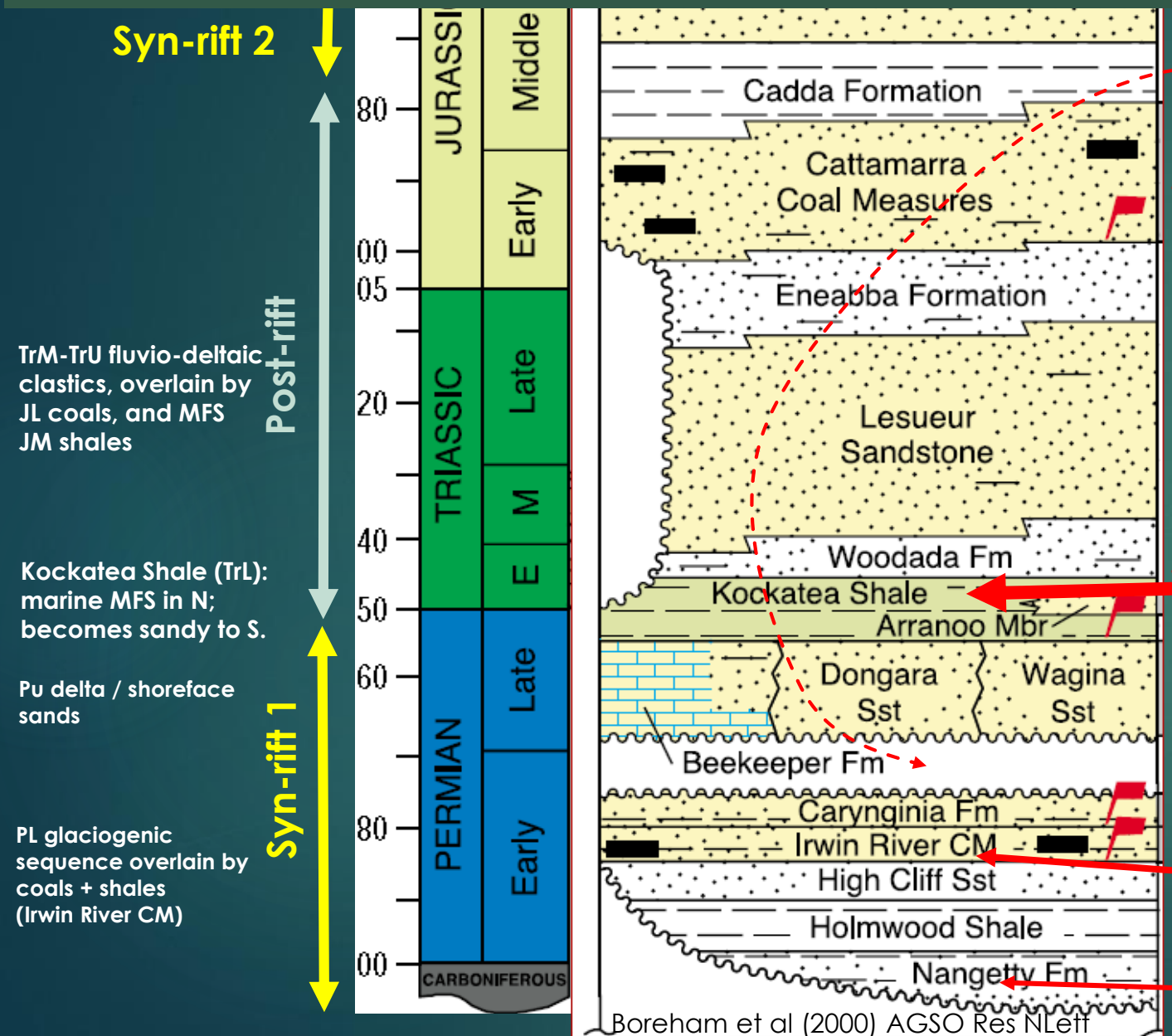
Jm-Ju slope-basinal mudstones: TOCs upto 5% reported. (Serinam-1: mm-lamin shale + lst; TOC 2.2% @ 1.3% VR. Orig est TOC = 3-5%, HI ~400)

Syn-rift Lwr Jurassic Andafia Shales: rich type II in outcrop (Beronono: TOC upto 70%; HI upto 770). TOCs upto 5% in Manera-1.

Middle Sakamena shale: fw-brackish lacustrine; type I/II, average 50m. Analyses 1-6%; original TOC 4-12%; original HI upto 750. Tied to Bemolanga, Tsimiroro (Tr Isalo resvr), and Manadaza (Late P resvr) oils. All have delta C13 values of -33 to -36. Not proven in S. Karroo Corridor

Sakoa coals and black shales: type III/II. Average coal thickness in S of basin ~25m; max seam thickness ~10m. S. Karroo Corridor seeps/shows have delta C13 values of -27 to -30 (Clark, 1996) suggesting they are NOT sourced from Middle Sakamena.

Carboniferous – Early Jurassic stratigraphy of the Perth Basin, and comparison to Morondava Basin, Madagascar.



Smith et al (2017), S&D 51443: report base Wagina-Dongara unconformity to be diachronous – Pm in W, Pu in E.

* Boreham et al (2011) AAPG Hedburg Conf.
** Volk et al (2009) Jl Geoch Expl.

Triassic-earliest JJ continental sands, = Upp Sakamena + Isalo Fms

Lwr Triassic source rock = Middle Sakamena. Both show richest SR @ basal 50m. Original TOC upto 12.6%, HI upto 800.

Delta C13 of expelled oils = -33 to -34.**

Permian sands, = Lwr Sakamena Fm

Permian coals, = Sakoa Fm

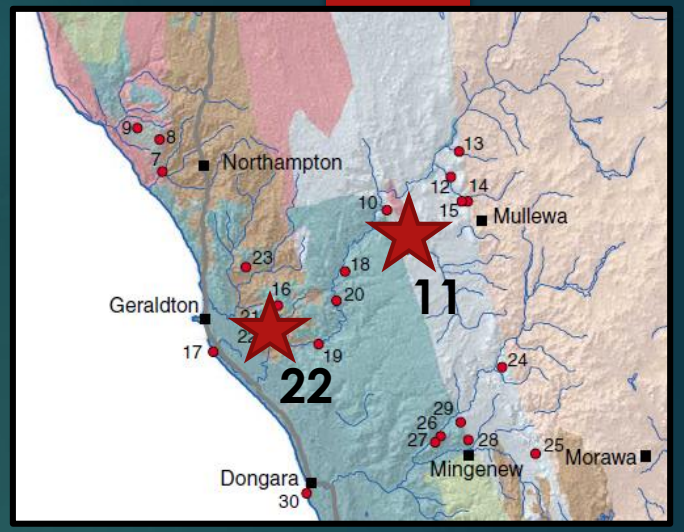
Delta C13 of expelled gas/oil = -24 to -30.*(Whicher Range)

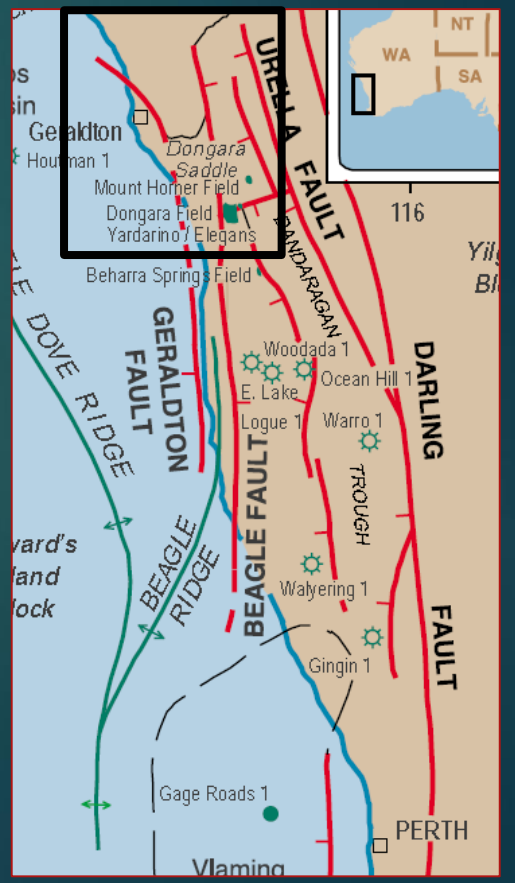
Permo-C glacials, = Sakoa Fm

Perth Basin outcrops

Kockatea Sh transgressive over intra-basinal bmt horst, Sheehan Hill, Glengarry WA. (Loc 22)

Carb-PL diamictite, Nangetty Fm, with boulders upto 1m diameter, Kockatea Gully, WA. (Loc 11)





Mory et al (2005) Geology of N.Perth Basin. WA Geol Surv 2005/9.

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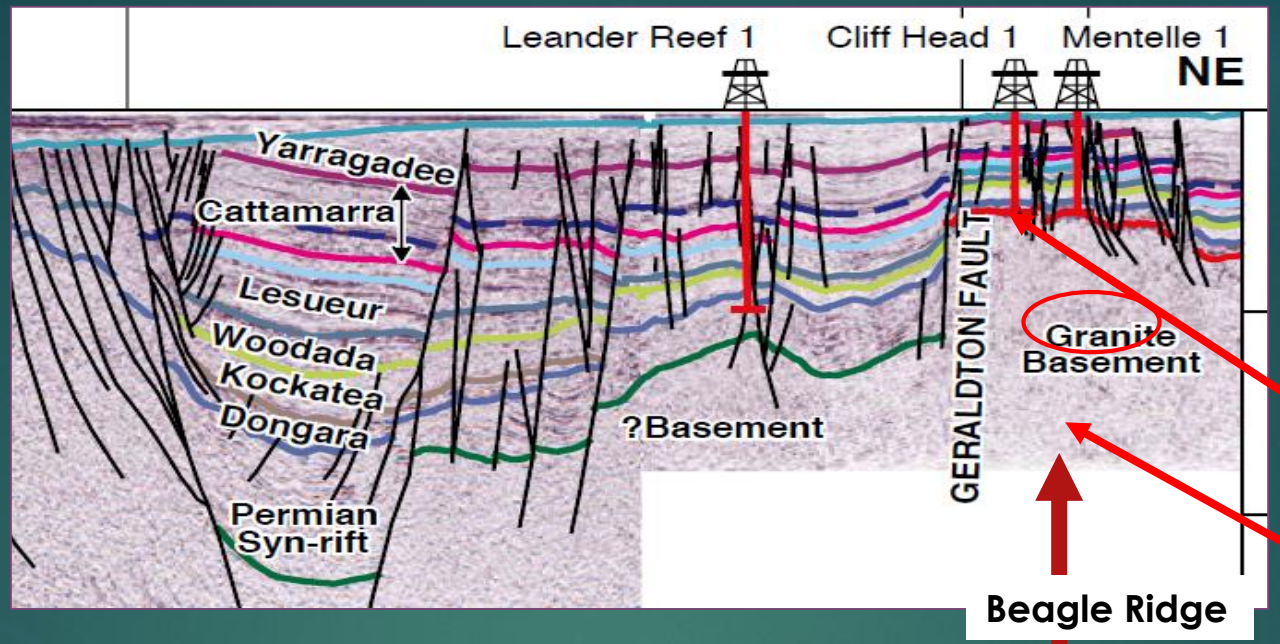
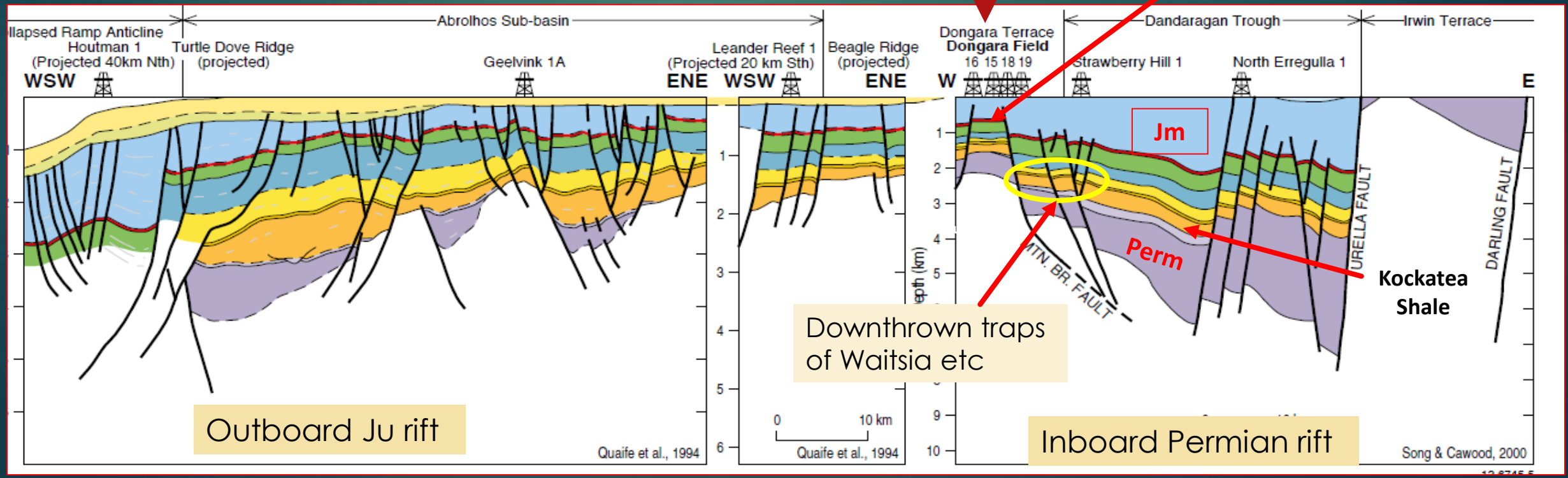
Cross sections from the N. Perth Basin.



Cliff Head URR ~25 mmbo
Oil = waxy, 33*API, high PP, v low GOR. Sourced from TrL Kockatea Sh

Tsimiroro / Antaotao ridge analogue ?



Play cross section of Morondava Basin, highlighting plays of the Karroo Corridor and the JJ-TT passive margin.

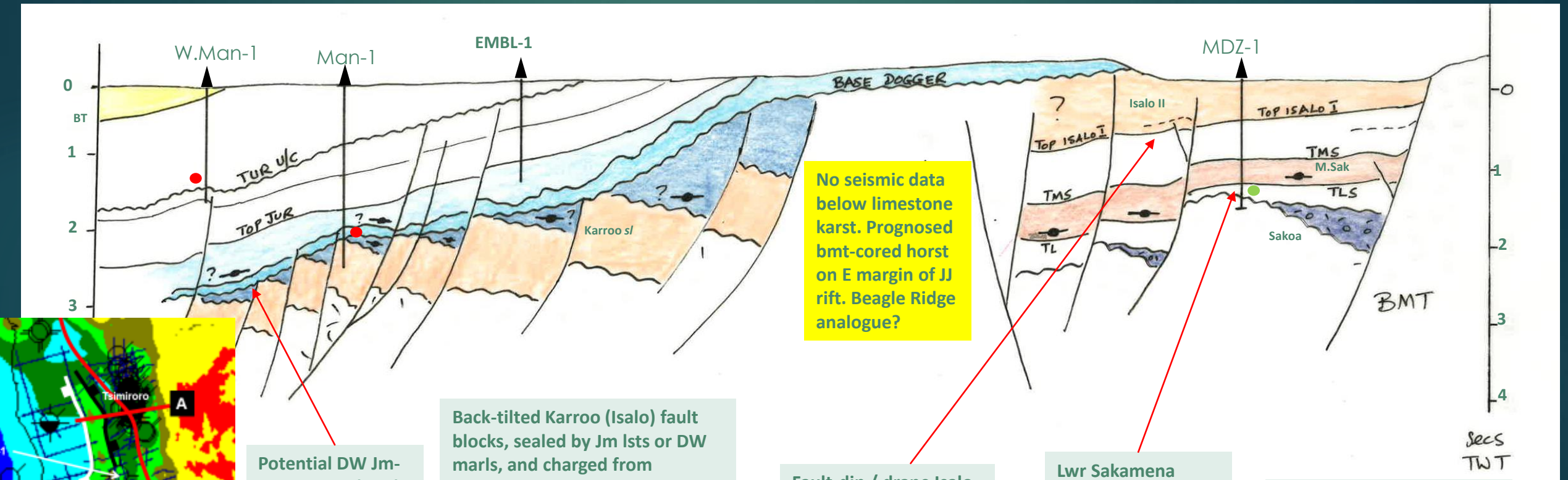
West Manambolo-1: small gas pool in poor Ku sst Tested 23 mmcf/d from 2 thin sands (7.5m pay). I Inferred JJ source.

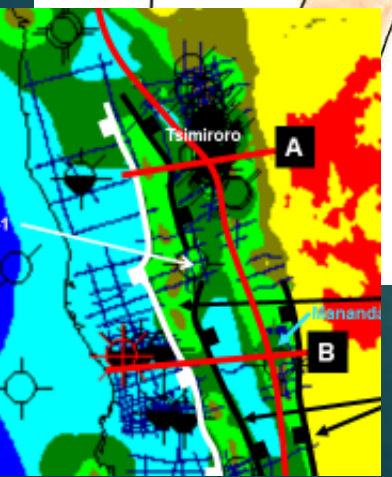
Manambolo-1: tilted Triassic fault block: resvr poor. Oil show from KK sst, phi 12%,. Gas to sf from Jm lst.

MDZ-1: rec 10 bbl 42* API oil from L.Sakamena. 100m oil column, phi=4%. Sourced from M.Sak – as are Tsimiroro and Bemolanga crudes.

B

JL rift; Jm – TT passive margin | **Jm limestone plateau** | **'Karroo Corridor'**





No seismic data below limestone karst. Prognosed bmt-cored horst on E margin of JJ rift. Beagle Ridge analogue?

Potential DW Jm-Ju SR: postulated (as on conjugate Tanz-Moz DW margin).

Back-tilted Karroo (Isalo) fault blocks, sealed by Jm lsts or DW marls, and charged from adjacent JL half-graben: SR-bearing in outcrop and in several (3) Morondava Basin wells. TOC upto 5%.

Fault-dip / drape Isalo II structures (same resvr as Tsimiroro)

Lwr Sakamena f/dip traps. (Tested by MDZ-1: oil bearing but tight)

Albert / Lokichar-style hanging wall traps (3WDC against Bmt; rollover)

Karroo Corridor: play cross section over the West and East Tsimiroro basins

A

W

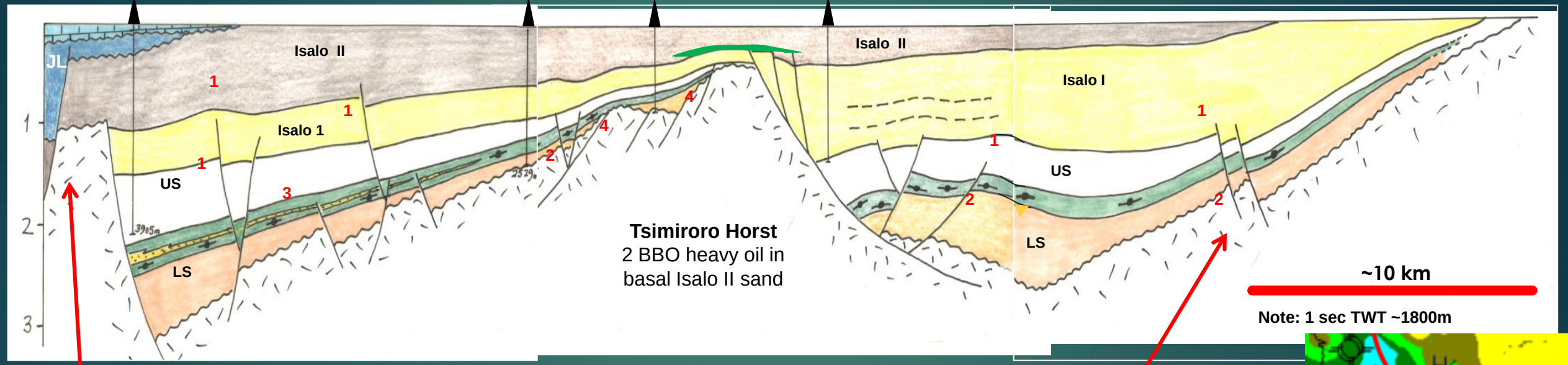
E

ANT-1
(proj ~70 km from S.)
TD 3905m
in U.Saka

BLT-1
TD 2529m
in Bmt

BLT-3
TD 1201m
in Bmt

BLT-2
TD 2503m
in U.Saka



Tsimiroro Horst
2 BBO heavy oil in basal Isalo II sand

~10 km

Note: 1 sec TWT ~1800m

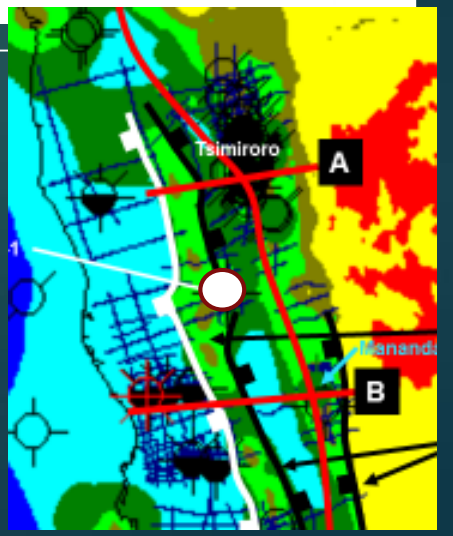
Antaotao-1 stratigraphy taken from Clark (1996) i.e. M.Sak not reached.

Prognosed basement-cored horst separating the inboard Karroo rift from the outboard Jurassic rift.

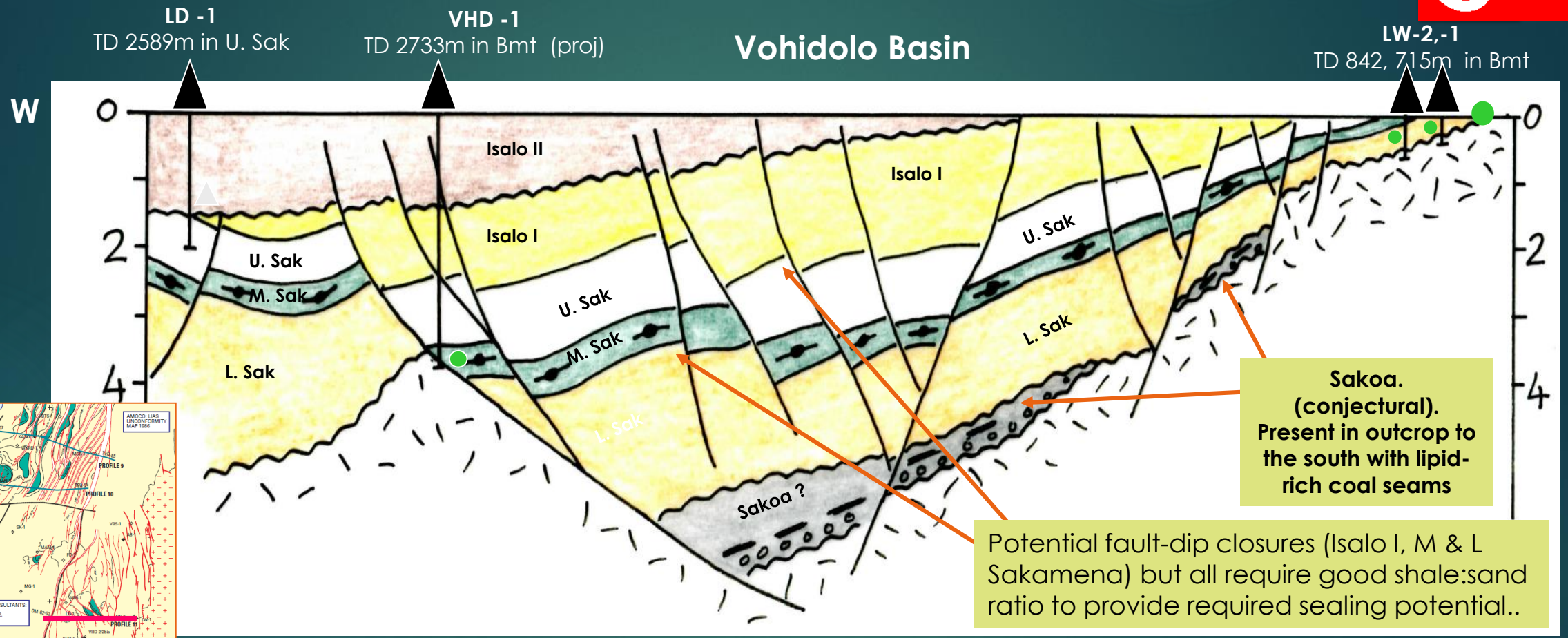
Potential plays:-

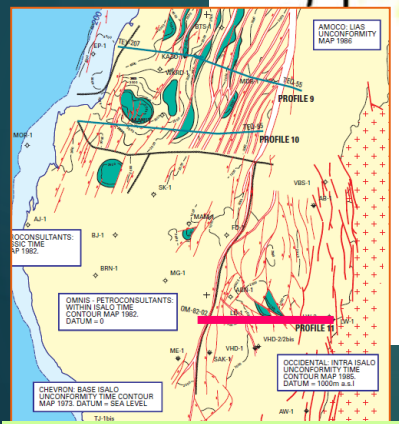
1. Isalo / Upp Sakamena drape or fault-dip closures
2. Lwr Sakamena fault-dip traps
3. Middle Sakamena sands (if present)
4. Lwr Sakamena strat traps on flank of Tsimiroro horst

'E. lead: deep enough to be below bio-degradation zone (~1 sec), but shallow enough to retain reasonable phi/K in the Lwr Sakamena resvr.



Sketch play diagram for the S. Morondava basin

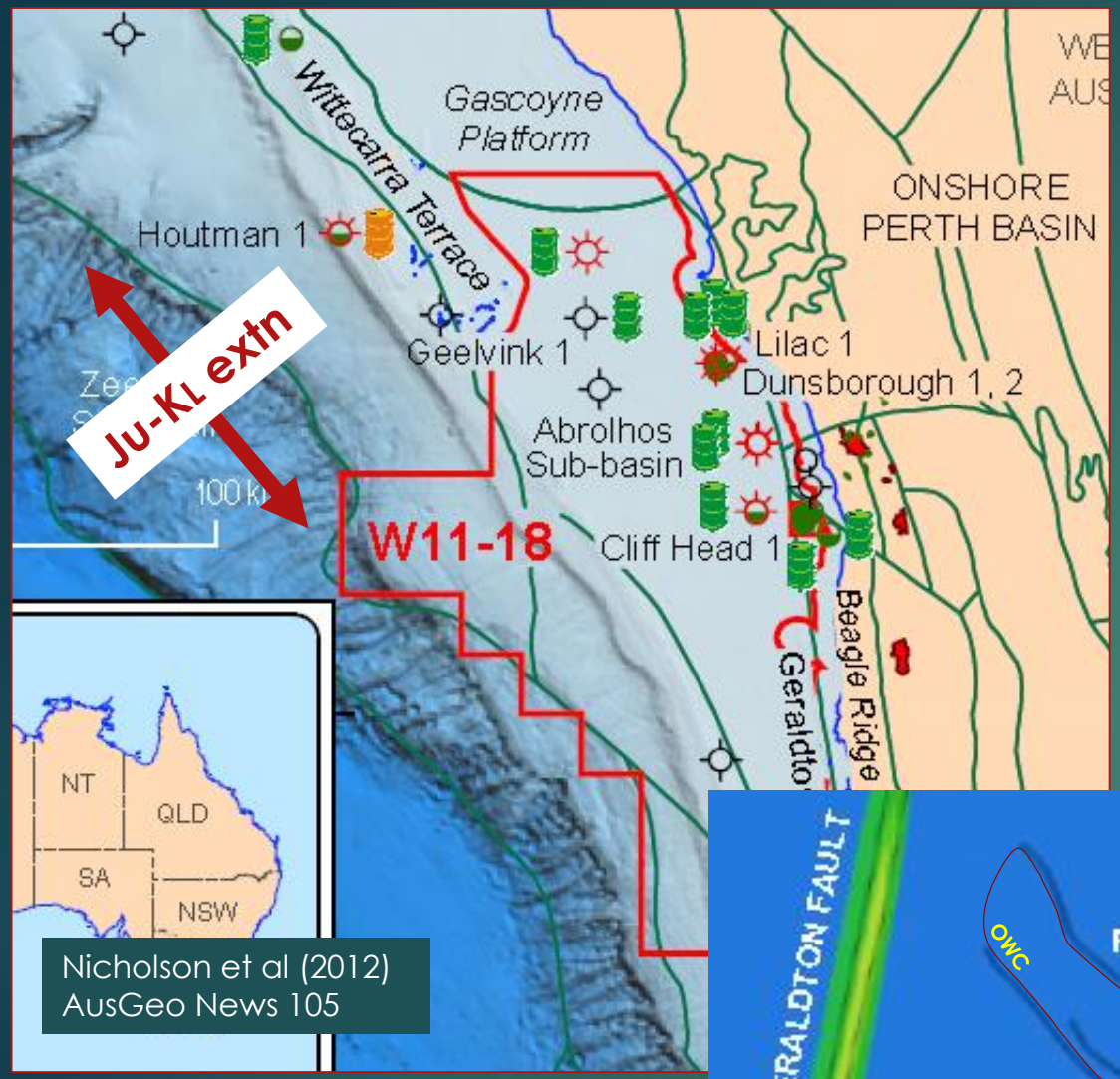




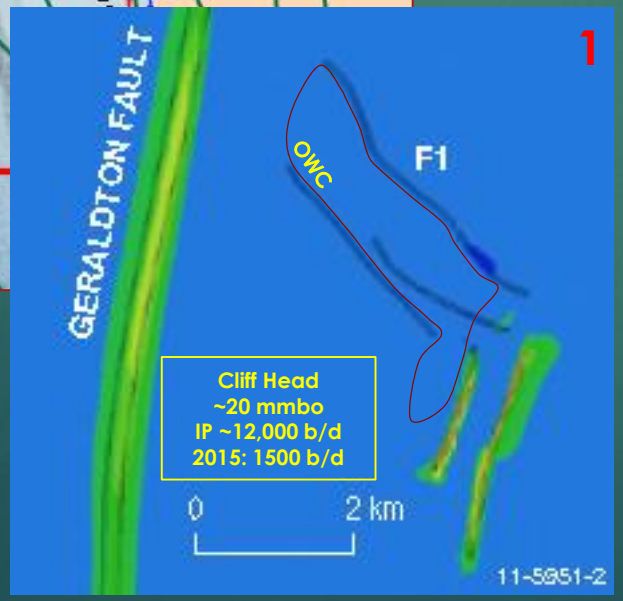
HC habitat is poorly known. Richness of M. Sakamena SR not known but reports from outcrop suggest low TOCs. However, basin is HC-bearing (Chinese oil/gas discoveries (no data); seeps at basin margin; sctd oil shows in wells (tho' no recovery to surface). Clark (1996) reports delta C13 of seeps/shows are -27 to -30 ppt. This implies that the Sakoa coals (lipid-rich (HI 400)) must be the source, i.e. the S. Morondava has a different HC system from the N.Morondava Basin.

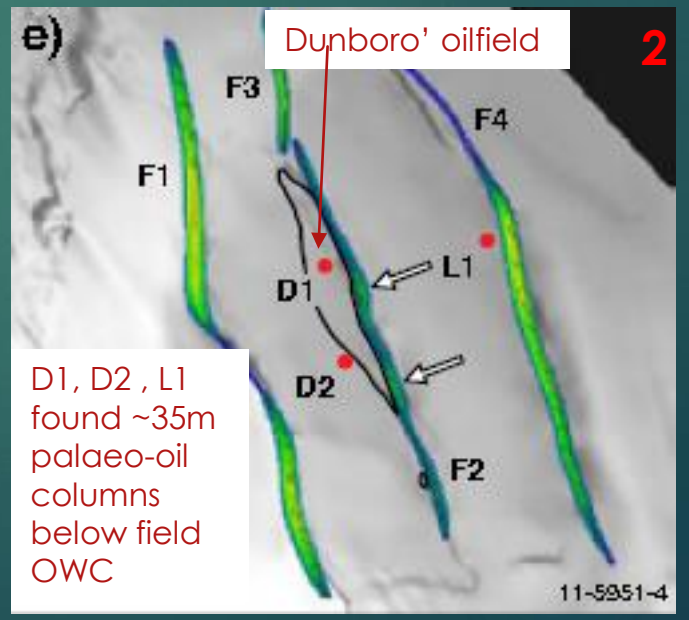
Conclusions from trap integrity studies of Perth Basin structures.

1. Major faults (~N-S) can protect smaller fault blocks behind them from re-activation.
2. The closer the trend of fault/dip closures is to the (later) extension direction, the less likely is the fault to be affected by re-activation / leakage.
3. Fault/fault/dip traps especially prone to leakage

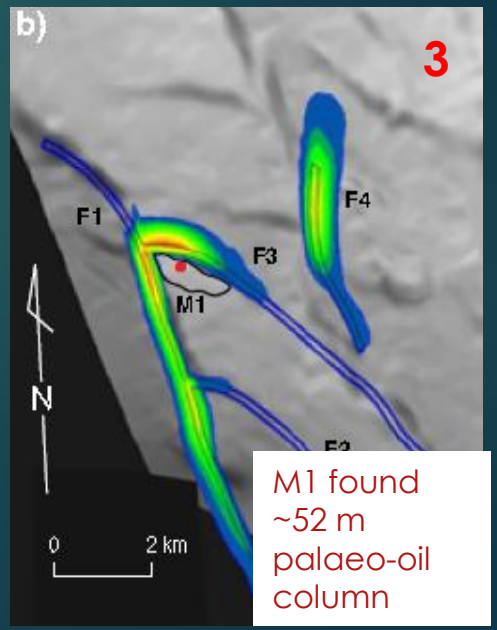


Nicholson et al (2012)
AusGeo News 105





D1, D2 , L1 found ~35m palaeo-oil columns below field OWC



M1 found ~52 m palaeo-oil column

1 = Cliff Head (horst on Beagle Ridge)
2 = Dunsborough / Lilac
3 = Morangie

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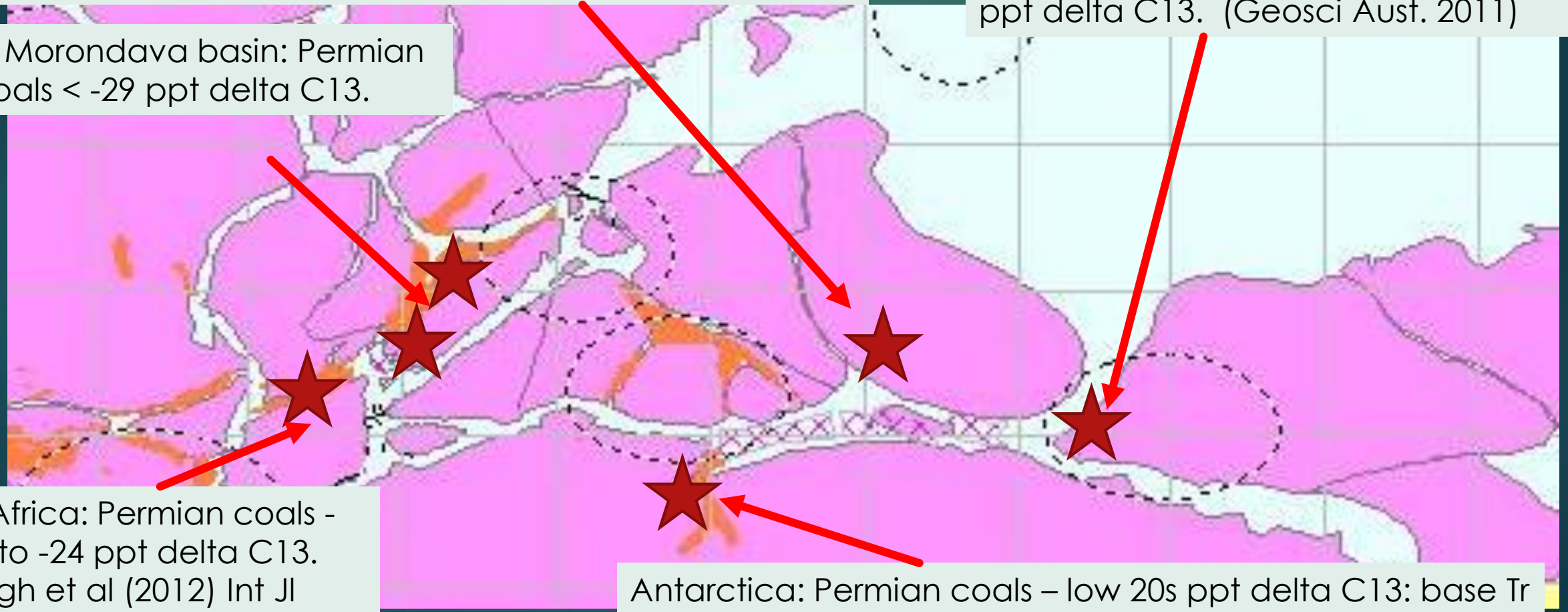
Perth and Morondava basins: delta C13 → age of SR (syn-rift Permian)

Damodar/W.Bengal coalfields: Permian coals -22 to -25 ppt delta C13. Singh et al (2012) Int Jl Coal geol 90-91.

Perth basin: Permian coals -23 to -28 ppt delta C13. (Geosci Aust. 2011)

S. Morondava basin: Permian coals < -29 ppt delta C13.



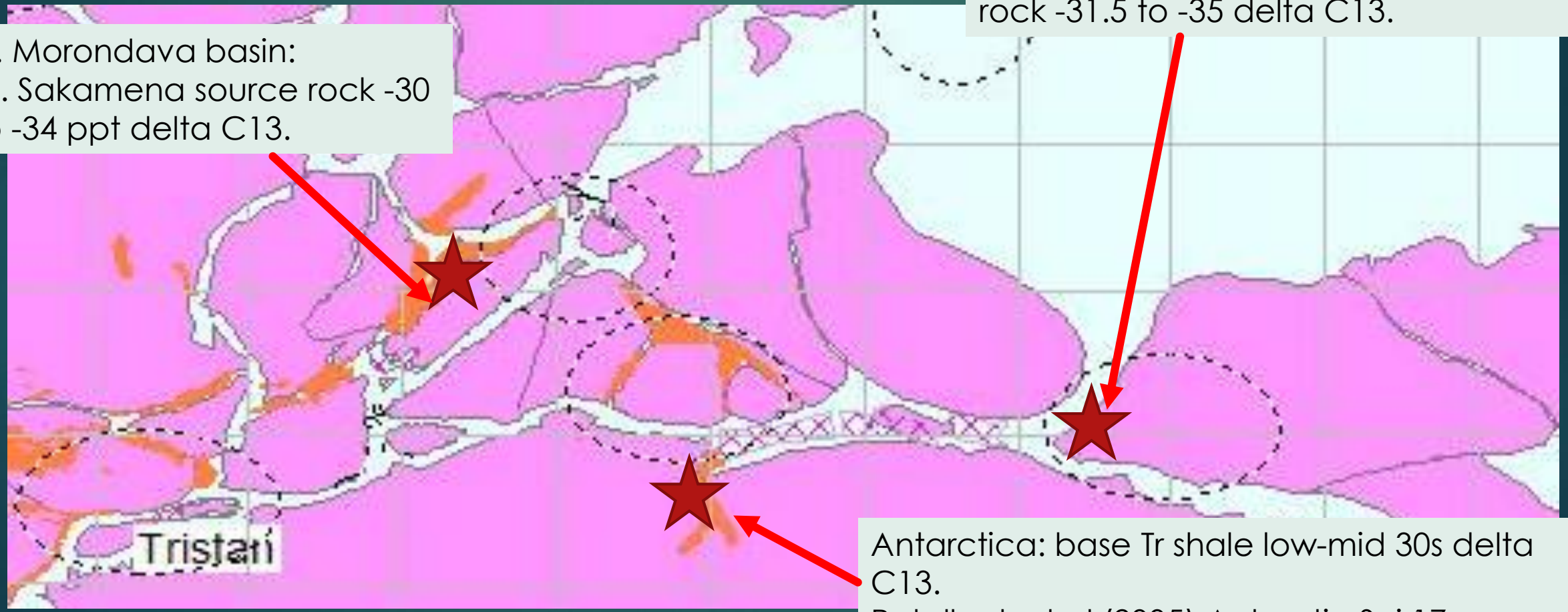
S. Africa: Permian coals -22 to -24 ppt delta C13. Singh et al (2012) Int Jl Coal geol 90-91.

Antarctica: Permian coals – low 20s ppt delta C13: base Tr shale low-mid 30s. Retallack et al (2005) Antarctic Sci 17.

Perth and Morondava basins: hydrocarbon system comparison (post-rift Lwr Triassic)

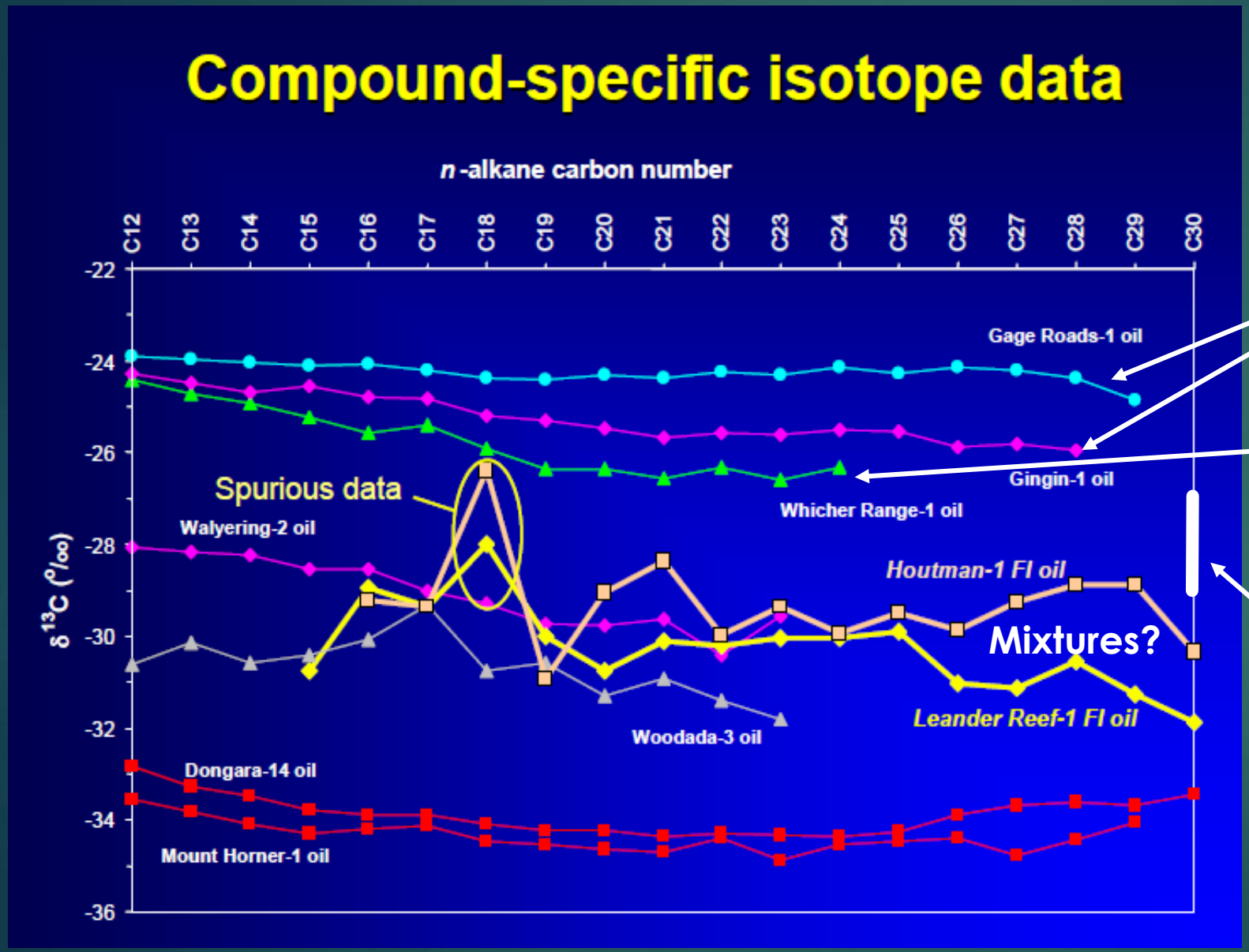
N. Morondava basin:
M. Sakamena source rock -30 to -34 ppt delta C13.

Perth basin: Kockatea Shale source rock -31.5 to -35 delta C13.



Antarctica: base Tr shale low-mid 30s delta C13.
Retallack et al (2005) Antarctic Sci 17.

Delta C13 data from Perth Basin



Sourced from Permian (or Jurassic) coals and black shales

Whicher Range oil sourced from Permian coals / black shales Ghori (2015) S&D 10805.

Carboniferous oils (Canning / Bonaparte basins (Maslen et al (2011))

Sourced from Lwr Triassic Kockatea shales (also Cliff Head and Xanadu)

Volk et al (2004) www.petroleum.csiro.au

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Perth Basin: recent HC discoveries

Two significant oil and gas discoveries have been made in the last 5 years or so, and show what a good technical understanding, and an active farm-out process can achieve (with a little serendipity):-

- The Waitsia gas field
- The Xanadu oil field

One successful appraisal benefitted from this, too, but was then derailed by the green lobby (1-year moratorium on fraccing)

- The Warro tight gas field.

These are illustrated as analogues for possible future Karroo Corridor exploration.

Perth basin: P-Tr HC systems / targets

Permo-Triassic petroleum system & plays

AWE

Kockatea Shale
Regional Seal
Oil and Gas Prone Source Rock
Unconventional target

DONGARA/WAGINA PLAY
12 commercial discoveries

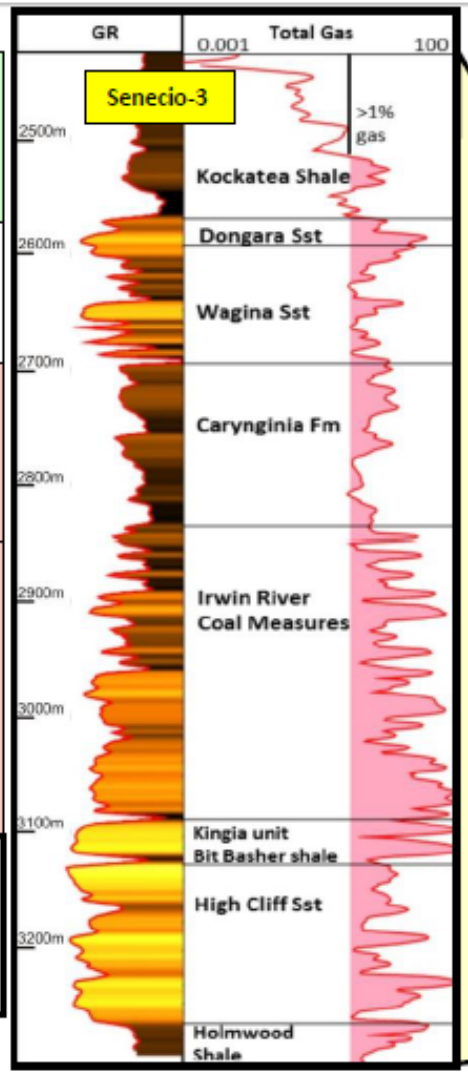
Dongara
Beharra Springs
Senecio/Irwin

Carynginia Formation
Regional Seal
Gas Prone Source Rock
Unconventional Target

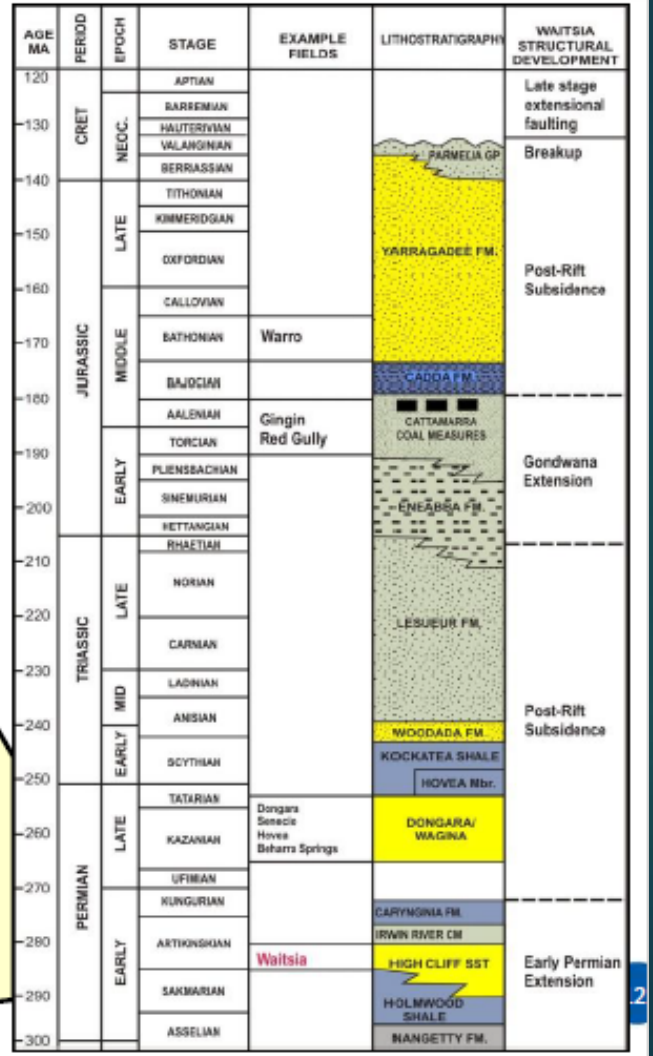
Irwin River Coal Measures
Gas Prone Source Rock
Unconventional Target

KINGIA/HIGH CLIFF PLAY
>20 wells in basin without commercial success

Waitsia

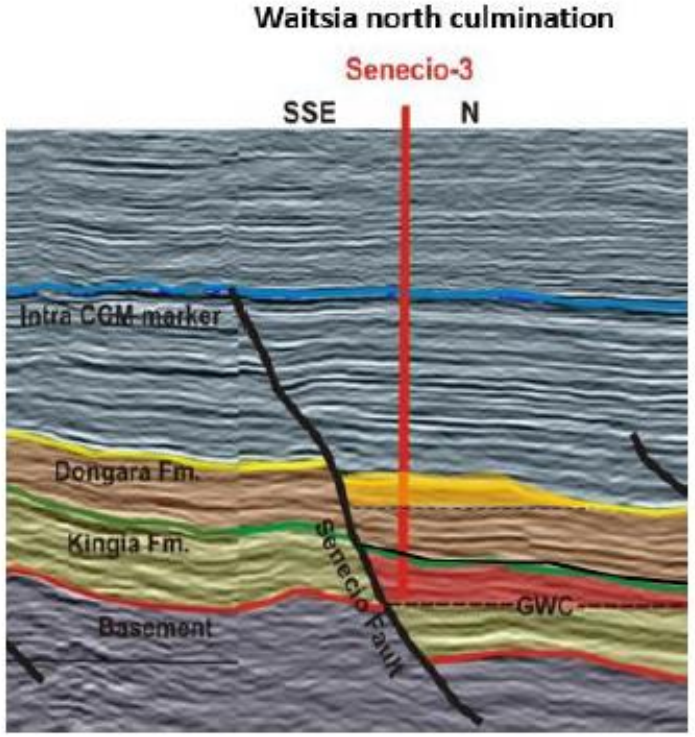


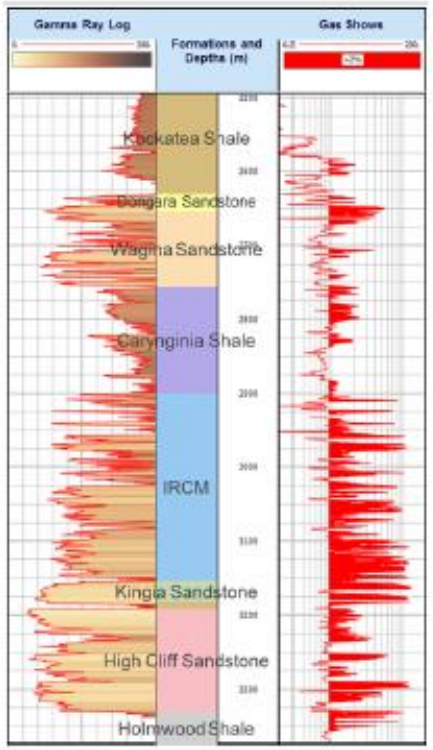
PERMO-TRIASSIC PETROLEUM SYSTEM

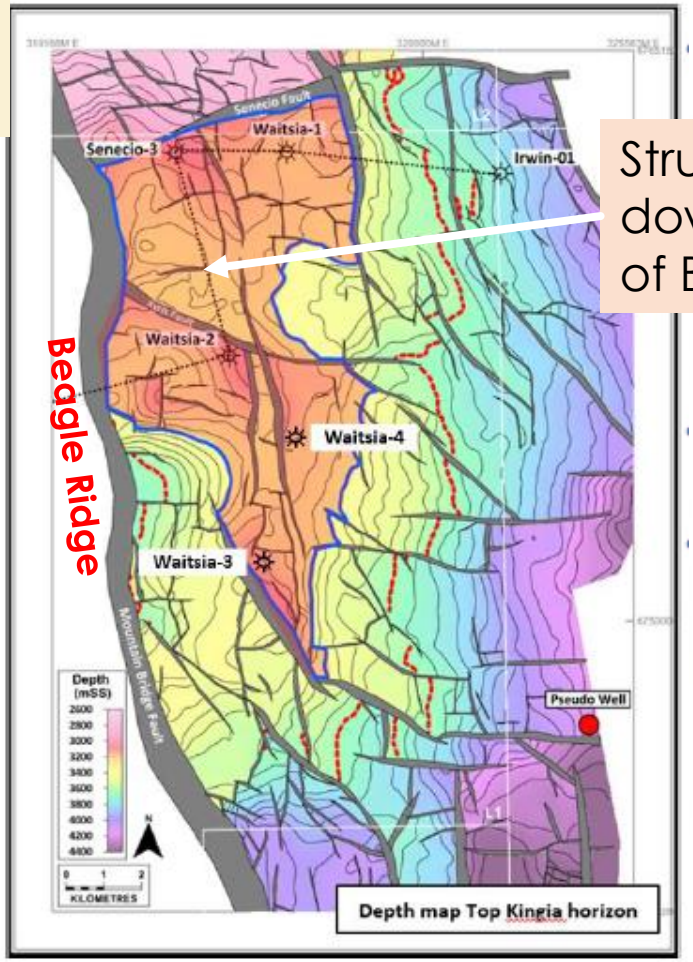


Waitsia discovery: how did it happen?

Senecio-3 targeted the Dongara-Wagina sands, below which still in gas shows. Drill bit was in good condition, and well was under budget, so it was decided to continue. Kingia / Highcliff sands found gas-bearing, good phi/K.







Structure sits on downthrown (E) side of Beagle Ridge

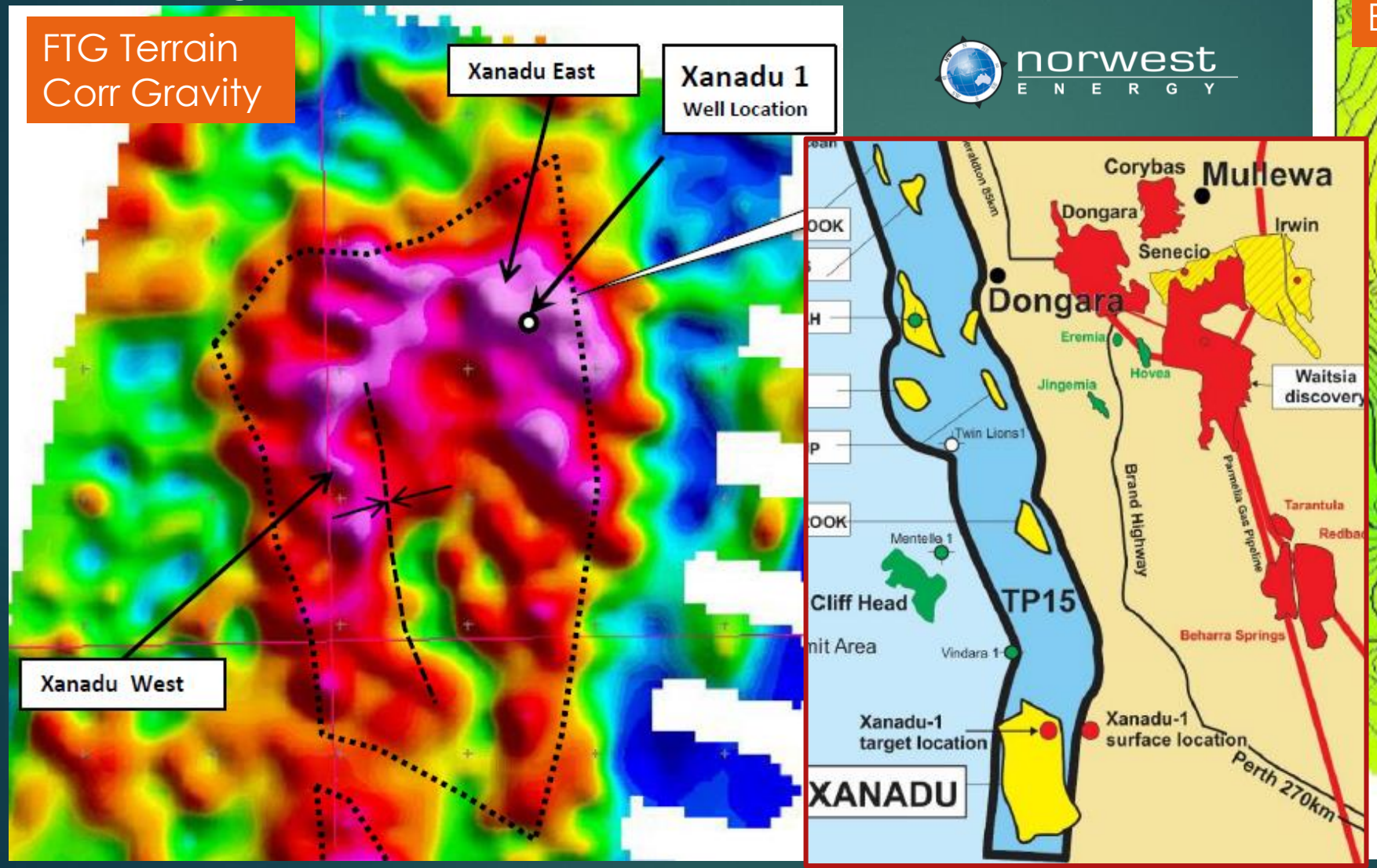
Kingia/Highcliff sands:
est URR 0.9 tcf (end 2017).

Pre-Senecio-3:
- 19 wells drilled to Dongara in Waitsia area, but TD'd before reaching Kingia / High Cliff Ssts.
- perceived poor resvr quality and issues with fault seal.

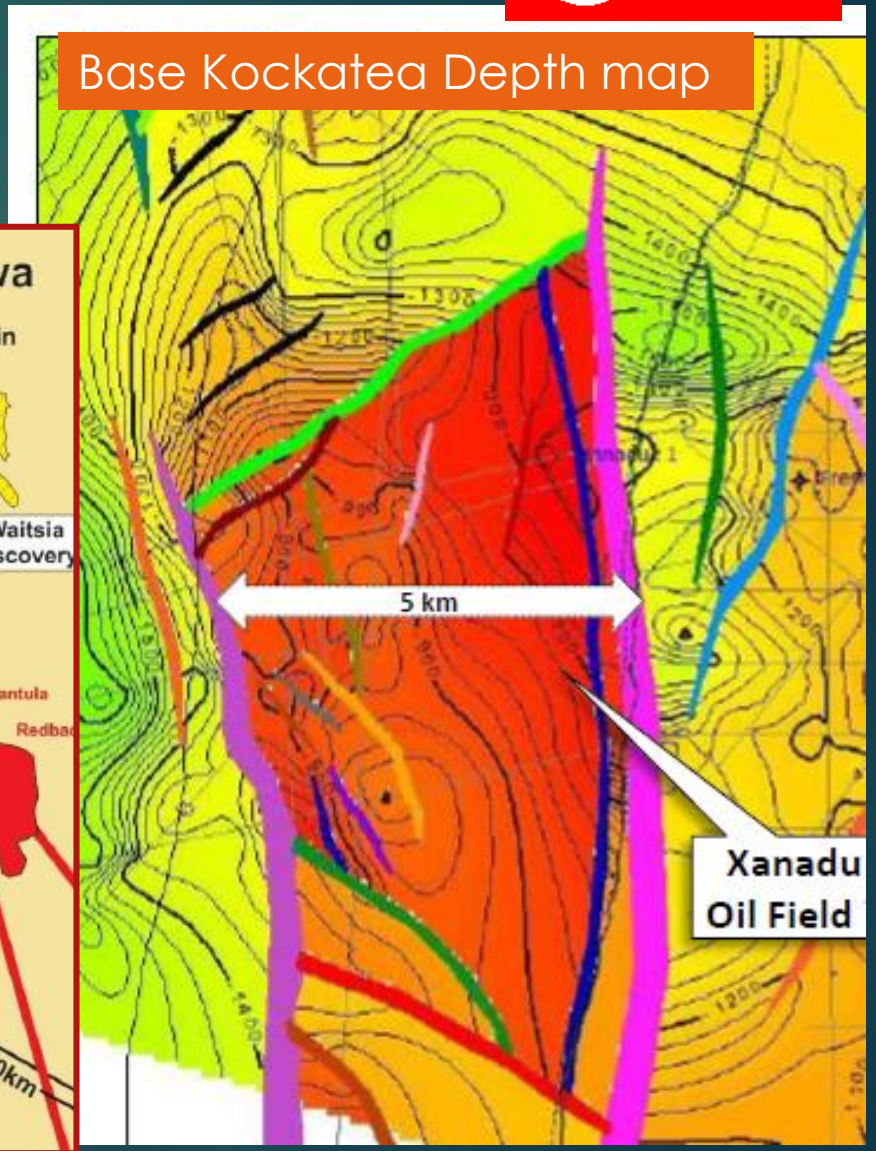
AWE website

Xanadu discovery: gravity high

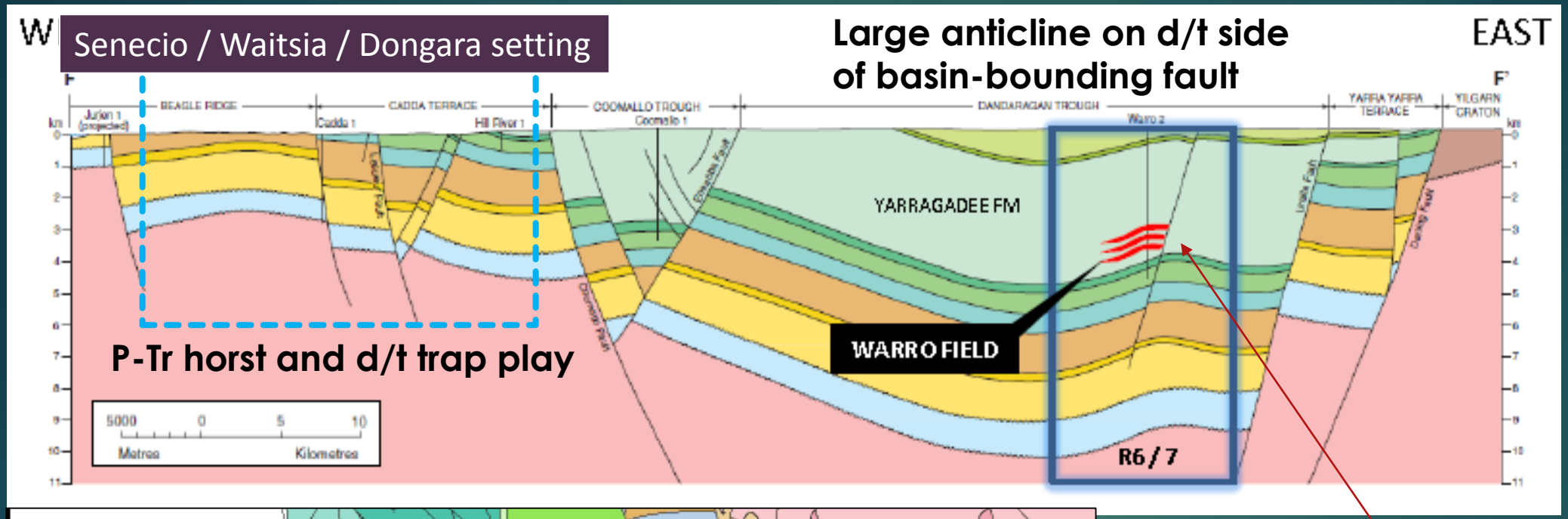
Found IRCM unconf below Kockatea Sh; 3 HC-bearing sands (phi 15-16%); top sand 5m NOP. NNW-SSE horst between Permian and Jurassic rifts. Oil and stratigraphy identical to Cliff Head; est 18-26m oil column.

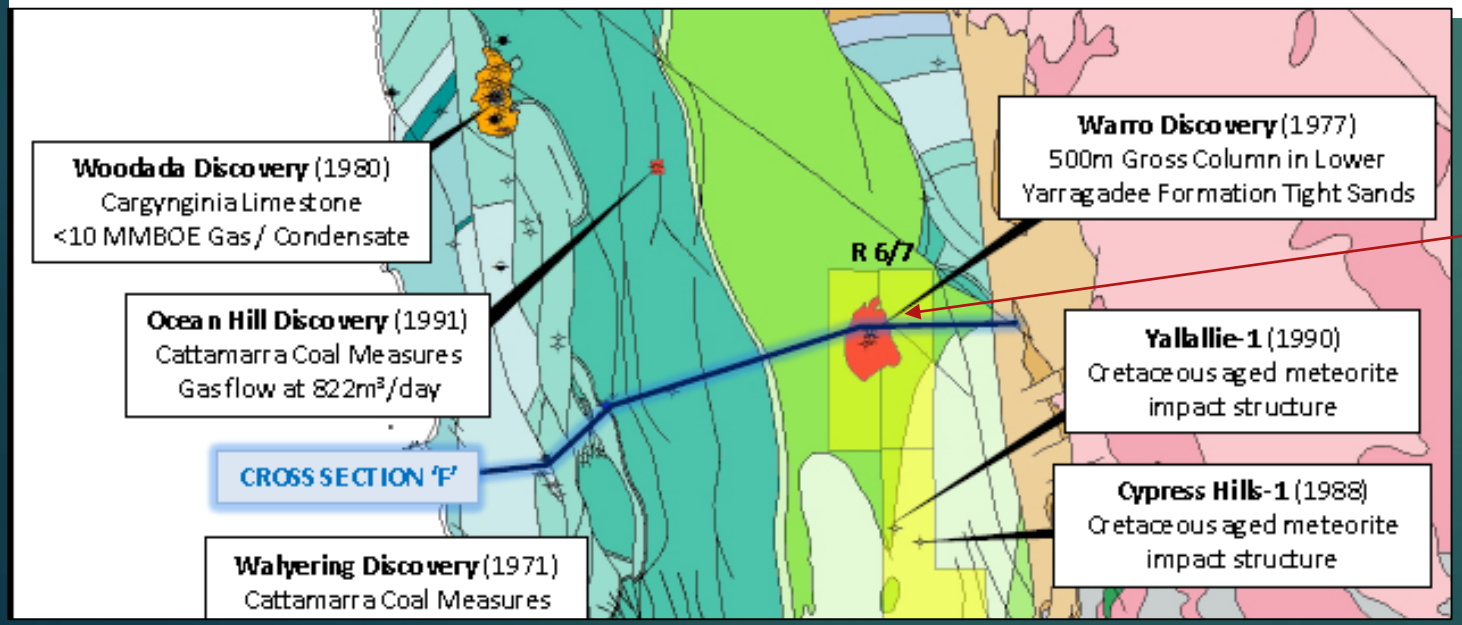


norwest ENERGY



Warro gas field (Jurassic resvr)





Warro:
Giant gas accumulation.
Revised mean GIIP = 7.3 tcf; mean URR = 3.8 tcf.
Lower Yarragadee resvr gas-bearing down to~4500m.
Phi upto 10% ; K upto 0.1 mD; Sg = 50 – 70%.
Resvr probably requires horizontal wells; fraccing; and effective water shut-off for commerciality.

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Conclusions / learnings (from Perth Basin to Madagascar)

- Perth Basin: gas-dominated + oil in N (largely Tr-sourced); shows in S (Permian sourced: facies change of Lower Triassic)
- Karroo Corridor: oil-dominated in N (Tr-sourced); limited gas / oil in S (Permian sourced: facies change in Lwr Triassic)

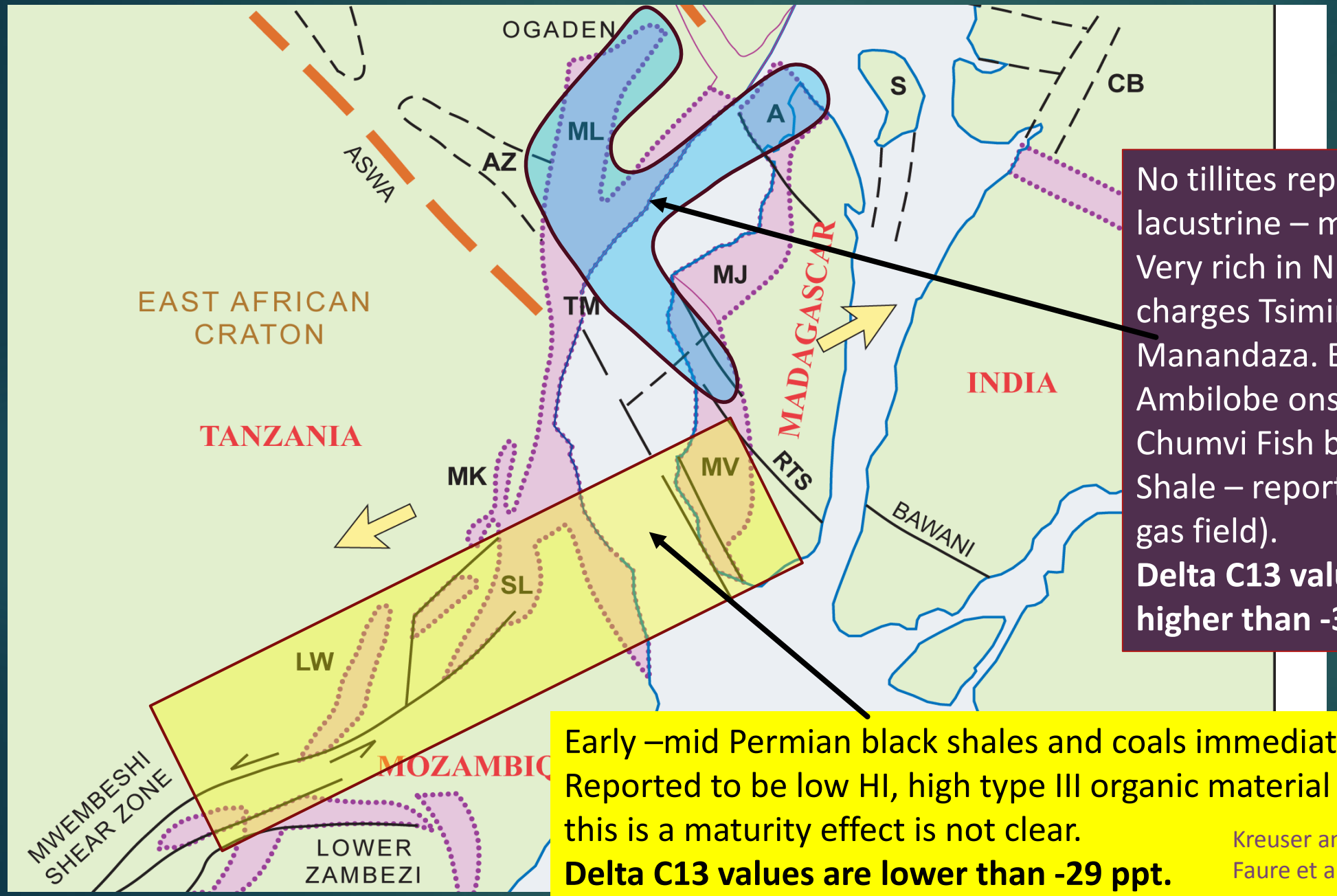
- Basement-cored horsts adjacent to JJ rift margin
  - Beagle / Cliff Head / Xanadu Ridges in Perth Basin; untested in KC
- Downthrown fault traps on flanks of basement-cored ridge work in PB; untested in KC
- Possibility of porosity preservation deeper in Permian section: proven in PB
- Trap integrity studies in PB should provide an analogue for KC - what fault orientation is 'protected'?
- Is there a Jurassic tight sand play in Madagascar, outboard of the KC?

..... and finally.....

Is there a billion barrel heavy oil / bitumen accumulation hidden in the northern Perth Basin?

Thank you.

2 distinct Karroo source facies known from Madagascar – E. Africa



No tillites reported. Lwr Triassic lacustrine – marginal marine SR shales. Very rich in N. Karroo Corridor – charges Tsimiroro / Bemolanga / Manandaza. Equivalents exist in Ambilobe onshore, S. Kenya (Maji ya Chumvi Fish beds) and Ethiopia (Bokh Shale – reported source for 2 tcf Calub gas field).

Delta C13 values from Tsimi etc higher than -30 ppt.

Early –mid Permian black shales and coals immediately overlying glacial tillites. Reported to be low HI, high type III organic material (in E.Africa) but whether this is a maturity effect is not clear.

Delta C13 values are lower than -29 ppt.

Kreuser and Woldu (2010) GSAmer Sp Paper 468.
Faure et al (1995), Grocke (1996), Geology.