The Petroleum Prospectivity of the Oobagooma Sub-basin and the Adjacent Leveque Platform , North West Shelf, Australia

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APPEA Conference Brisbane 2016

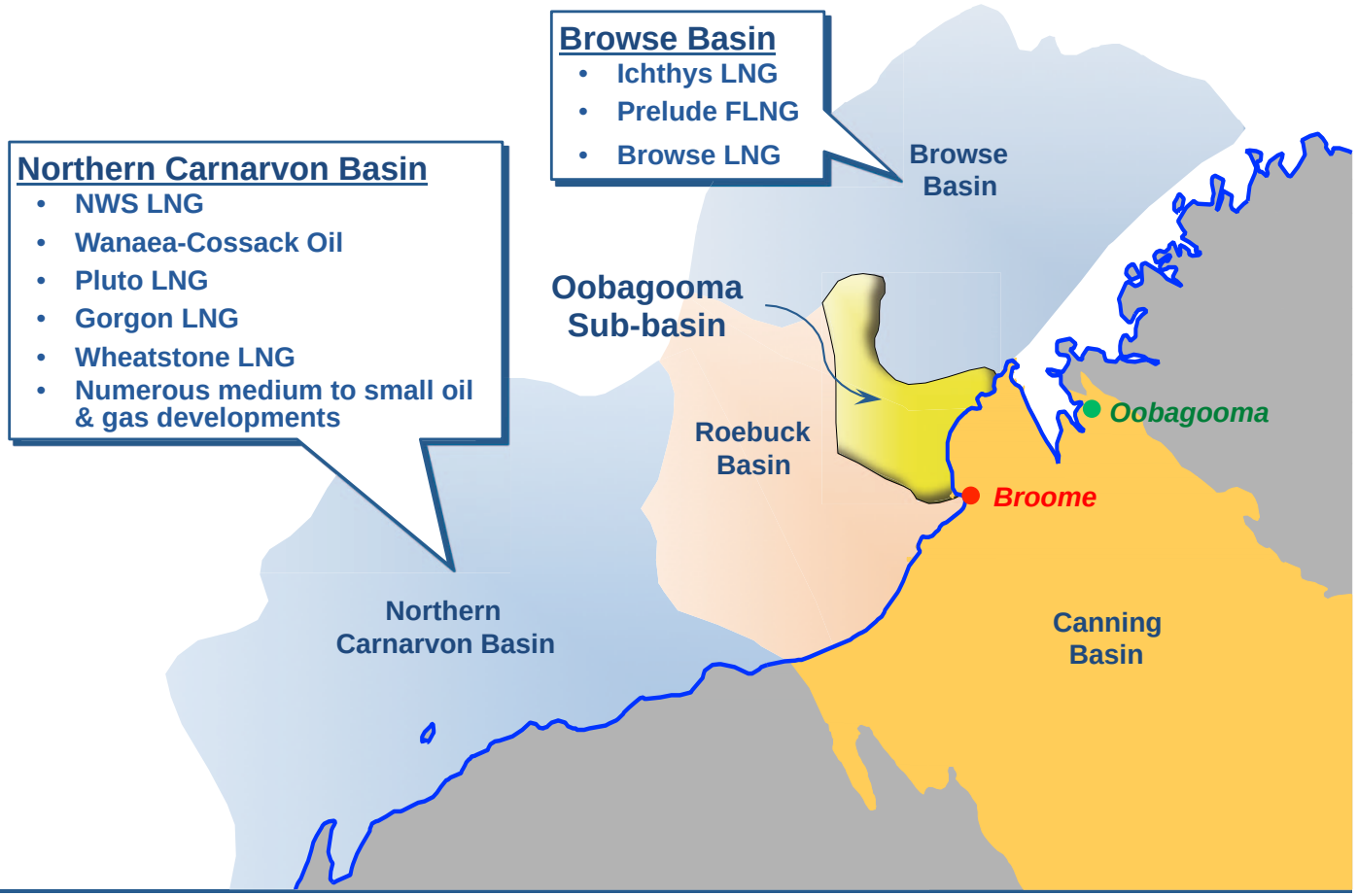
1. Introduction

2. Laurel Formation source
3. Middle Jurassic source
4. Early Triassic source
5. Conclusions

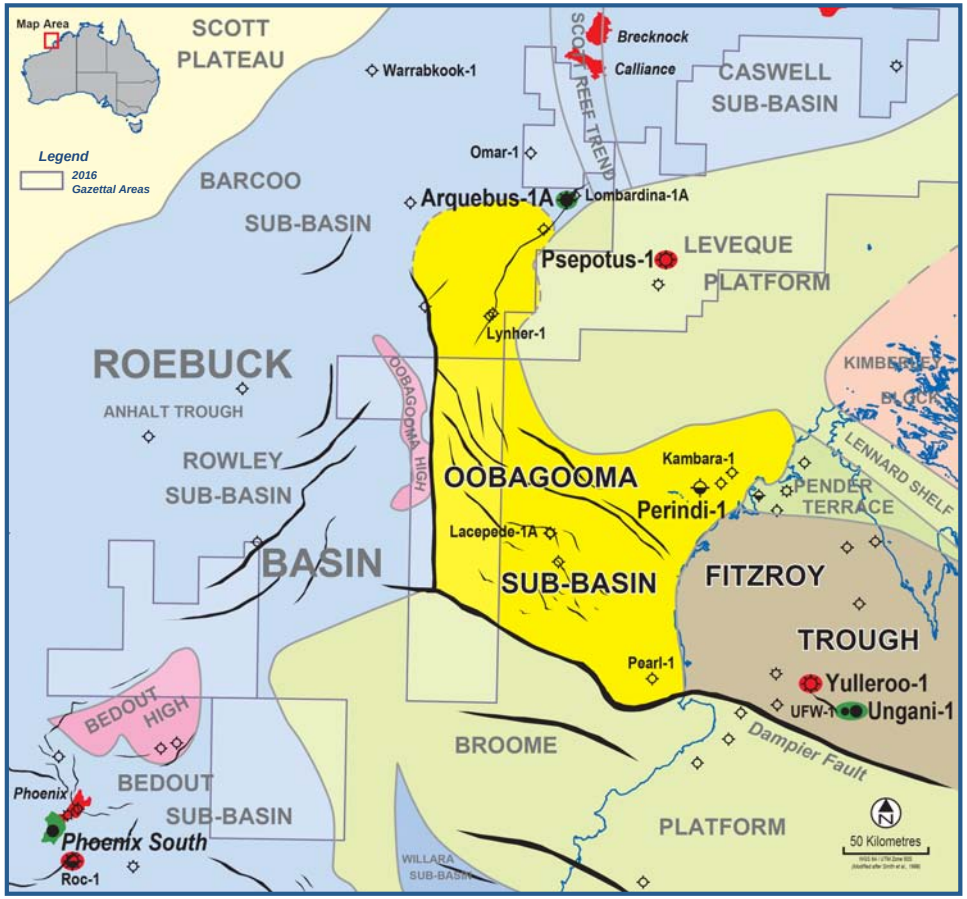
Oobagooma Sub-basin

Oobagooma Sub-basin

- Least explored area of NW Shelf
- Conspicuous absence of commercial oil or gas compared to adjoining basins
- Limited shows, old perception: gas source if any

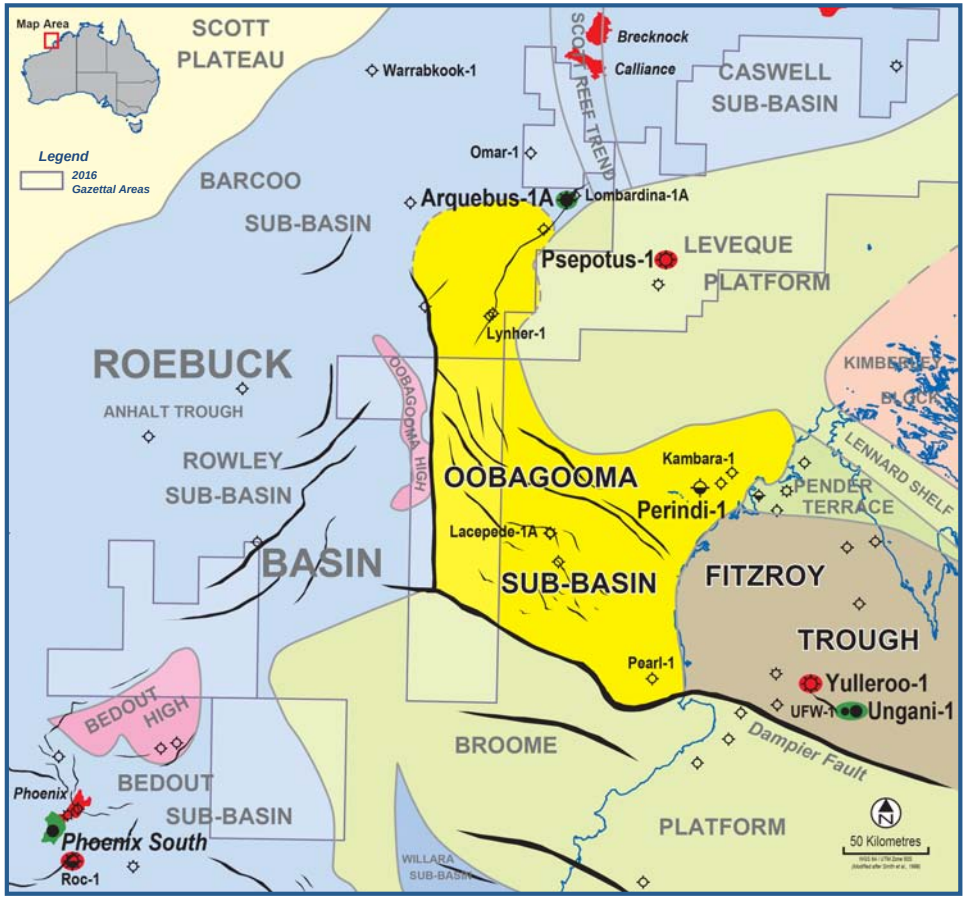


Oobagooma Sub-basin



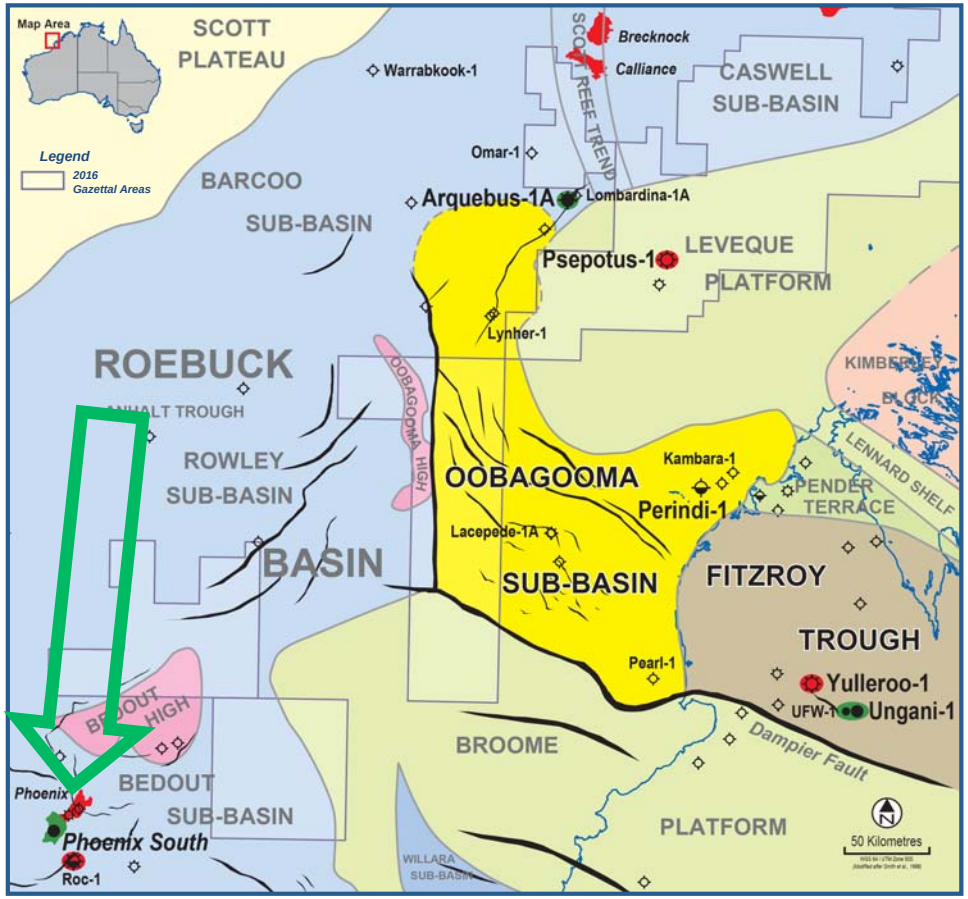
- Oobagooma SB and Leveque Platform: 50,000 sq. km.
- Offshore extension of Fitzroy Trough, Canning Basin
- Thick sequences of Ordovician, Devonian, Carboniferous, Permian, Jurassic, Cretaceous and Tertiary, up to 10,000 m thick
- Water depth : generally < 100 m; up to 500 m in far north
- Triassic thin to absent
- SE limit: Dampier Fault system
- Western limit: high angle reverse fault
- Merges with Barcoo Sub-basin to north

Oobagooma Sub-basin: Why now?



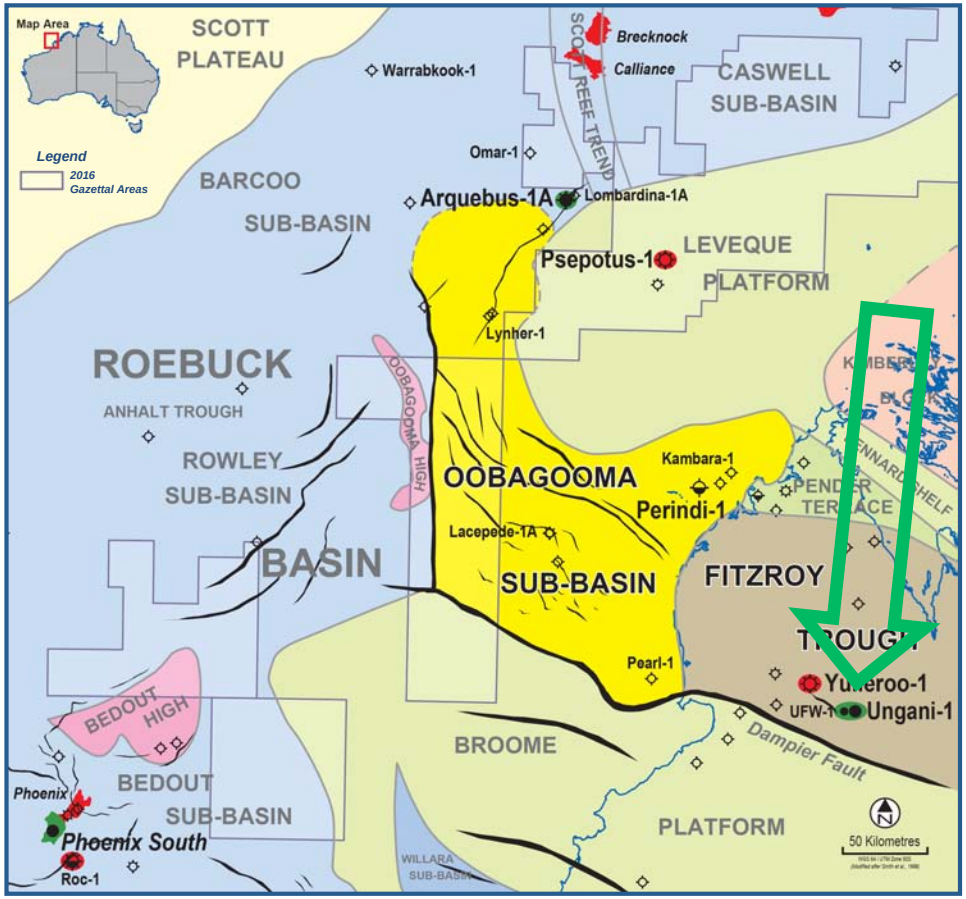
- **14 wells in Oobagooma Sub-basin and Leveque Platform, 5 in past 30 years, last 12 years ago**

Oobagooma Sub-basin: Why now?



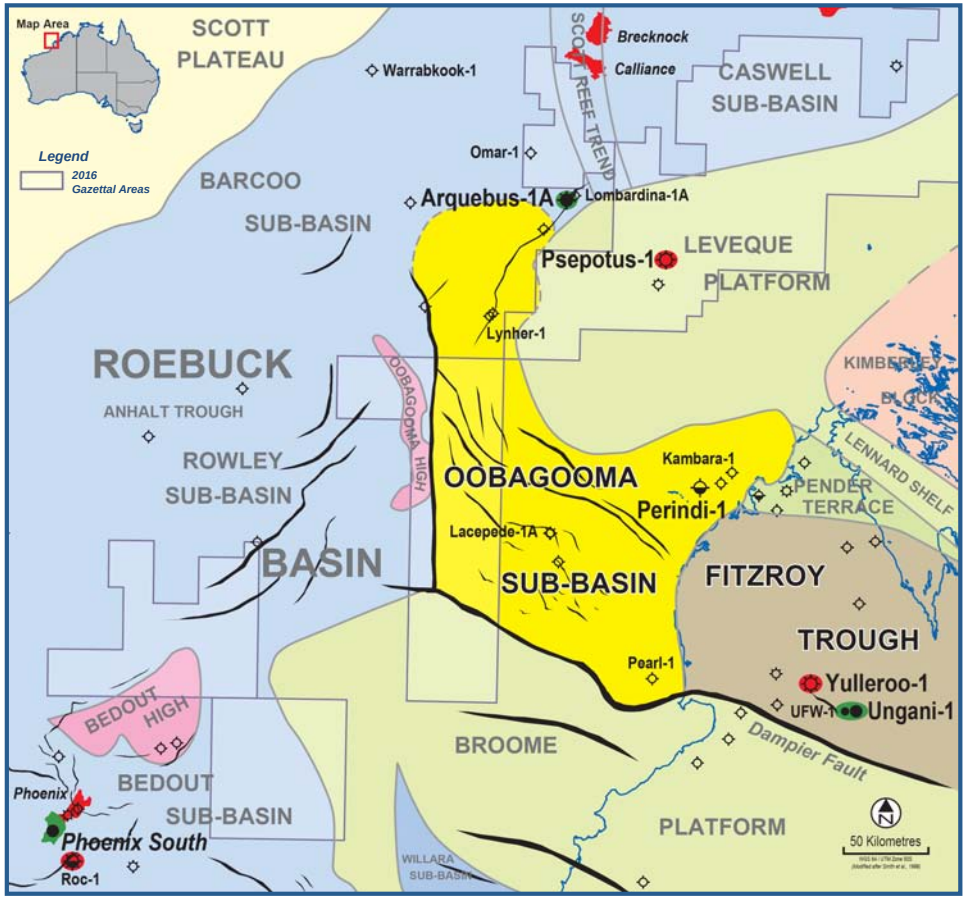
- **Oil discovery in Phoenix South in 2014, followed by gas-condensate at Roc-1 in 2016 by Quadrant JV**
- **Roc-2 to be spudded this year**
- **Proved existence of Early Triassic oil source in Bedout Sub-basin**

Oobagooma Sub-basin: Why now?



- **Oil discoveries at Ungani-1 in 2011 and Ungani Far West-1 in 2015 by Buru JV**
- **Early Carboniferous Laurel Formation source of oil plus major Basin Centred Gas system (BCGS)**

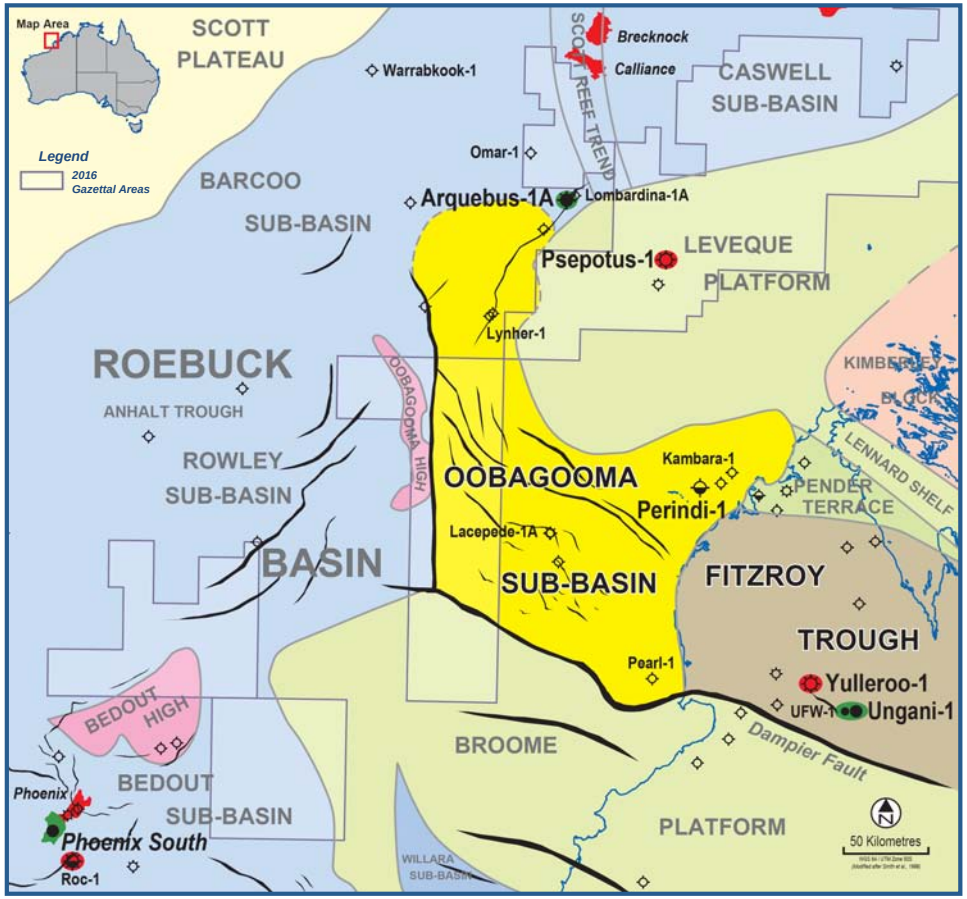
Offshore Canning Area Evaluation Project



- **Oobagooma Study evolved from large non-exclusive project between Insight Petroleum and Searcher Seismic**
- Inspired by Phoenix South

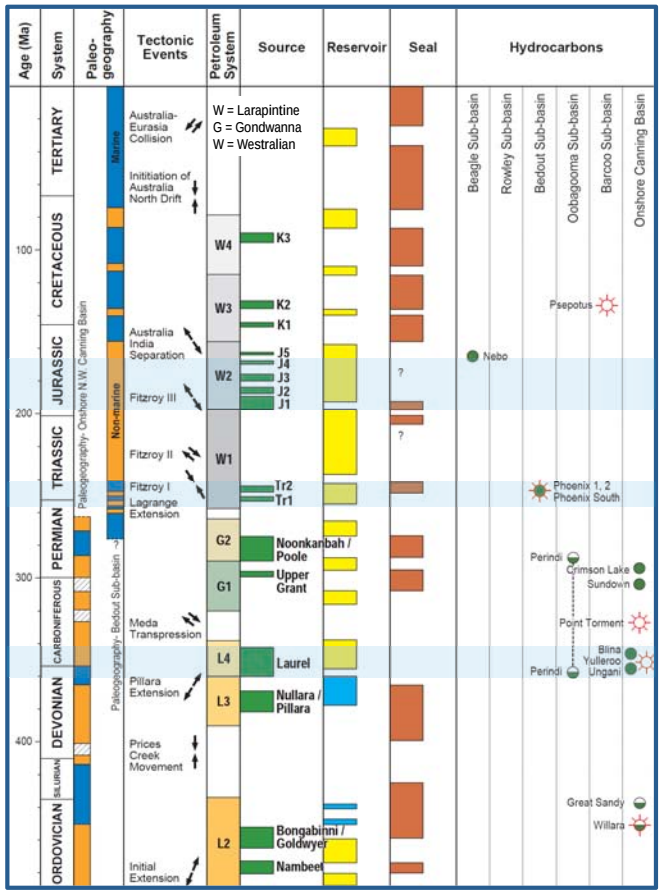
- 140,000 km 2D seismic and 46 wells
- Tied onshore Canning to offshore Oobagooma Sub-basin
- Comprehensive set of depth maps
- Timing of structuring
- Potential source rocks
- Hydrocarbon charge modelling of selected sources

Offshore Canning Area Evaluation Project



- Previous industry perception of relatively poor and gas prone source rocks
- Yet most well failures could be explained by other than lack of effective source rock
- Oobagooma Study focussed on “find the sources” and model their charge potential

Petroleum Systems: Follow the Source



(Modified after Kennard et al., 1994; Smith et al., 1999; Lisk, 2000 and Geoscience Australia, 2010)

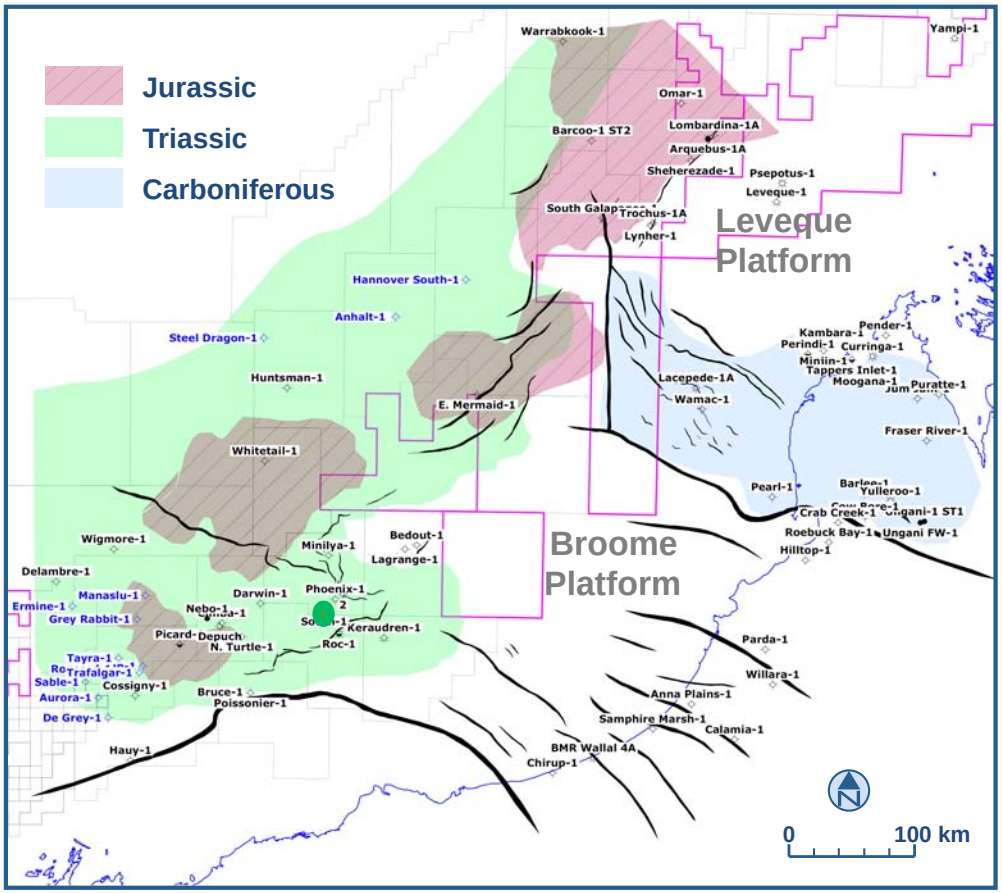
Jurassic

Early Triassic

Early Carboniferous Laurel Fm

- **Jurassic source rocks – is Jurassic thick enough and deep enough?**
- **Early Triassic proven oil source as in Phoenix South?- but thin to absent?**
- **Permian (Noonkanbah) good potential onshore but immature; offshore immature or eroded in Oobagooma Sub-basin**
- **Early Carboniferous Laurel Formation- does it extend offshore ?**
- **Ordovician good source in Canning- difficult mapping**
- **3 potential sources modelled**

Three sources modelled



- **Early Carboniferous Laurel Formation confined to the Oobagooma Sub-basin**
- **Middle Jurassic from the southern Browse Basin to the Beagle sub-basin**
- **Early Triassic source proven to be oil prone in Phoenix South**

Laurel Formation source

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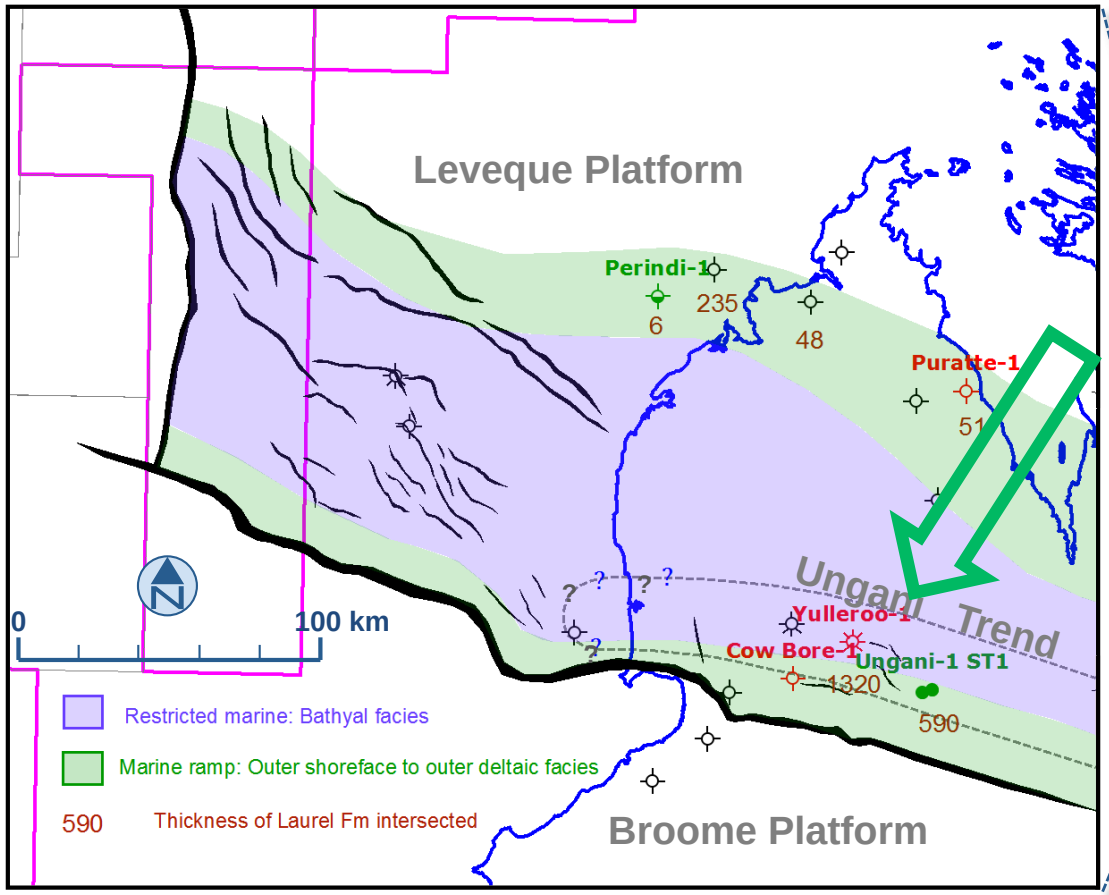
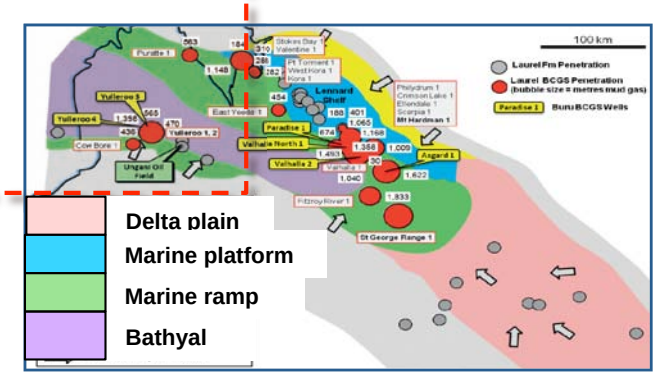
Laurel Formation sourced Fields and Shows

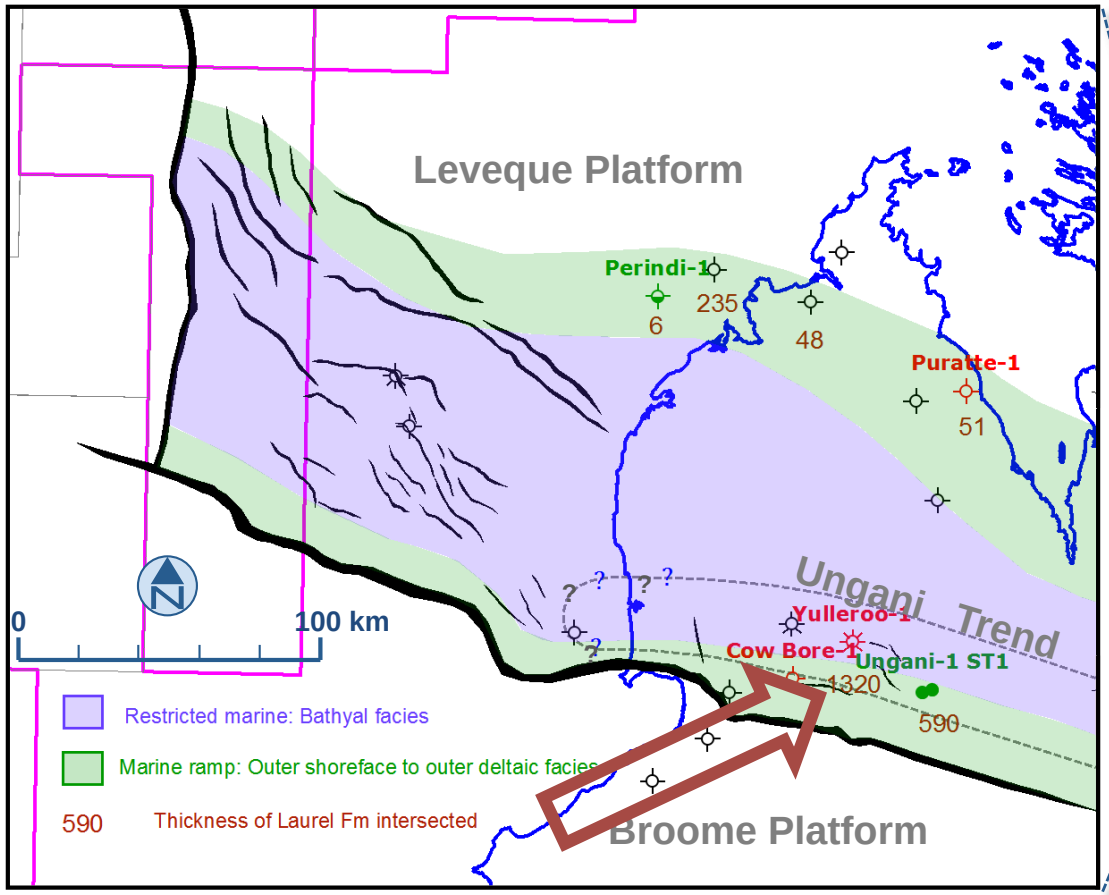


- **Laurel Fm has sourced oil in Ungani-1 and Ungani Far West-1 and gas in Yulleroo**
- **Buru Ungani Trend**

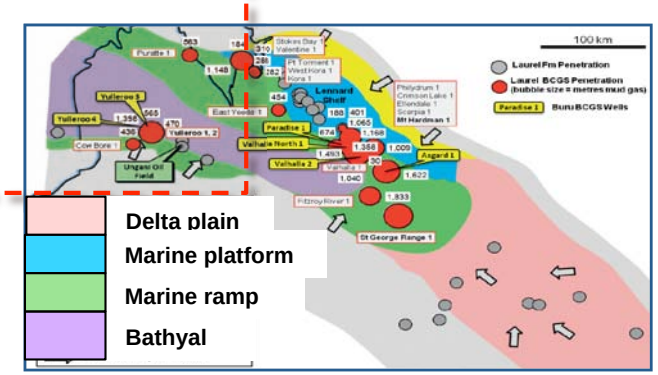


(after Kingsley and Streitberg, 2013)

Laurel Formation sourced Fields and Shows



- **Laurel 1,320 m thick at Yulleroo, 590 m at Ungani**



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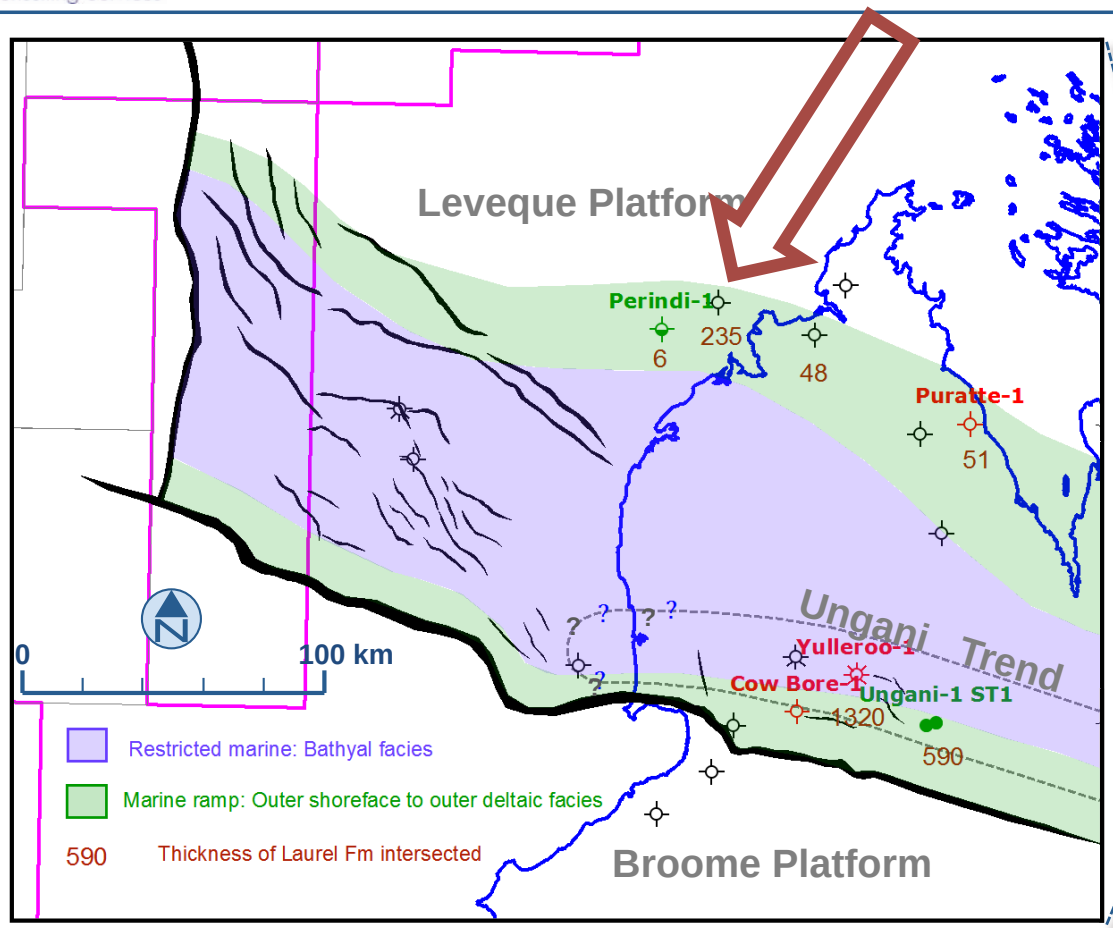
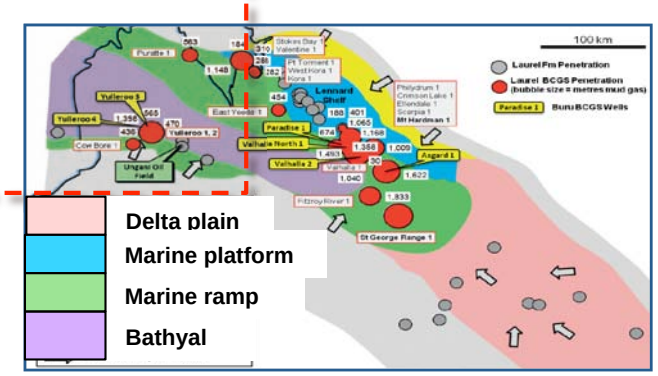


- Laurel 1,320 m thick at Yulleroo, 590 m at Ungani
- 2 offshore wells intersect Laurel
- 235 m at Kambara-1
- 6 m at Perindi-1



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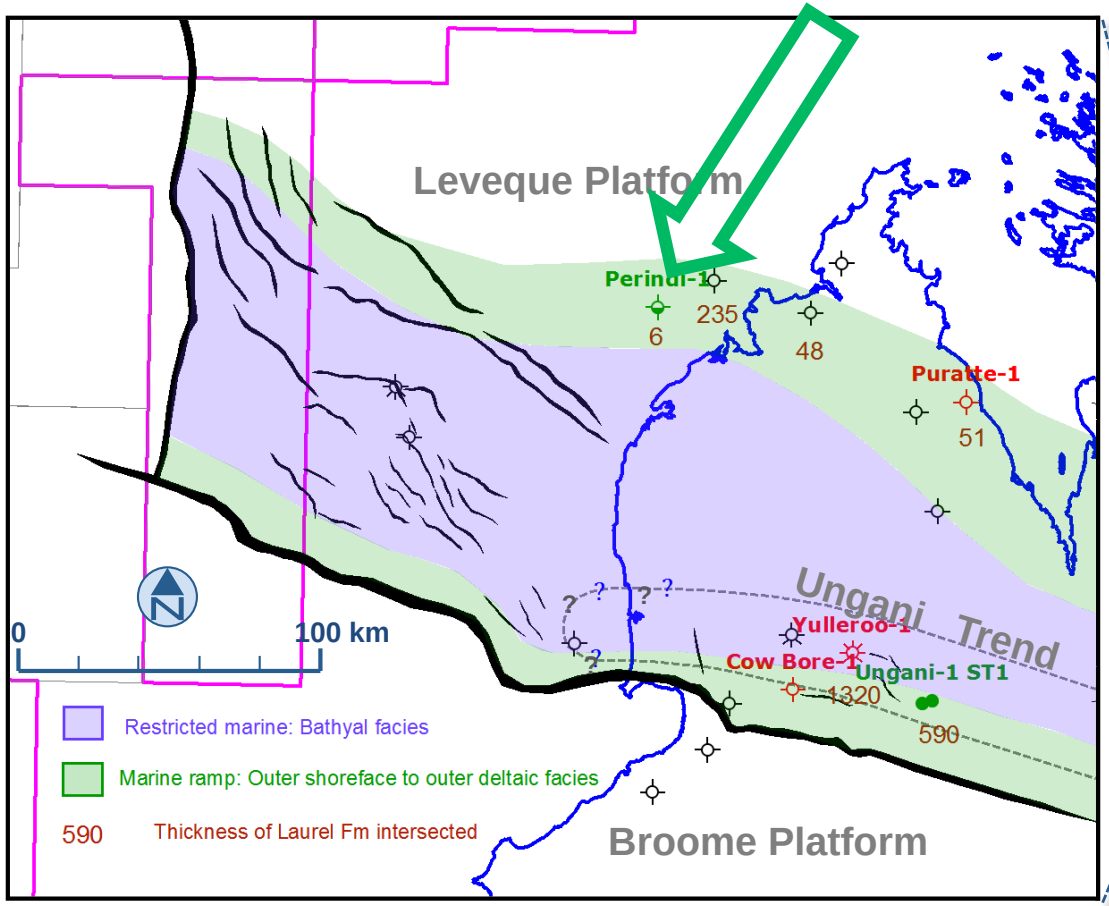
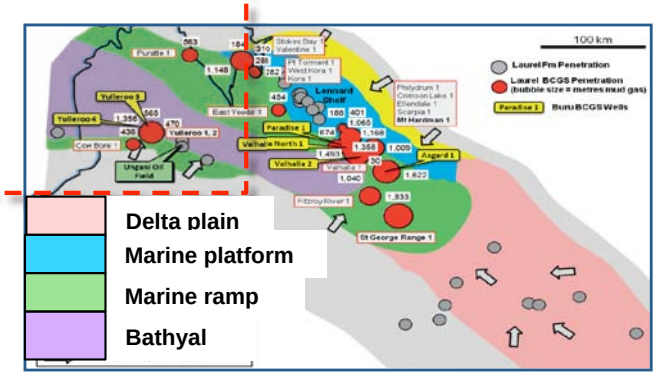
Laurel Formation sourced Fields and Shows



- **Perindi-1 had multiple oil shows in Permian, Carboniferous and Devonian, believed to be sourced from the Laurel**



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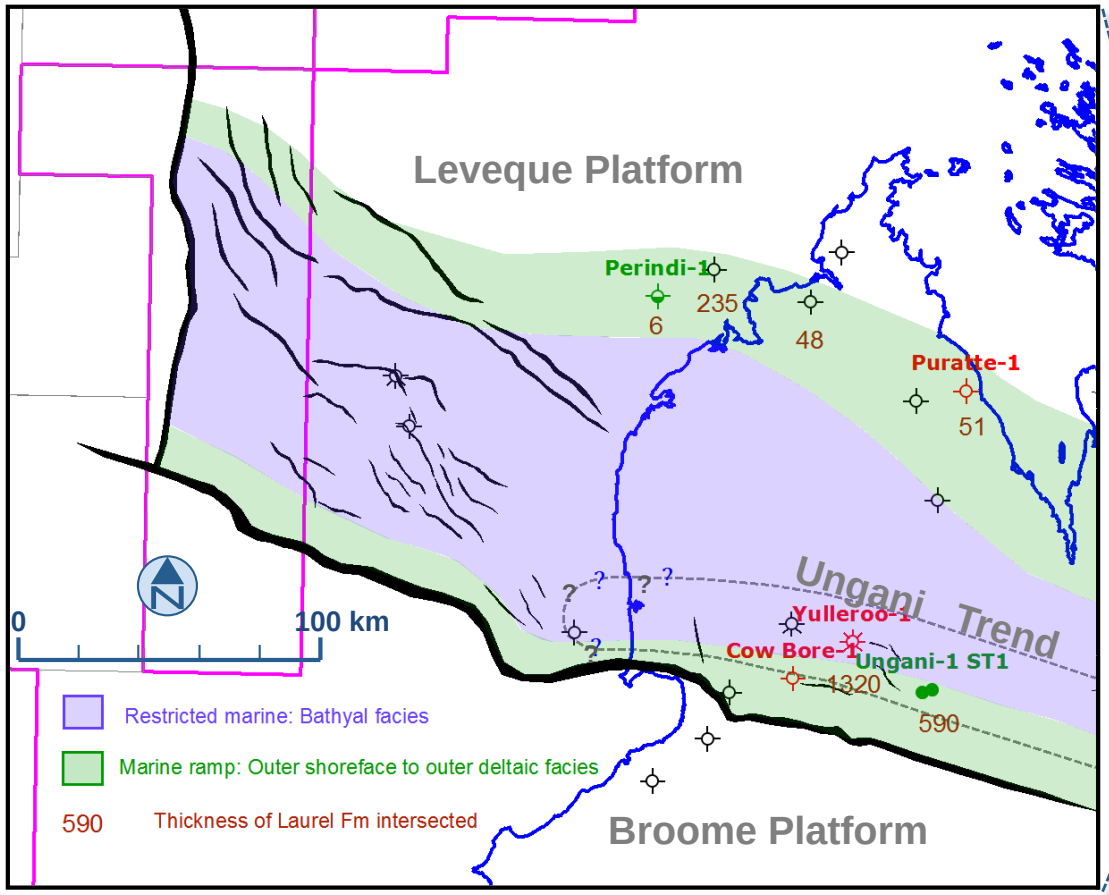
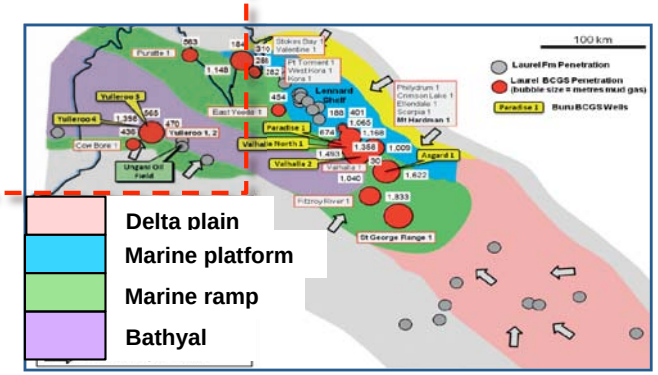
Laurel Formation sourced Fields and Shows

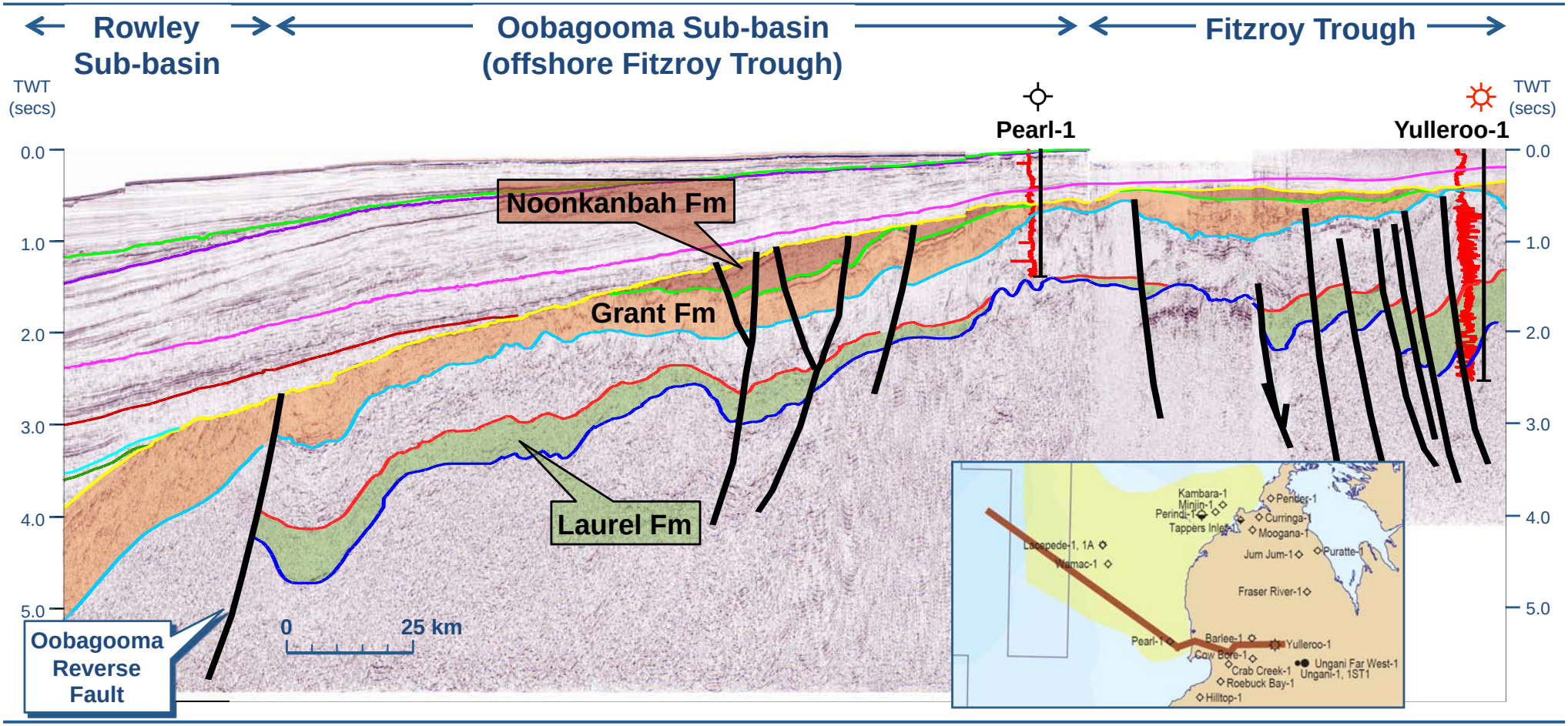


- **Extension of environments of deposition offshore favour deep marine shales in central Oobagooma SB**

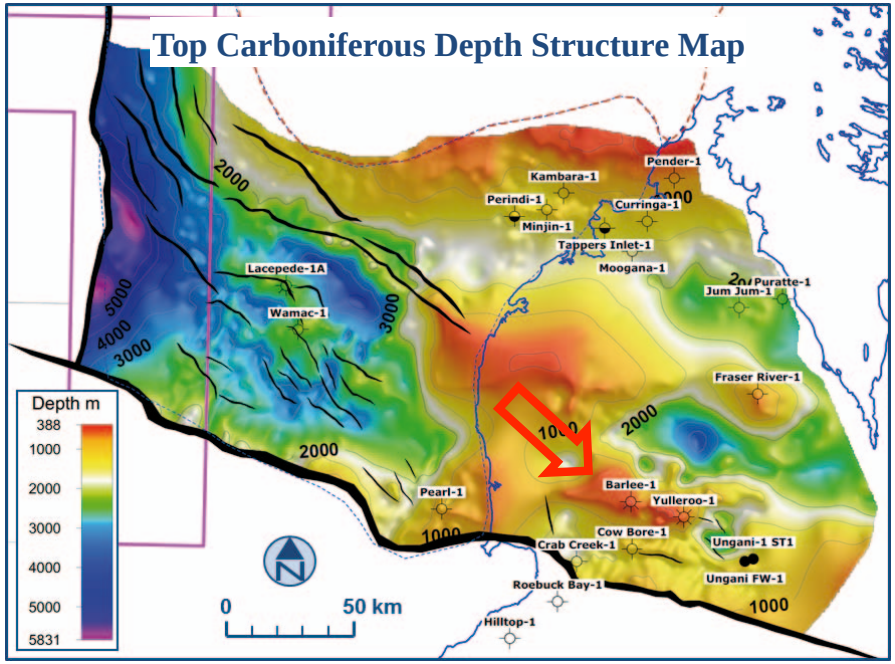


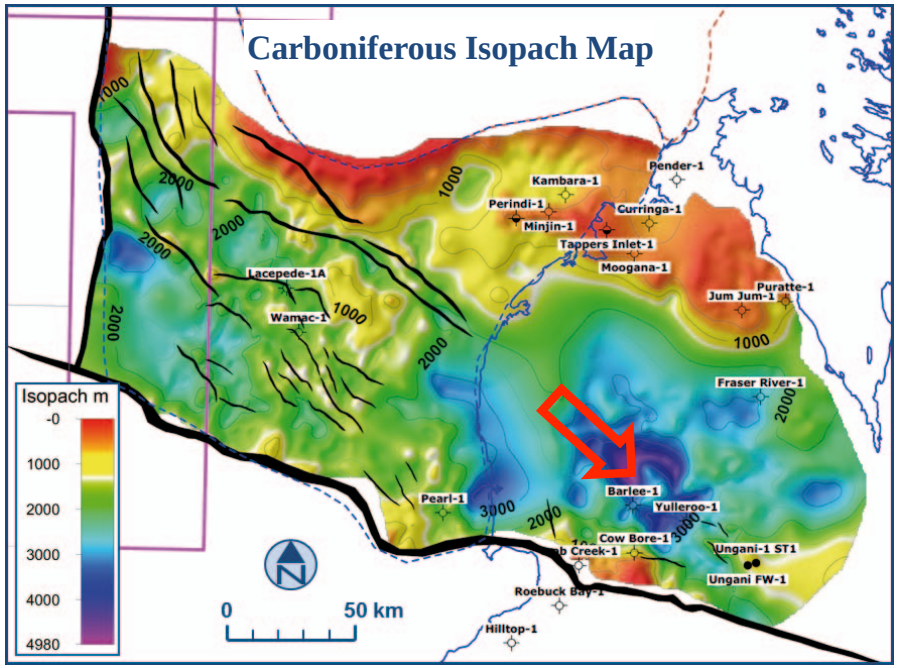
(after Kingsley and Streitberg, 2013)

Extension to Offshore - Yulleroo to Pearl

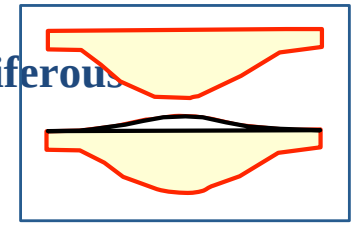


Carboniferous and Devonian Mapping





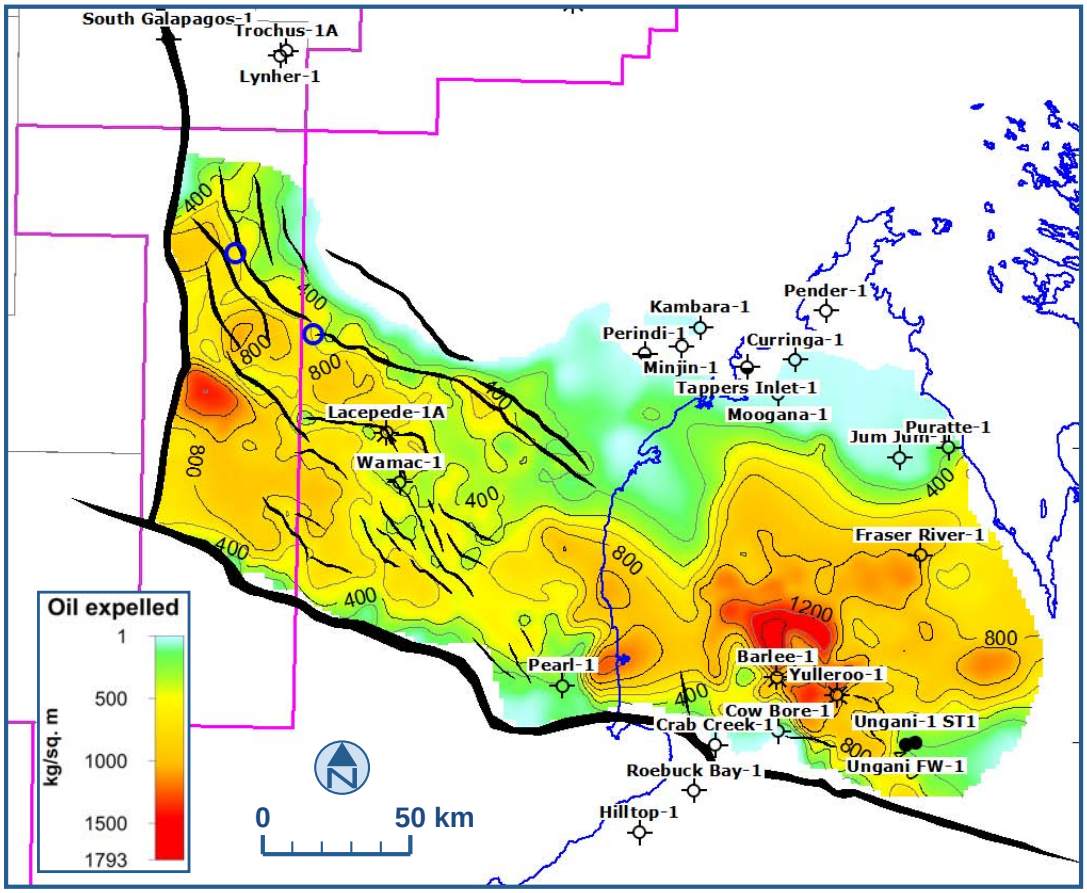
- **Strong correspondence between isopach thick onshore and shallow Top Carboniferous**
- **Basin inversion in Late Permian with greater uplift at the thicks**



Hydrocarbon Charge Modelling

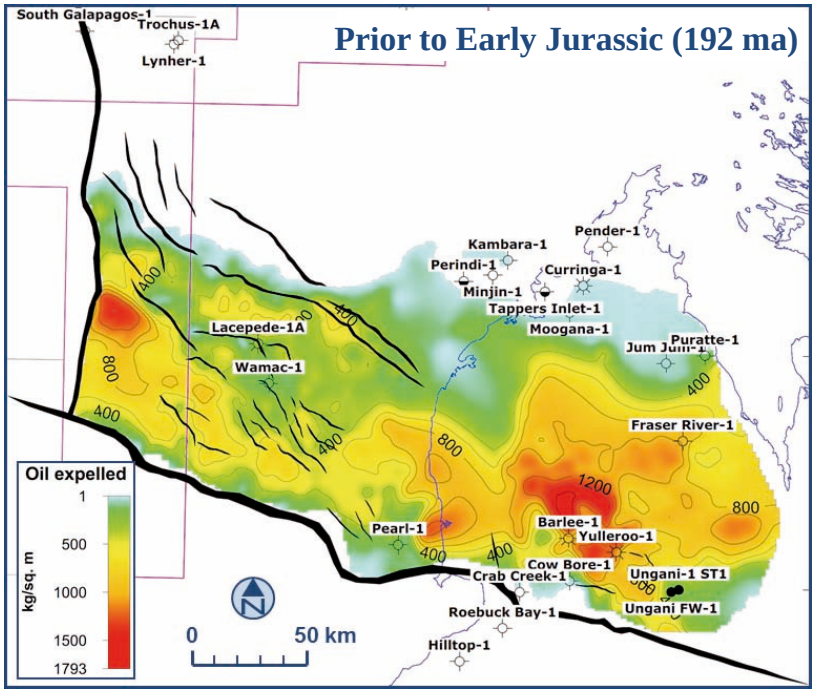
- **Platte River Associates software**
- **11 seismic depth horizons**
- **23 wells to calibrate porosity, corrected BHT and vitrinite reflectance**
- **Lithologies extrapolated from wells; insufficient data for detailed facies maps**
- **Thermal calibration in the calibration wells addressing compaction and thermal conductivities**
- **1,500 m of erosion in mid-Late Permian from seismic interp., consistent with vitrinite reflectance**

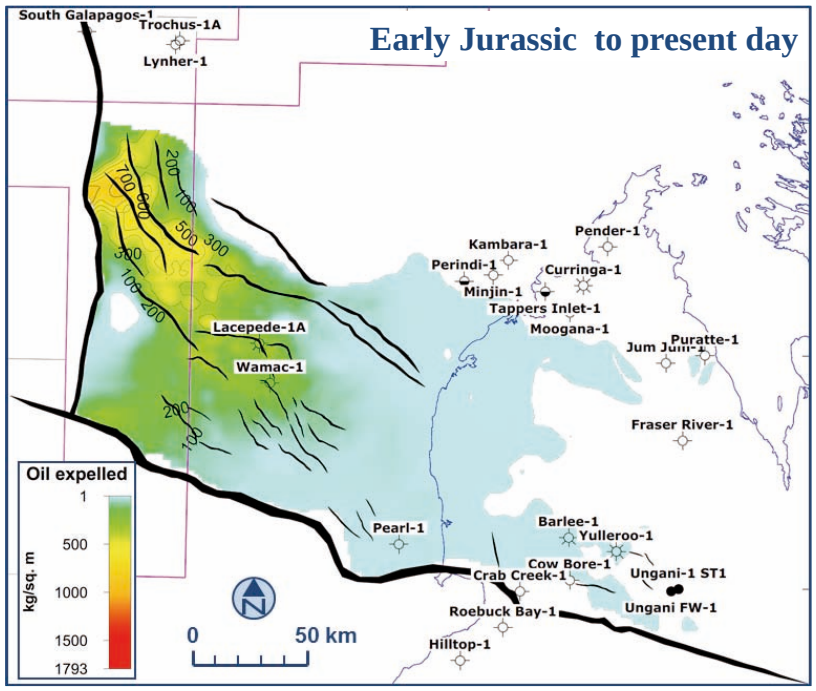
Laurel Formation oil expelled to present day



- Laurel Fm up to 750 m thick offshore
- This map shows the total cumulative oil expulsion from Late Permian to present day
- For marine clastic source, assumes 4% TOC over 2% of section
- Alternative waxy coal generates both oil and gas and less oil overall than the marine clastics

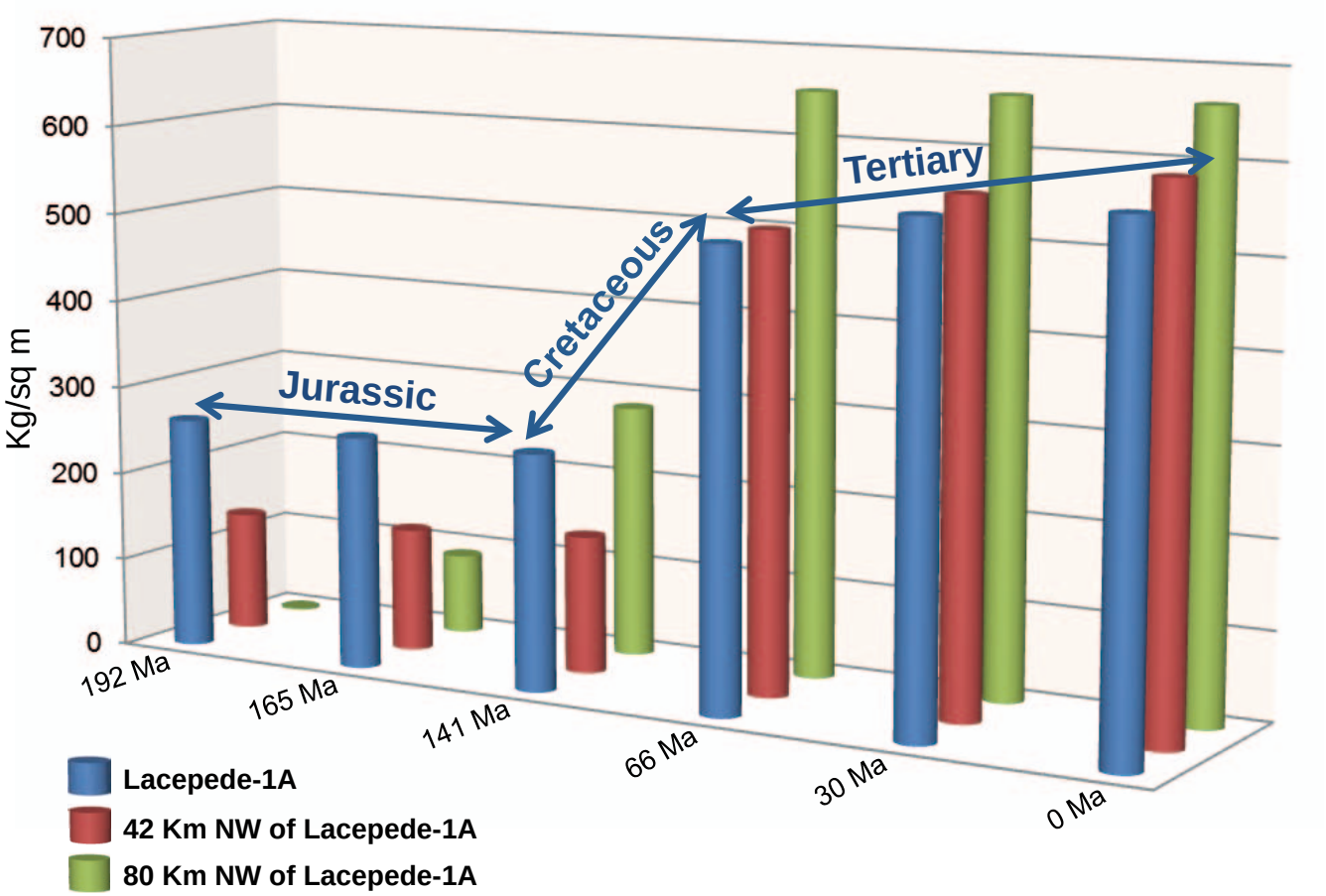
Laurel Formation oil expelled Pre and Post Jurassic

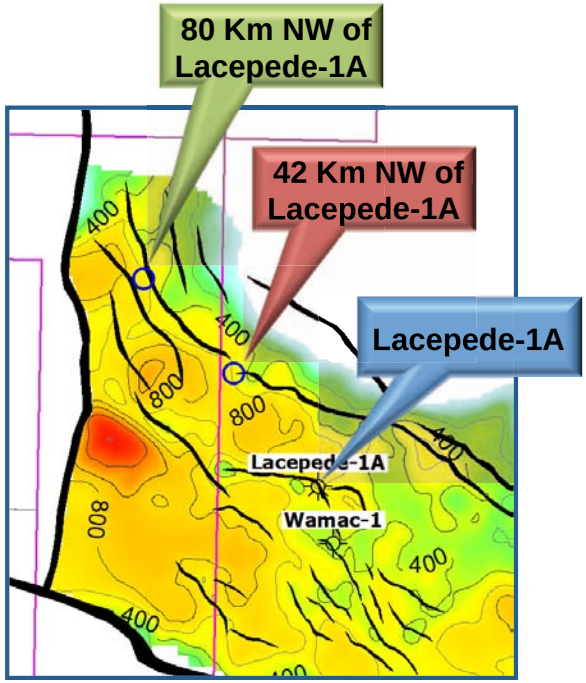




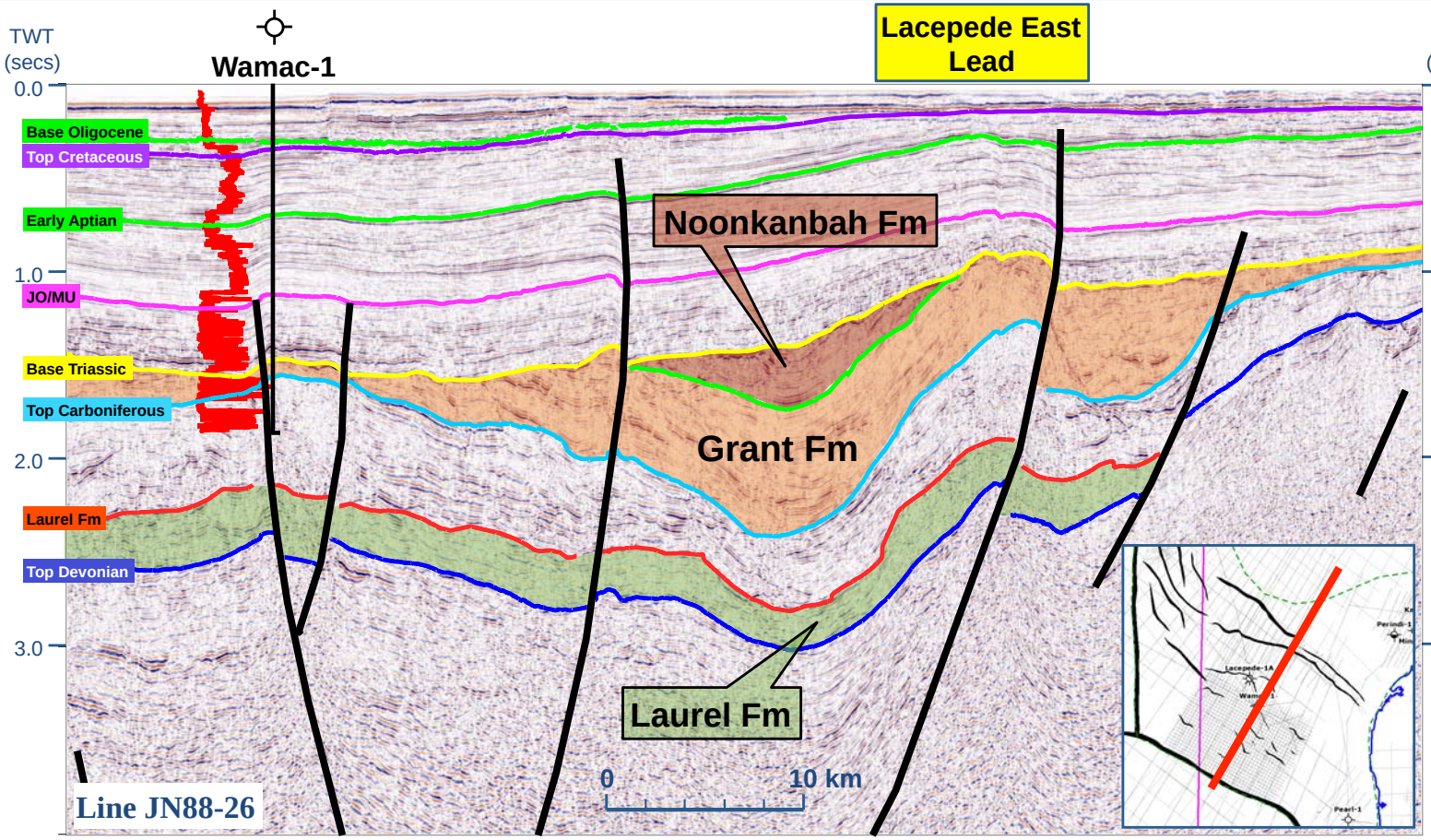
- **Until the Early Jurassic expulsion occurs both onshore and offshore**
- **Ceases onshore in Early Jurassic**
- **Continues offshore to present day**

Laurel Fm expulsion history at selected points



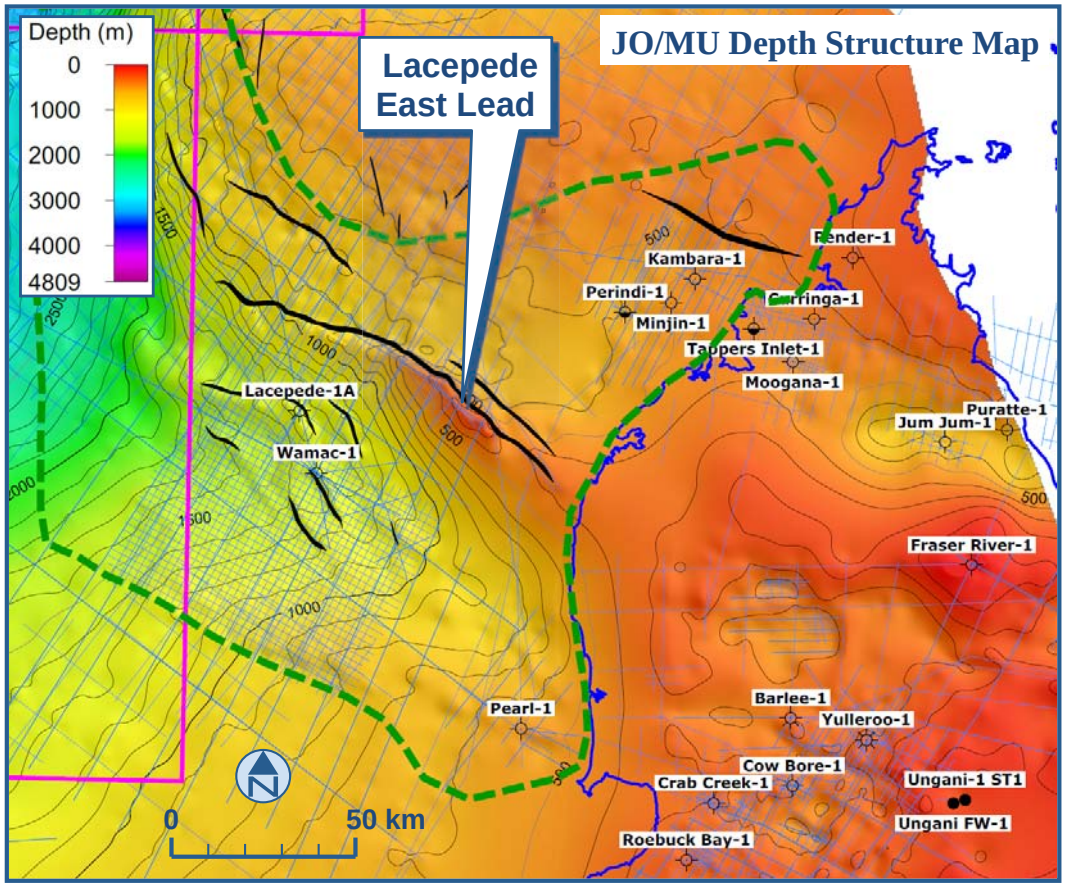


Seismic line over Lacepede East Lead



- Structure is a large inversion feature with a high angle reverse fault cutting the Paleozoic section
- Formed in two stages: Late Permian
- Late Cretaceous
- No fault to sea floor; shallow unconformity
- Wamac-1 no closure

Lacepede East Lead



- Lacepe East Lead has closure at
- Carboniferous, Permian and Jurassic
- Old structure reactivated in Cretaceous and Tertiary
- Deterministic oil:
- Jurassic: 450 mmbbls OIIP

- Wamac-1: no closure
- Lacepede-1A : closure at Jurassic and Permian but Tertiary structuring only

Jurassic source

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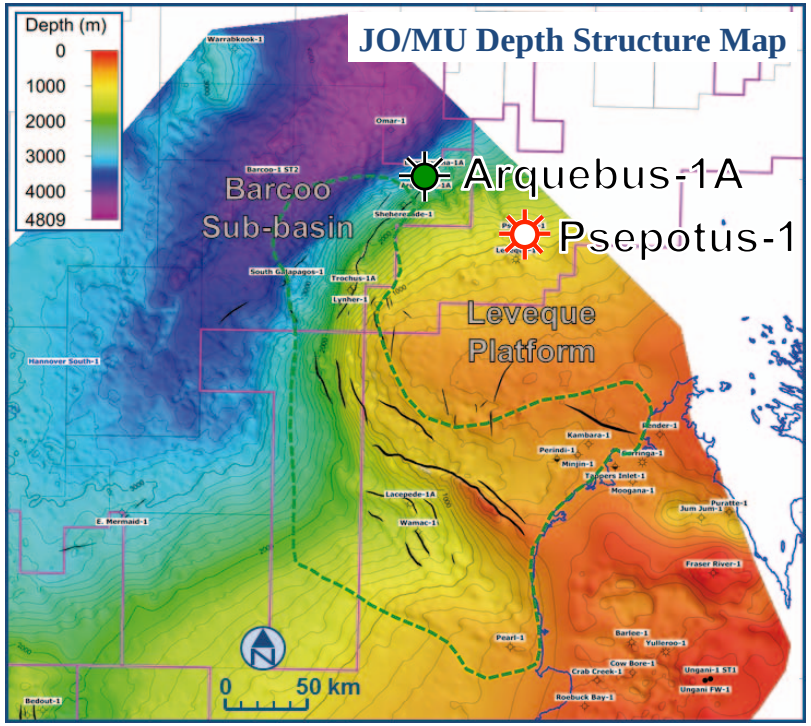
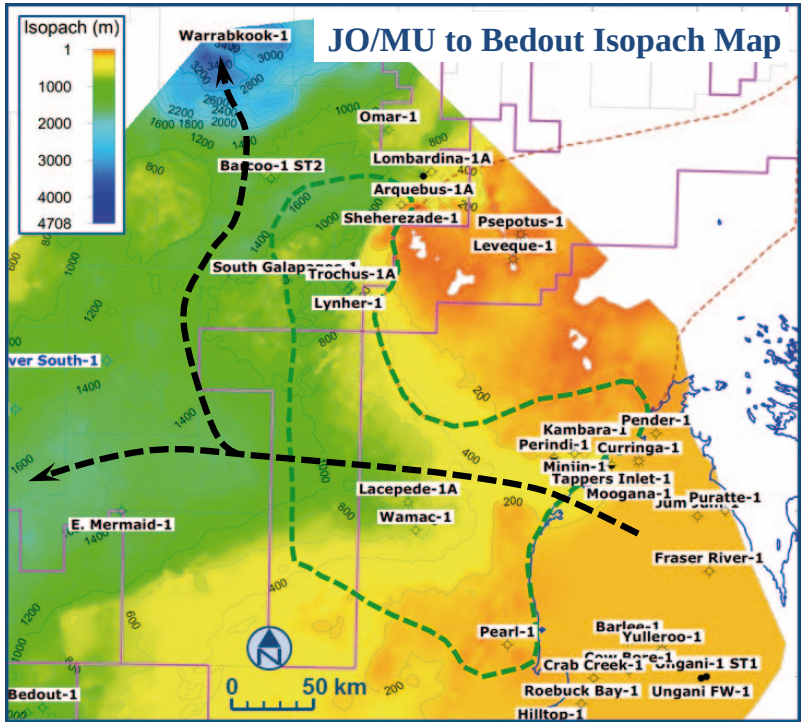
Jurassic Structure and Isopach

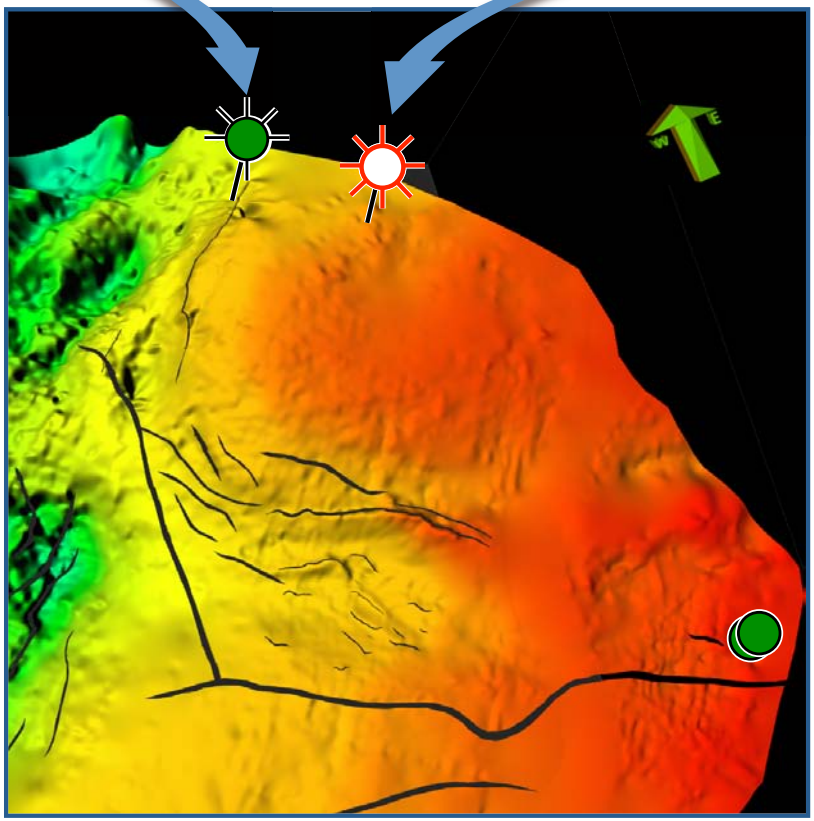




- **Top Jurassic up to 4,800 m deep in Barcoo Sub-basin**
- **Major feeder for Middle Jurassic deltaic and shallow marine sediments crosses the Oobagooma Sub-basin and forms thick trough near Warrabkook-1; Middle Jurassic section up to 3,400 m thick**

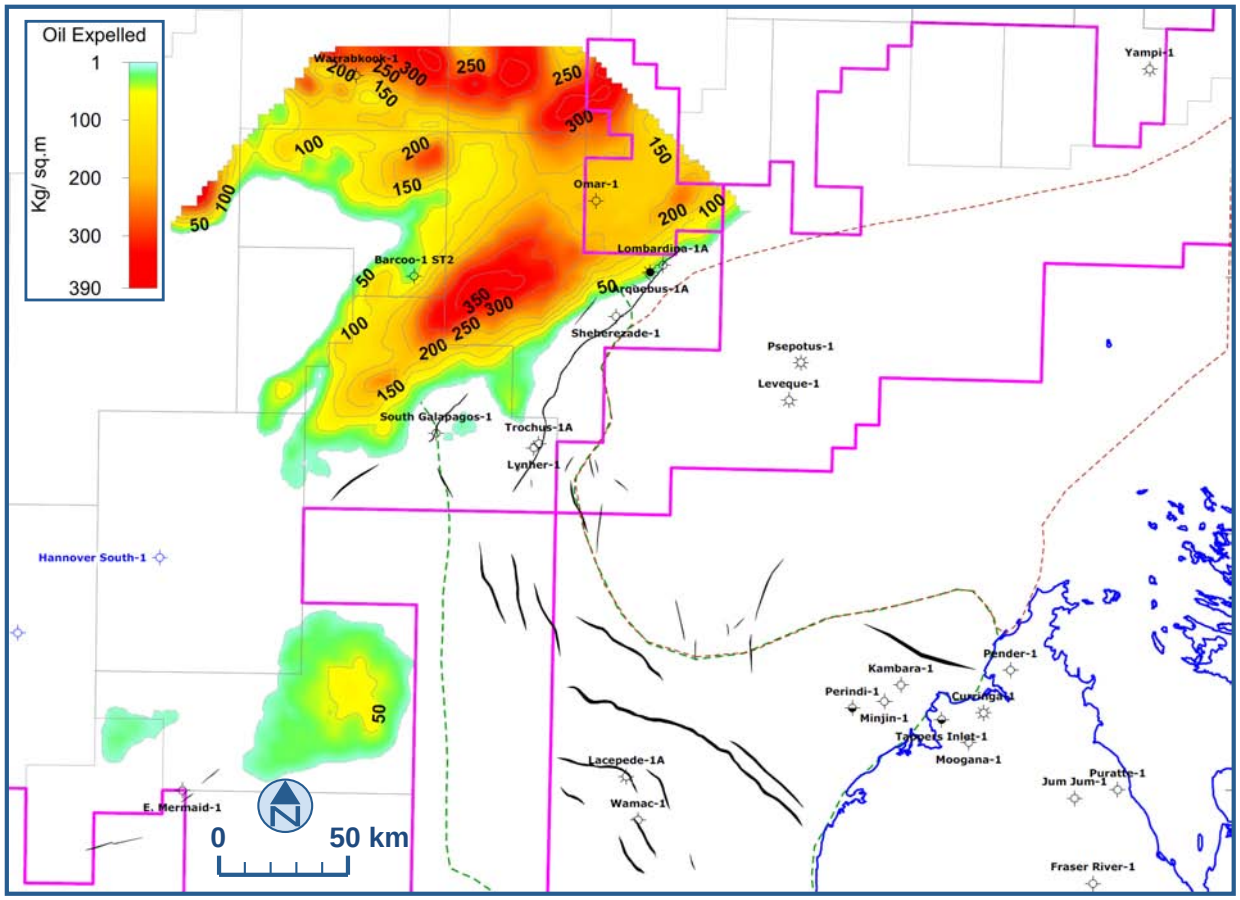
Discoveries in the north!

Arquebus-1A (Amoco 1991)
Inverted normal fault with dip and fault closure
Middle and Late Jurassic sands Average porosity: 9% Perm: 0.1 to 56 mD
Significant oil and gas shows from 2430 to 2595 m (165 m)
5 RFTs recovered only filtrate
Low clay content, slow drilling and overbalance for 47 days suggest formation damage
Log analysis and pressure data indicate a 6 m gas column over a 45 m light oil column



Psepotus-1 (Woodside 1998)
4-way drape over basement high
Early Cretaceous (Barremian) sands
Top porous sand: 834 m MD
Average log porosity: 35%
Gross gas column: 10 m TVD
Average gas saturation: > 60%
Full to spill
OGIIP: 30 Bcf approx.

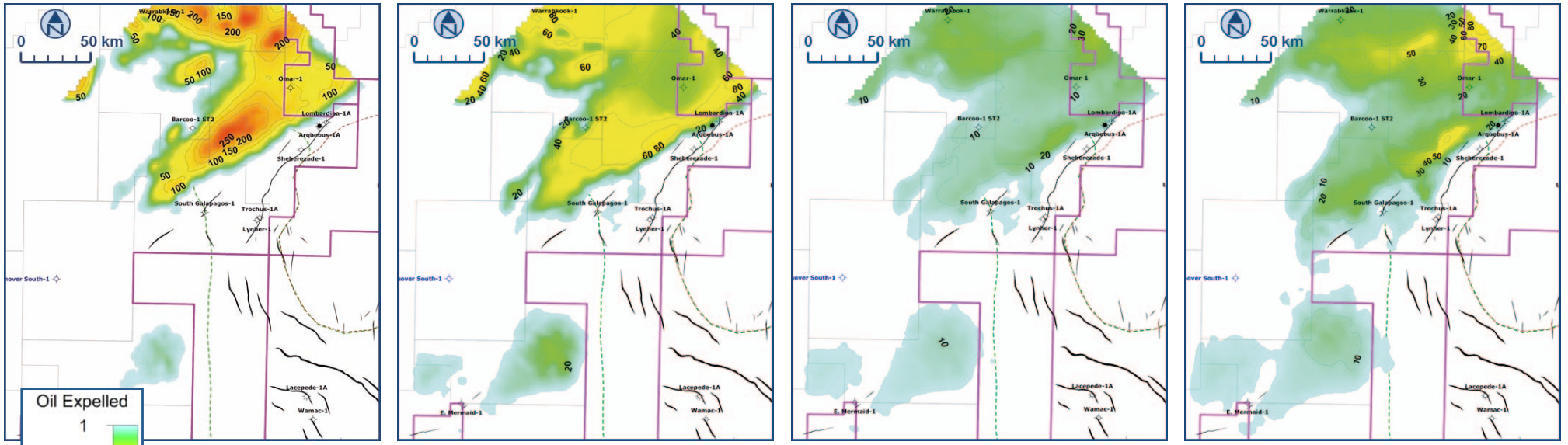
Middle Jurassic Oil expulsion to present day



- Expulsion of oil from the Middle Jurassic commenced in Early Cretaceous and has continued to the present day
- The waxy coal organofacies expels both oil and gas; only the oil case is illustrated here
- Assumes 3% TOC over 5% of section
- Substantial oil was potentially expelled in a broad area north of the Oobagooma Sub-basin
- A small zone of expulsion occurs west of the Oobagooma SB

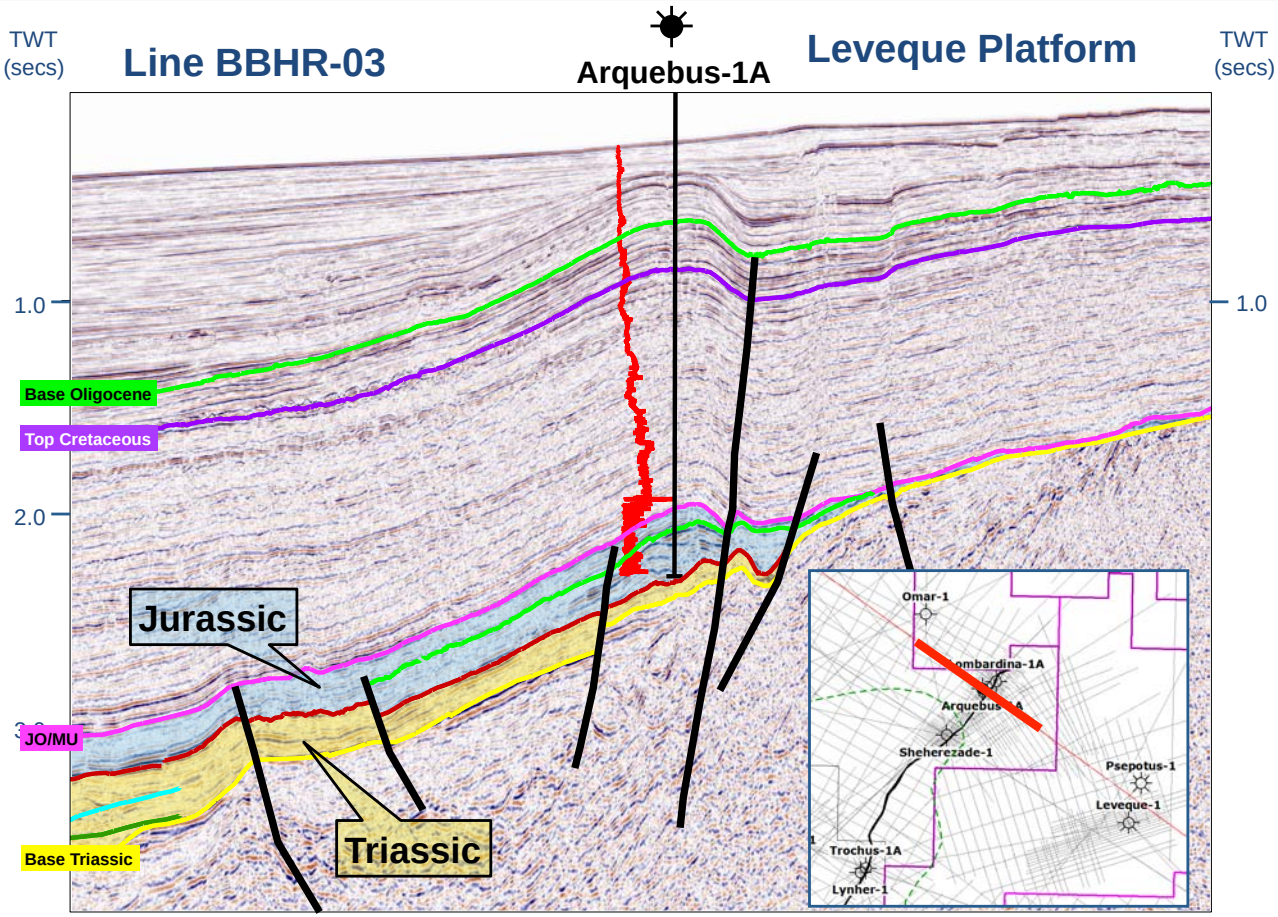
Middle Jurassic oil expulsion during Cretaceous and Tertiary

141 to 66 ma (Cretaceous) | 66 to 30 ma | 30 to 15 ma | 15 to 0 ma



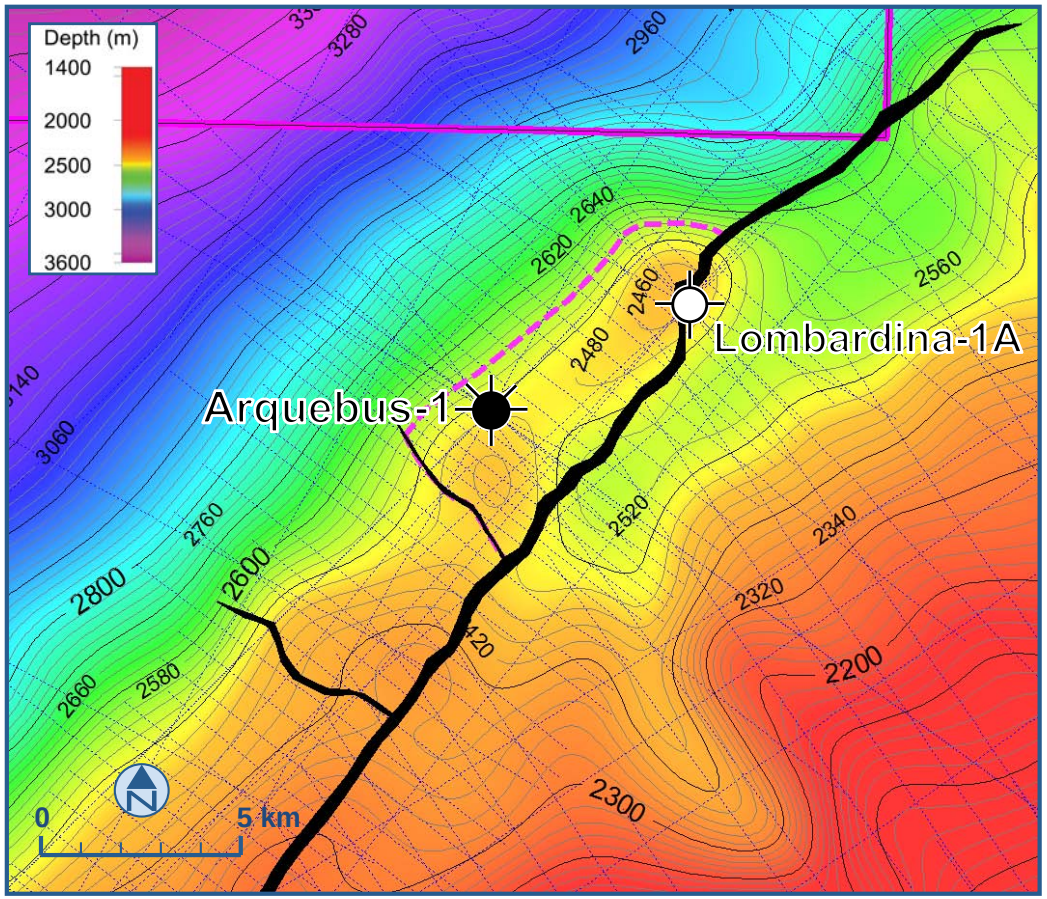
- **Late increase in expulsion (30 to 15 ma and 15 to 0 ma) related to thick Tertiary wedge deposited on the outer shelf**

Seismic Line through Arquebus-1A



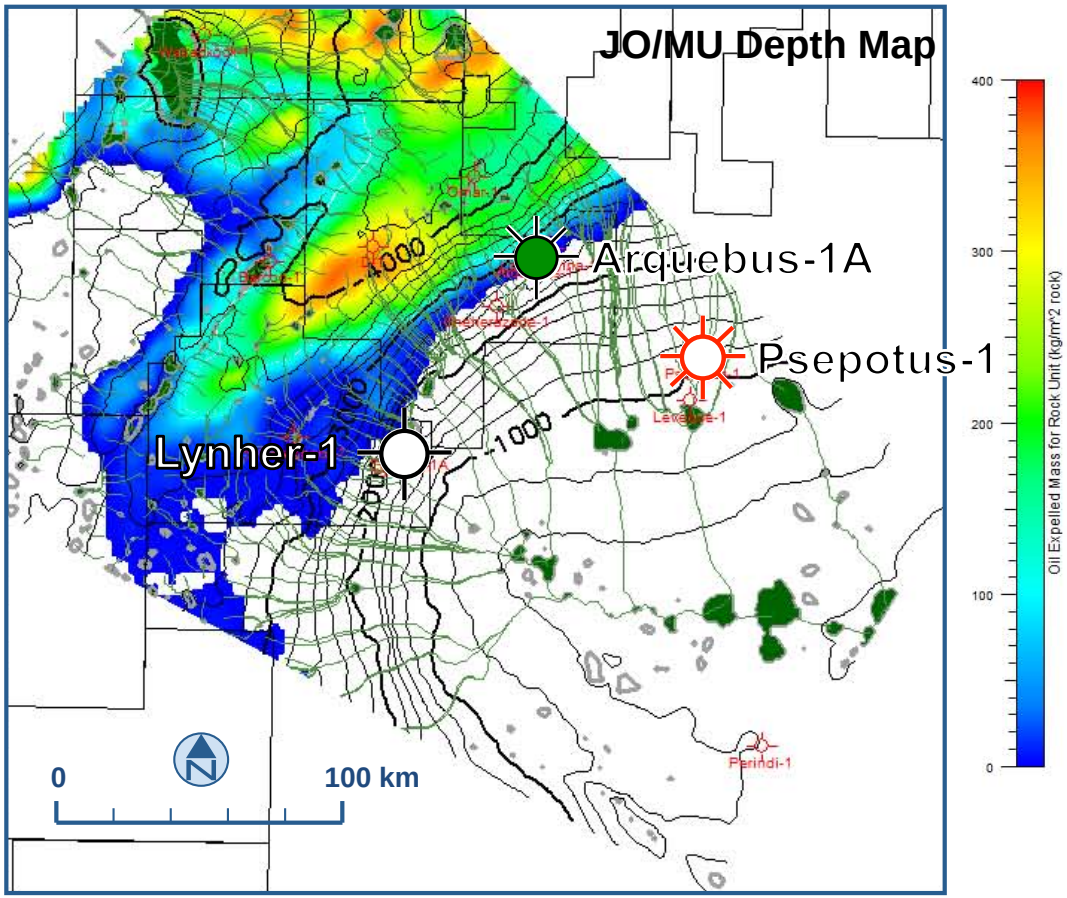
- Original normal fault system down to NW
- Inversion with right lateral wrenching
- Structure formed in two stages:
- Cretaceous
- Miocene
- Fault does not cut sea floor
- Late Tertiary unconformity

Arquebus Depth Structure Map at JO/MU and potential oil volumes



- 6m gas cap over a 45 m oil column (Amoco)
- OWC at 2,525 m, deeper than footwall block
- Trapping requires NE trending cross fault and fault surface seal on main fault
- Porosity: 9% but improves to 20% at Sheherezade-1 (20 km SW)
- Deterministic oil in place for Middle Jurassic sands:
- **OOIP= 200 mmbbls**

Migration pathways onto Leveque Platform



- Total oil expelled from Middle Jurassic waxy coal source
- Migration pathways and oil traps at Middle Jurassic
- Psepotus-1 gas discovery
- Analogies with Cornea, Gwydion, Wandoo, Stag

Early Triassic source potential

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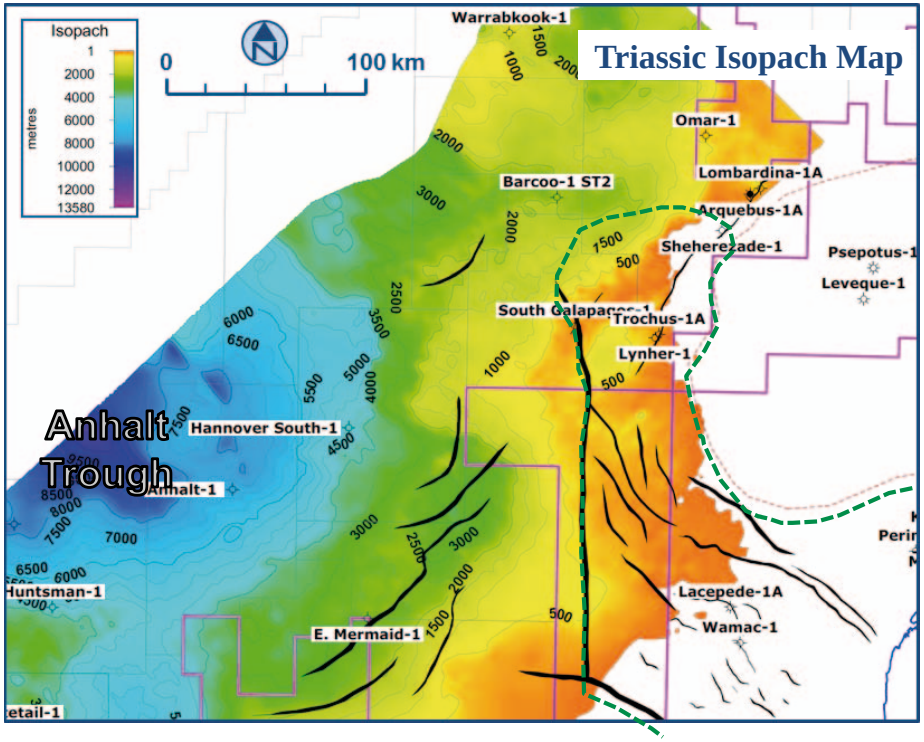
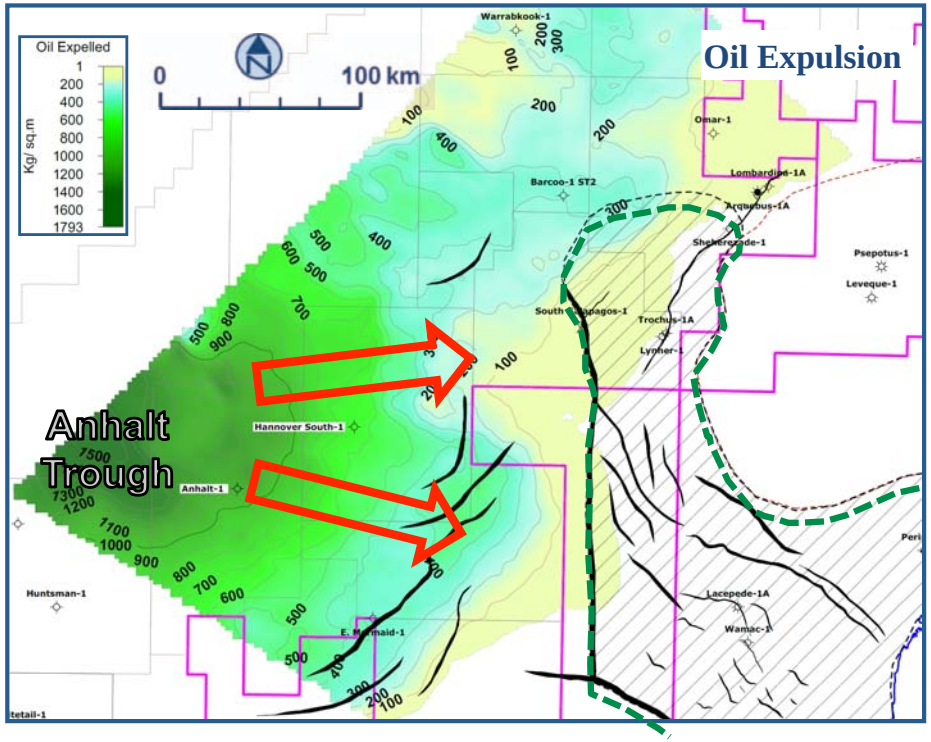
4. **Early Triassic source**
5. Conclusions

Triassic Isopach and Early Triassic Expulsion





- Early Triassic potential kitchen area (Anhalt Trough) west of the Oobagooma Sub-basin; this kitchen lies NE of the proven oil kitchen which sources Phoenix South
- Charging structures within Oobagooma Sub-basin requires long distance migration (50 to 150 km)

Conclusions

- Early Carboniferous Laurel Formation potential source (Late Permian to present day)
- Middle Jurassic (in the north) potential source (Early Cretaceous to present day)
- Supported by non-commercial oil and gas in Arquebus and gas in Psepotus
- Inversion structures formed in several stages including Late Permian, Cretaceous and Miocene
- Timing of structures and hydrocarbon expulsion could favour trapping

Conclusions

- Possible migration pathways from Middle Jurassic to traps in northern Oobagooma Sub-basin and Leveque Platform
- Analogies with Cornea, Gwydion, Wandoo and Stag
- Early Triassic less likely source; long distance migration required; (Triassic thin to absent in Oobagooma Sub-basin)
- Permian unlikely source- Noonkanbah Formation immature or eroded

Conclusions

- The Oobagooma Sub-basin and Leveque Platform warrant more exploration
- 14 wells drilled to date, only 6 were valid tests and resulted in two non-commercial discoveries
- Greatest need is modern seismic:
- 2D with longer streamers and broadband techniques
- 3D over high-grade areas eg Arquebus Trend

Acknowledgements

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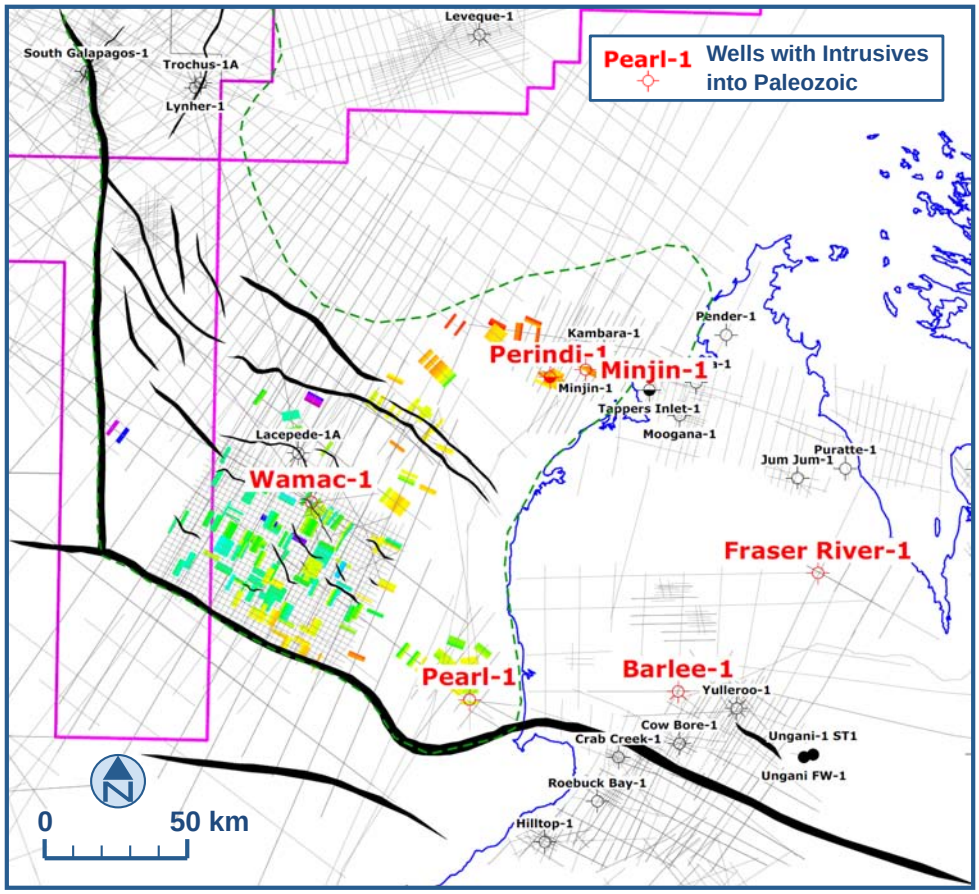
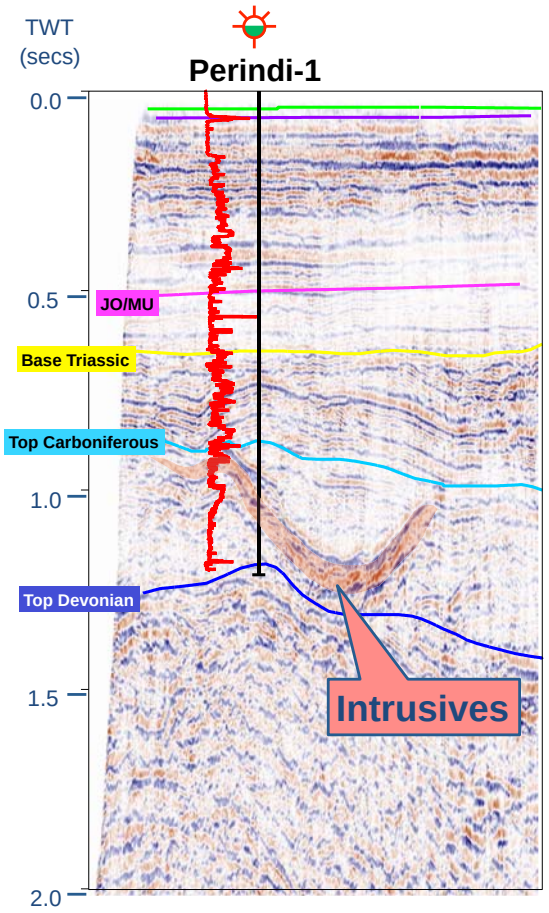
APPEA Conference Brisbane 2016

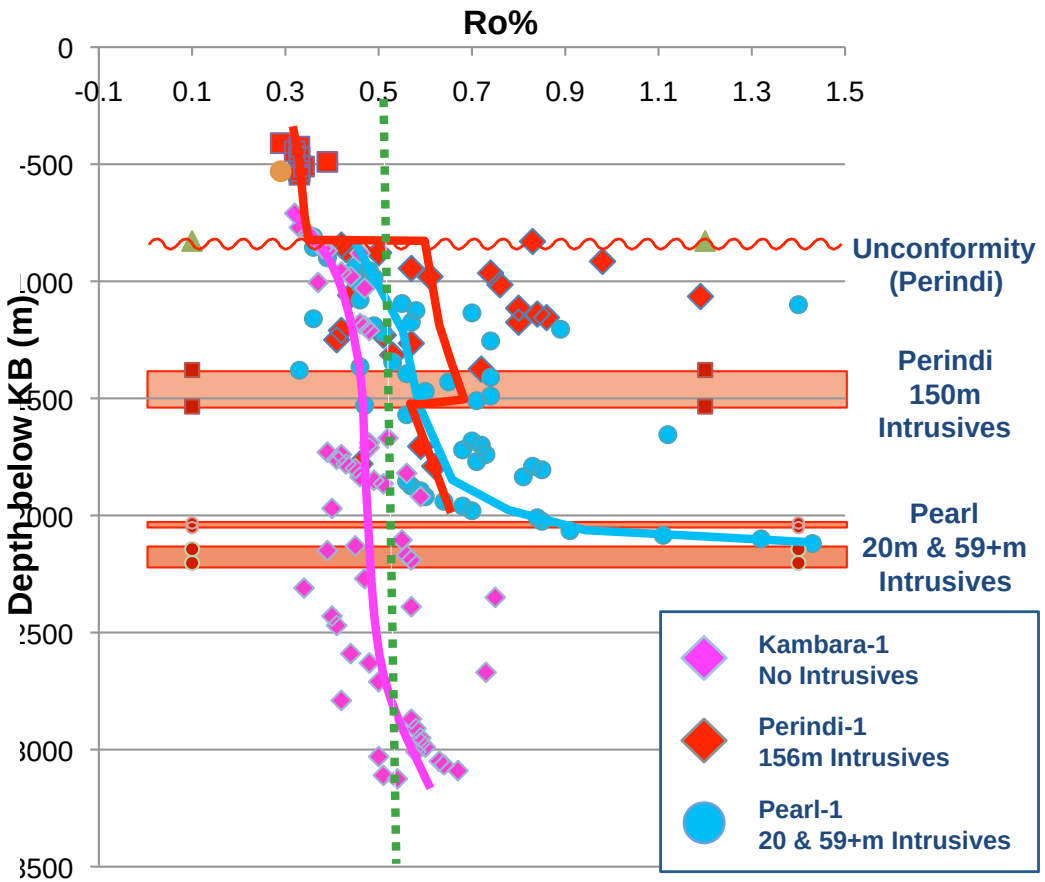
Intrusives in Oobagooma Sub-basin





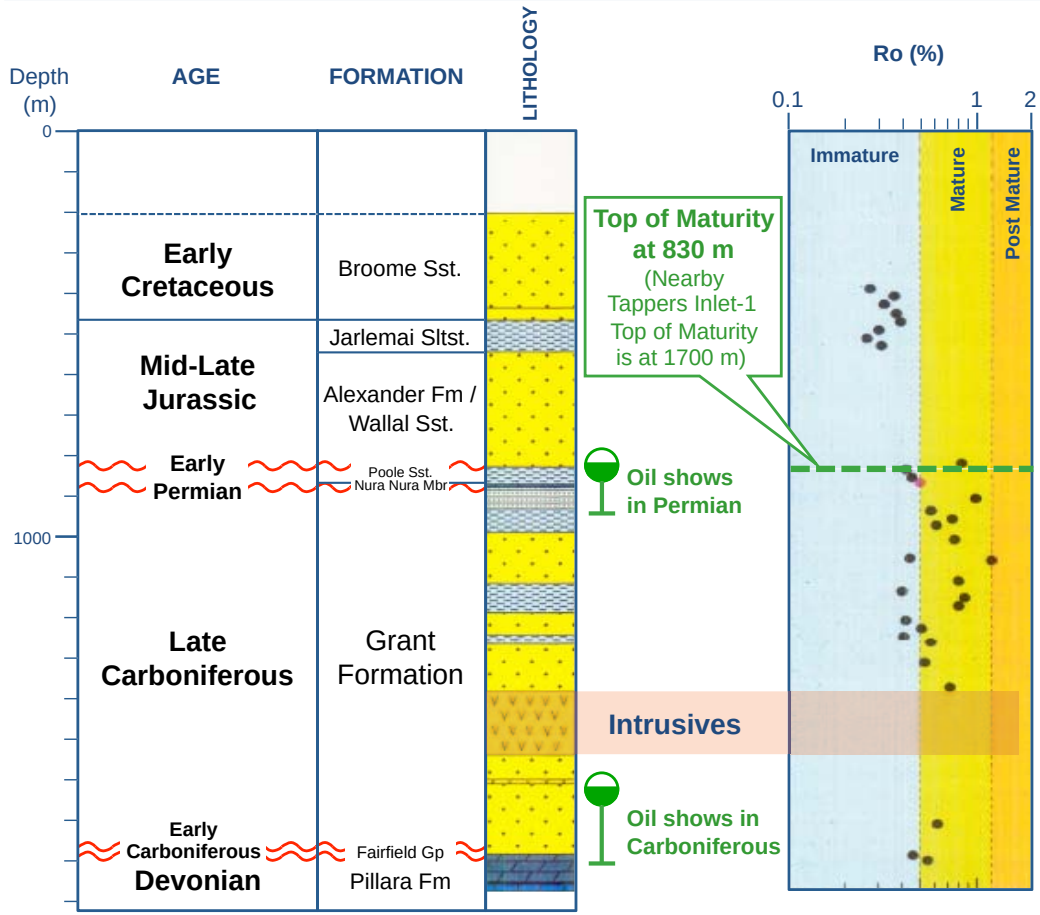
- Volcanic intrusives in the Oobagooma SB in the form of dykes and sills emplaced into Palaeozoic sediments in middle to Late Permian
- 2 onshore and 4 offshore wells intersected intrusives
- Perindi intersected a156 m thick intrusive
- Colours on the map indicate presence of intrusives interpreted from seismic data

Slide 17: Thermal Maturity Perindi-1, Pearl-1 and Kambara-1 (data from Core Labs Report S3599 A1, undated)



- Kambara-1 with no intrusives has most vitrinite points in the immature range
- Perindi with a single 156 m thick intrusive has most points in the mature to overmature range with an increase in maturity above the intrusive
- Pearl-1 has nearly all points in the mature range with several points between two intrusives in the overmature range
- Despite the wide scatter in the data there is evidence of thermal effects on maturity above intrusives more than simple contact would explain
- Does not explain the strong oil shows beneath the intrusives in Perindi-1
- More work required

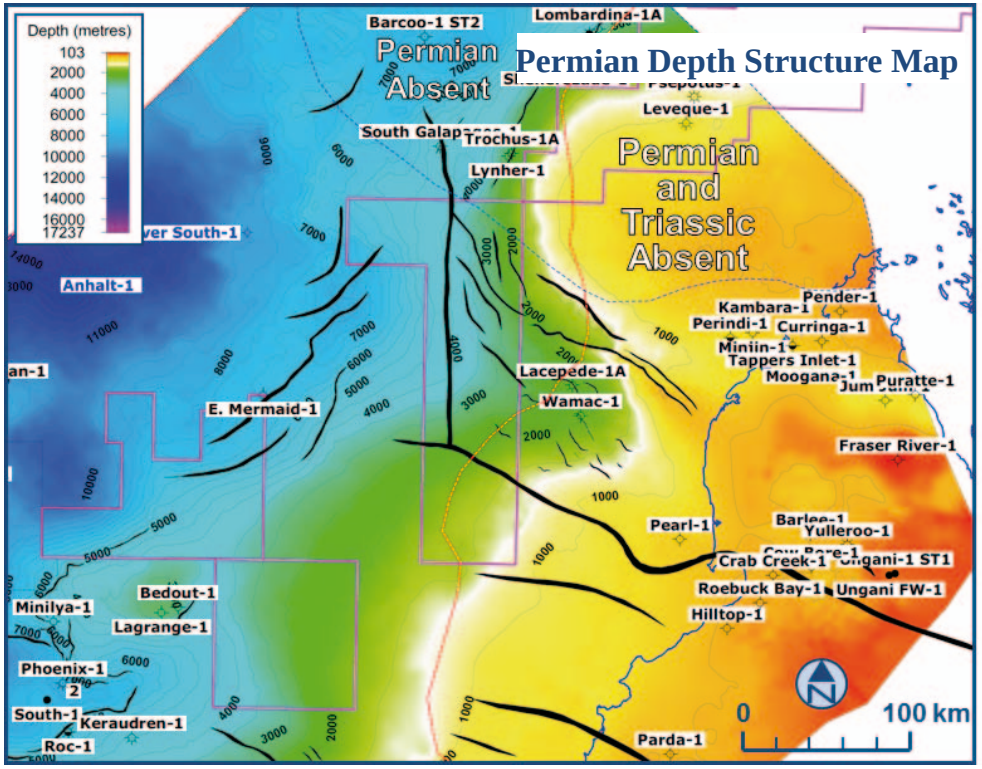
Slide 15: Perindi-1 Oil Shows,Volcanic Intrusion and Thermal Maturity

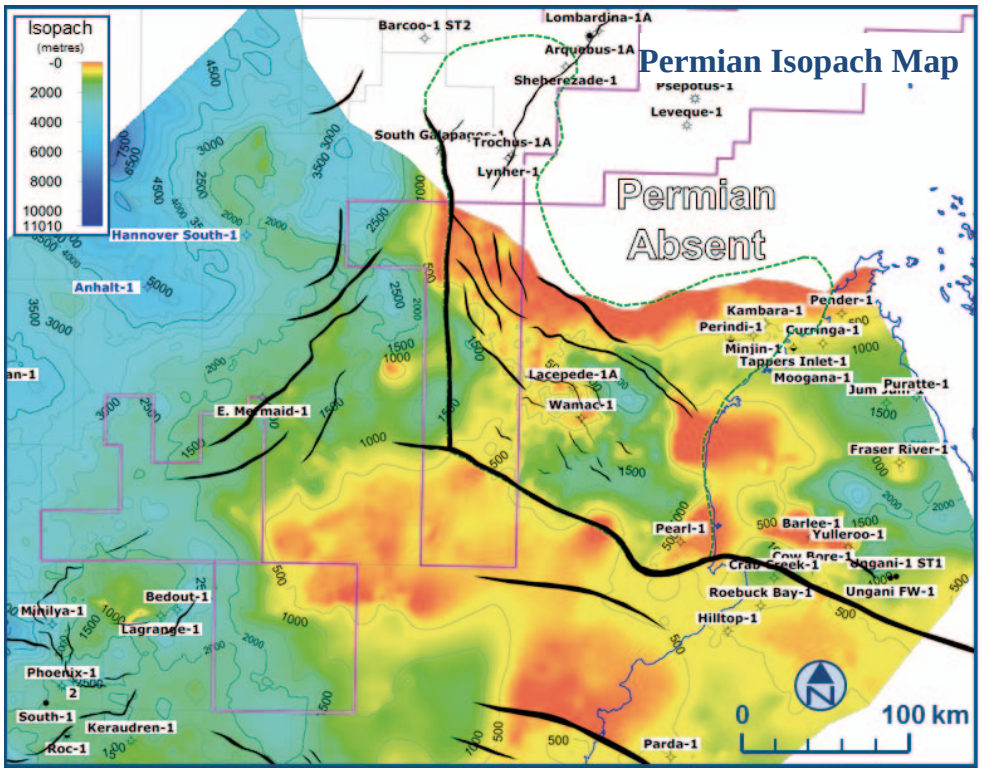


Perindi-1 shows:

- 8 zones with hydrocarbon shows were encountered in the Poole, Grant, Laurel and Pillara Fms
- All shows except in the Pillara consist of oil, oil staining, and/or cut and fluorescence with no associated gas
- Gas up to 1.7% and bitumen fragments were recorded in the Pillara Fm
- Free oil was obtained in a core cut in the Nura Nura Lst
- All RFT's were seal failures or tight tests
- Modified from Core Labs Report S3599 A1(undated)

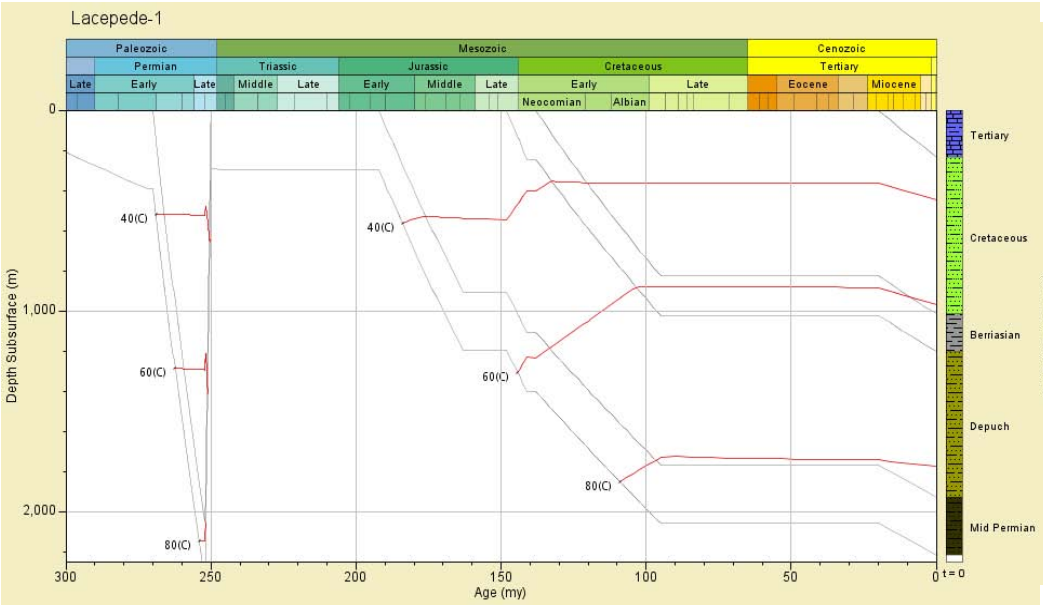
Permian Depth Structure and Isopach

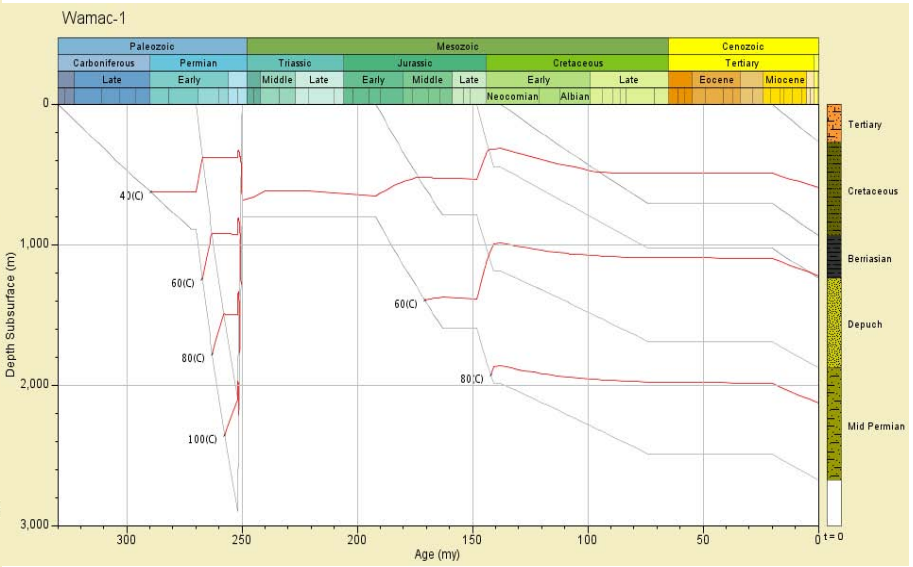




- **Permian Noonkanbah onshore Canning Basin has good source characteristics but is immature**
- **It is eroded over much of the Oobagooma Sub-basin and is immature where present**

Burial history plots





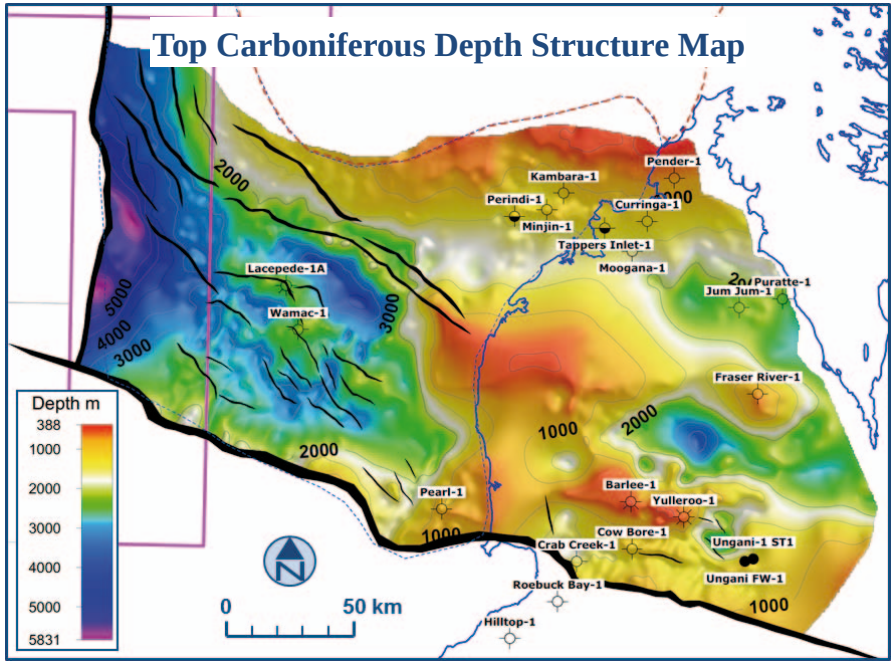
Stratigraphy for Charge Modelling

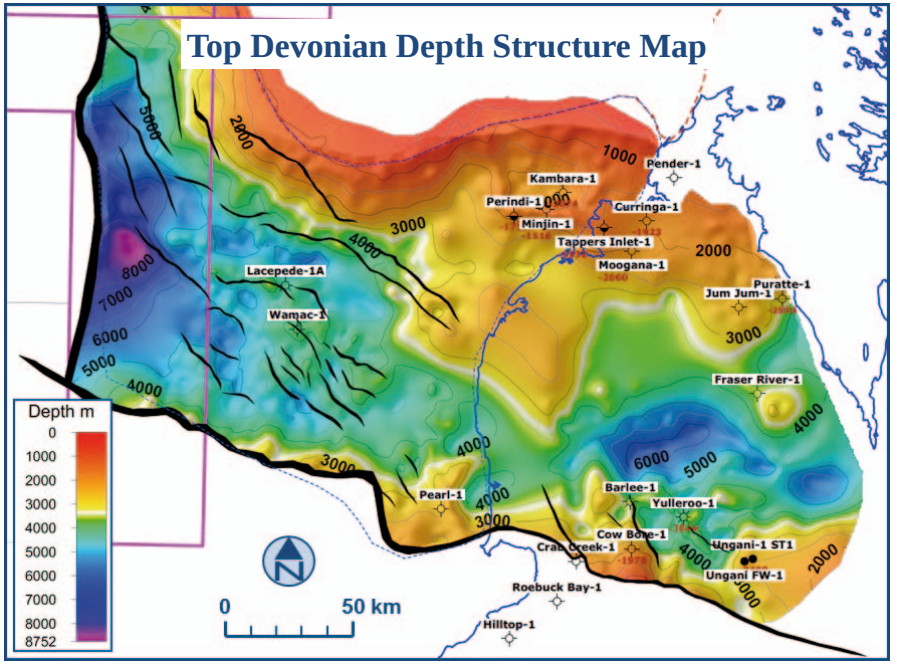
STRATIGRAPHY						
FORMATION	TYPE	DEFAULT END AGE	ERODED SECTION	ORGANOFACIES	TOC %	EFFECTIVE SOURCE %
Tertiary	F/D	0				
TO	H	30				
Eocene/Paleocene	F/D	35				
T	H	62				
Cretaceous	F/D	70				
KV	H	138				
Berriasian	F/D	141				
M/U	H	156				
Depuch	F/D	165		Waxy Coal	10	1
Athol	F/D	176		Waxy Coal	3	5
Bedout Fmn	F/D	192				
Cossigny	F/D	238				
L Keraudren Fmn	F/D	238.5		Waxy Coal	4	2
Locker Shale	F/D	240		Marine Clastic	4	2
P	E	250				
Top Permian	D	252	Constant=1500 (m)			
MP	H	270				
Mid Permian	F/D	272		Non Waxy Coal	3	5
C	H	285				
Carboniferous	F/D	290		Non Waxy Coal	3	5
Top Devonian	F/D	360				

Laurel Fm Organofacies

Laurel Formation	Marine clastics Organofacies	Waxy Coal Organofacies	Modelled as alternatives
Early Carboniferous	4% TOC over 2% of section (type II equivalent)	3% TOC over 5% of section	
Maximum gross thickness of section: • Carboniferous: 3,000 m • Laurel: 750 m	Offshore Laurel thickness estimated to comprise lowermost 25% of Carboniferous		

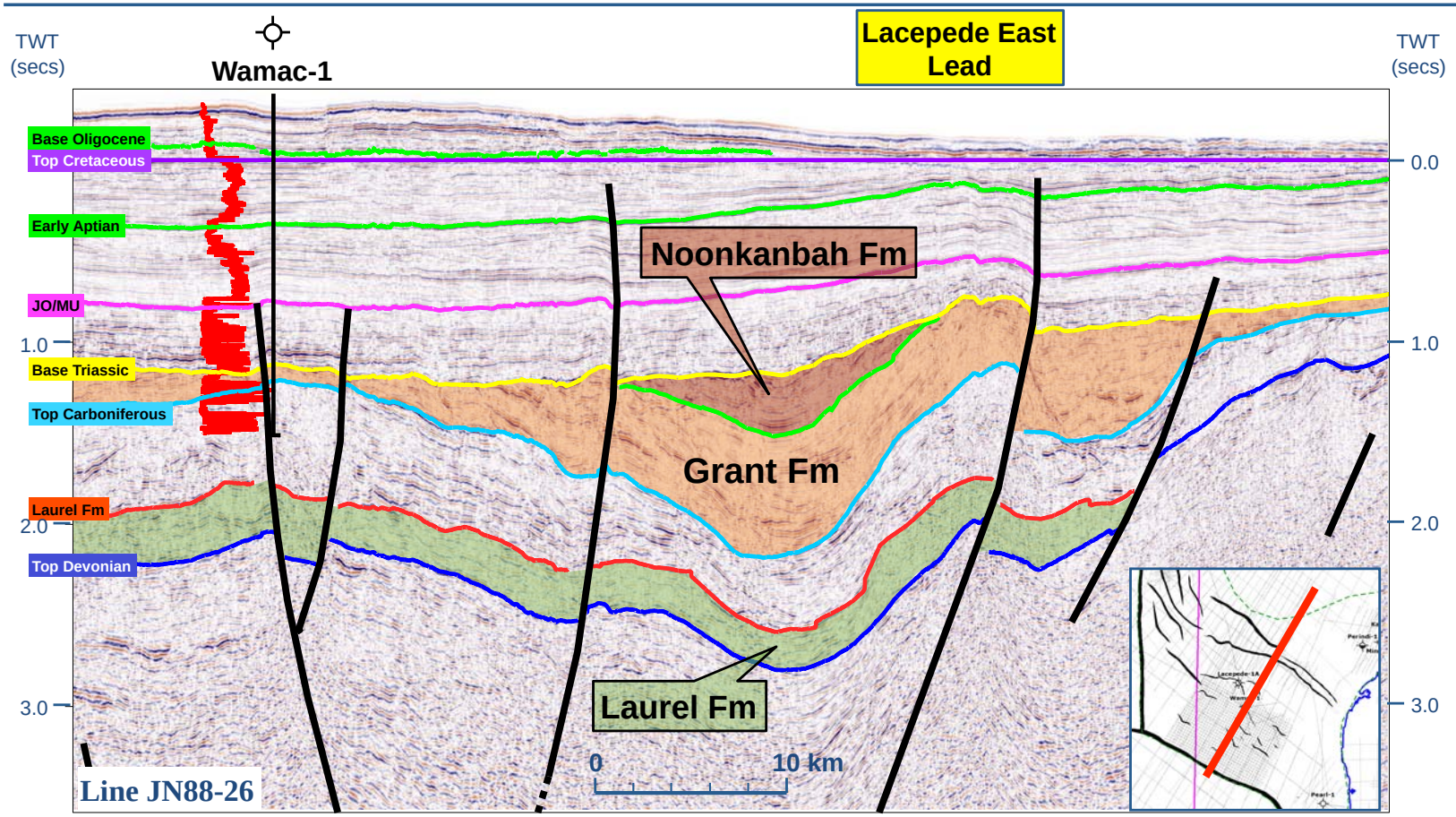
Carboniferous and Devonian Mapping





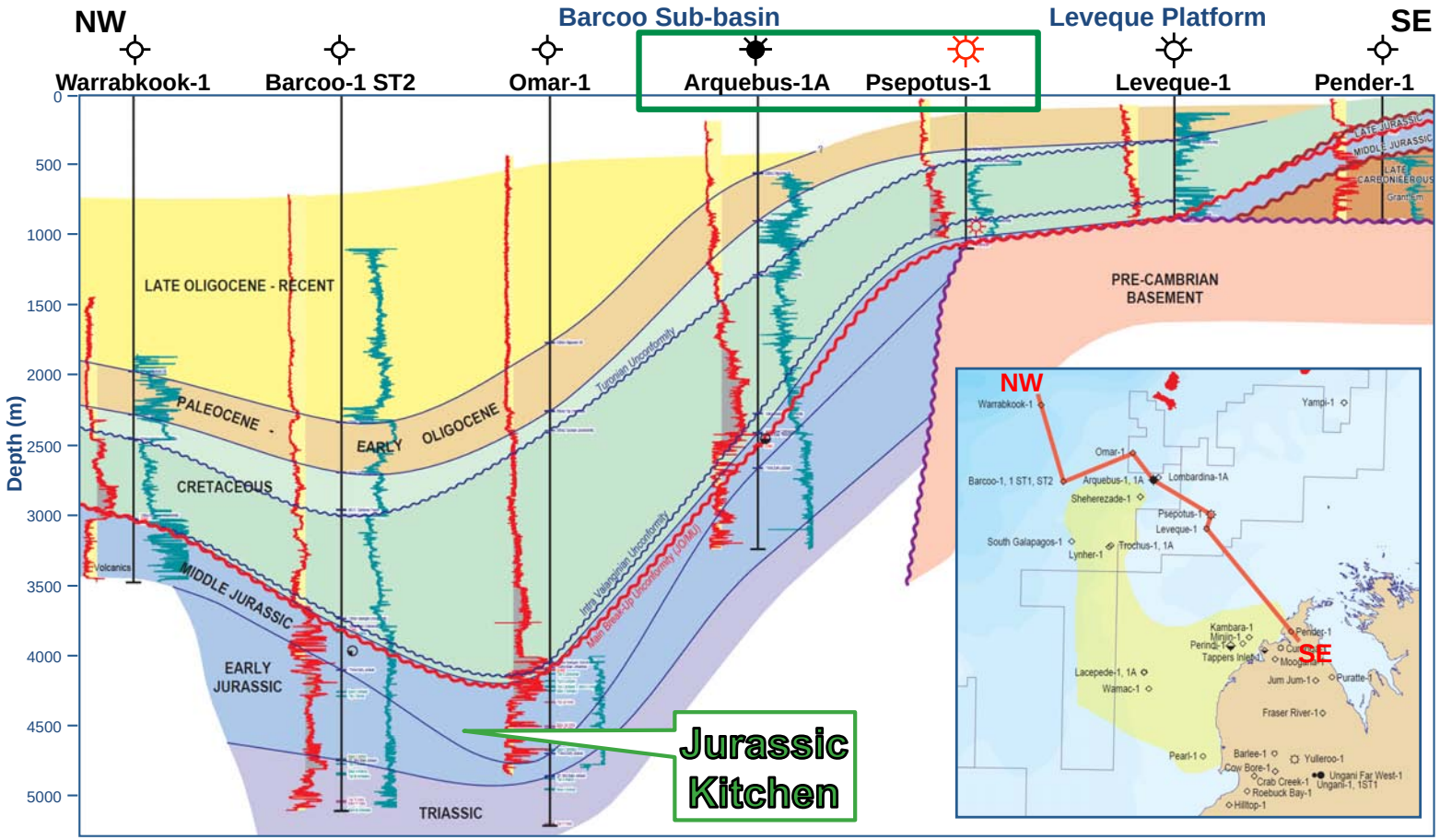
- Top Carboniferous onshore (depth 500 m to 3,000 m) generally shallower than the offshore (500 m to 8,000 m)
- Caused by more intense inversion onshore at Late Triassic (Fitzroy Movement) eroding more Permian section
- WNW to NW inversion structures both onshore and offshore
- Devonian : sinuous deep troughs partly separated by NNW trending high near coastline

Seismic line over Lacepede East Lead – flattened on Top Cretaceous

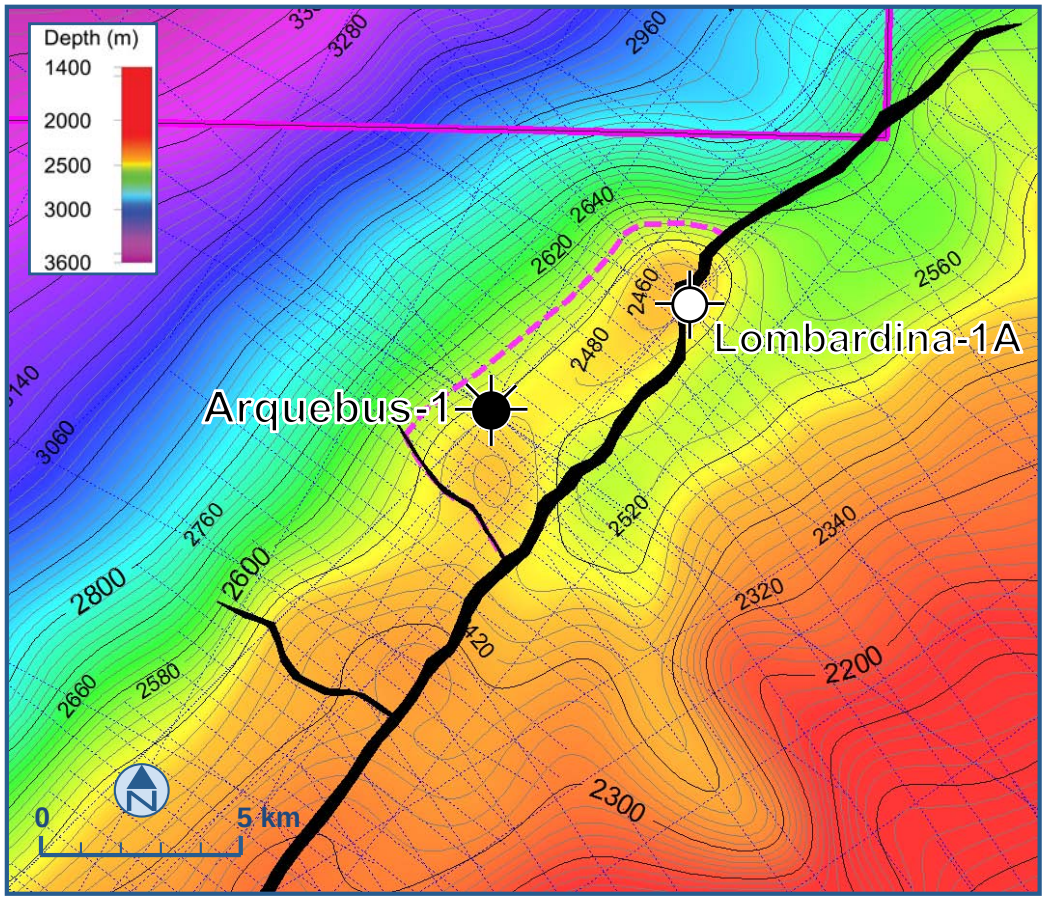


- This section has been flattened on the Top Cretaceous horizon
- Structuring is evident at all levels prior to the Top Cretaceous including the JO/MU and the Early Aptian
- Indicates further deformation occurred during the Cretaceous

NW well section
Barcoo Sub-basin to Leveque Platform



Arquebus Depth Structure Map at JO/MU and potential oil volumes



Arquebus-1A

- Amoco interpreted 6m gas cap over a 45 m oil column
- OWC at 2,525 m, deeper than the footwall block
- Trapping requires NE trending cross fault and fault surface seal on main fault
- Indicative deterministic oil in place for Middle Jurassic sands
- Areal closure: 29 sq. km
- Vertical closure: 98 m
- Net to Gross: 35%
- Porosity: 9%
- Sw: 35%
- Expansion: 1.1

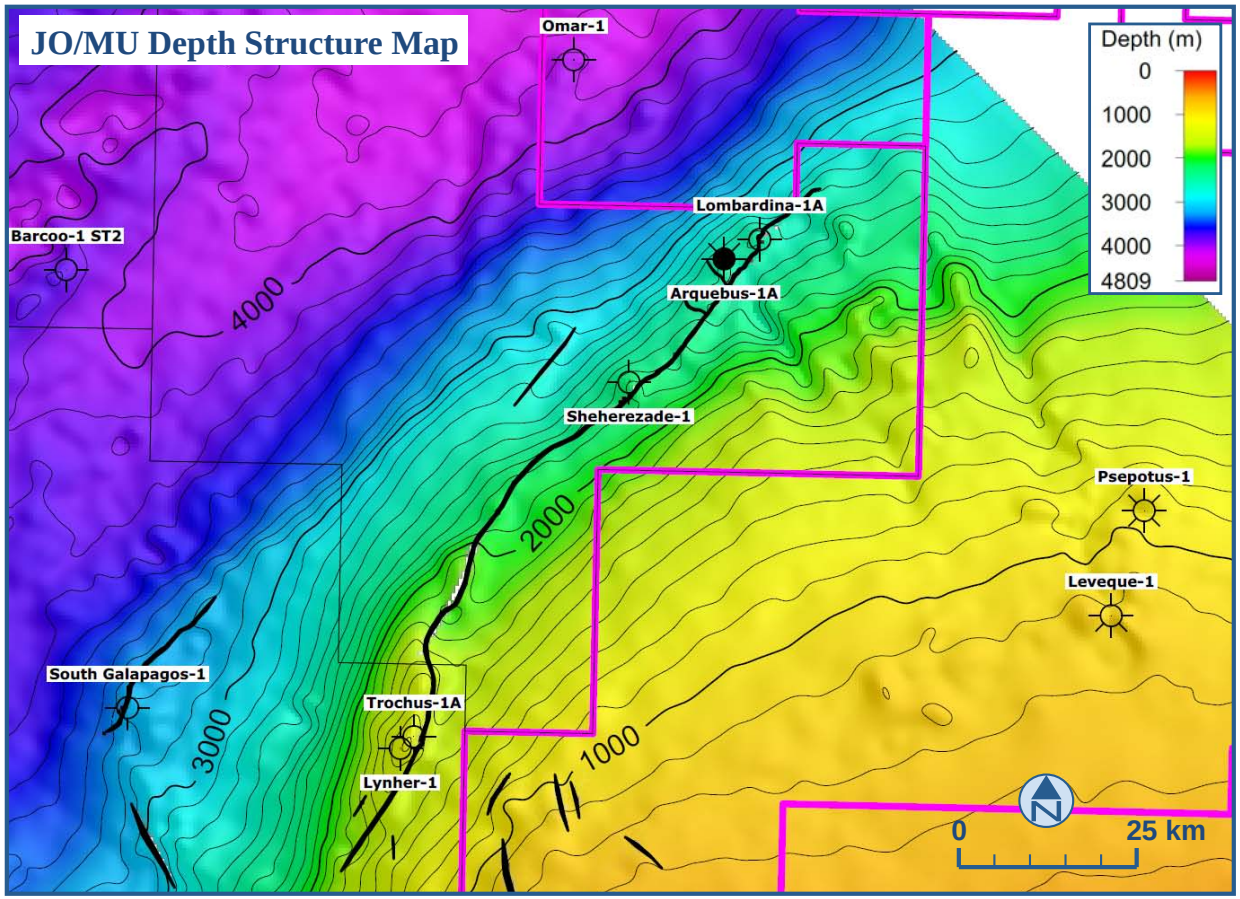
- **OOIP= 200 mmbbls**

Middle and Late Jurassic Organofacies

Athol and Depuch Formations	Waxy Coal Organofacies	Modelled as alternative
Middle Jurassic	3% TOC over 5% of section	
Maximum gross thickness of section: 3,400 m		

Dingo Claystone equivalent	Marine Clastics Organofacies	Modelled as alternative
Kimmeridgian (Late Jurassic)	5% TOC over total 5 m of section	

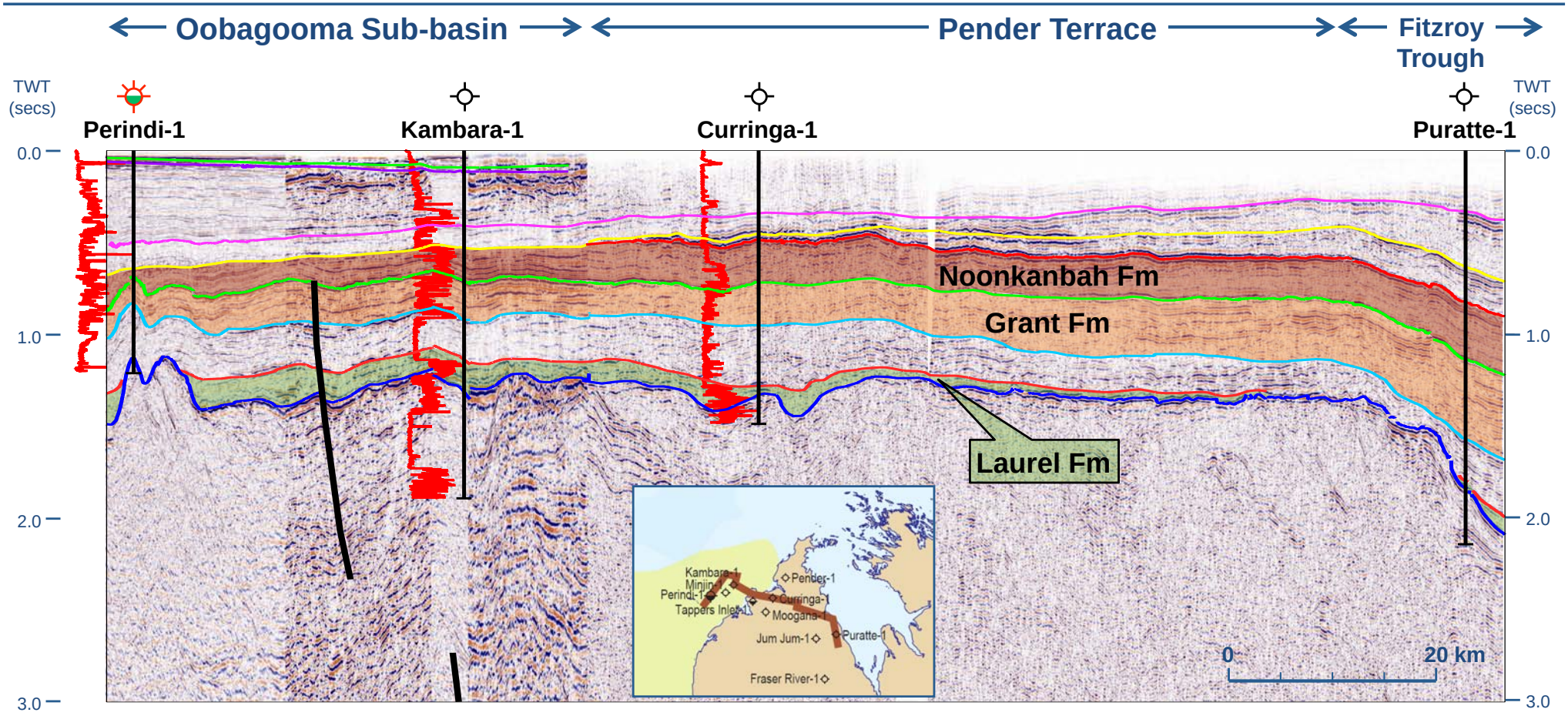
Lynher - Arquebus Inversion Trend and well post-mortems



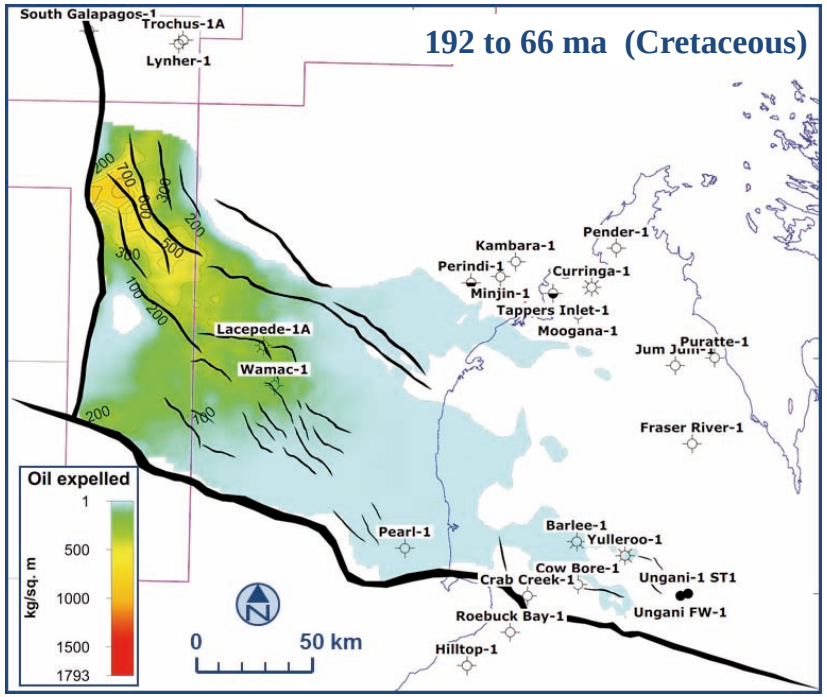
Why are other wells on the Lynher-Arquebus Trend dry?

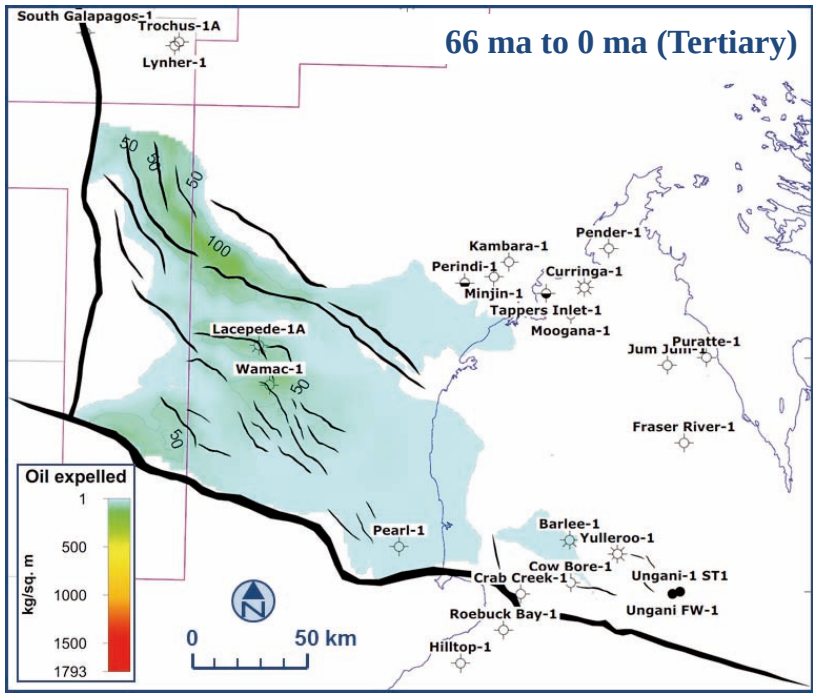
- the main fault at Arquebus dies out within the Cretaceous shales and deformation is taken up by folding
- At Lynher, Trochus and Sheherazade the main fault extends up through the Tertiary and dies out in late Tertiary (non-sealing) sediments
- This may be why Arquebus alone has retained hydrocarbons. The other tests may have failed because of leakage up the reactivated main fault

Extension to Offshore - Puratte to Perindi



Laurel Formation oil expelled during Cretaceous and Tertiary



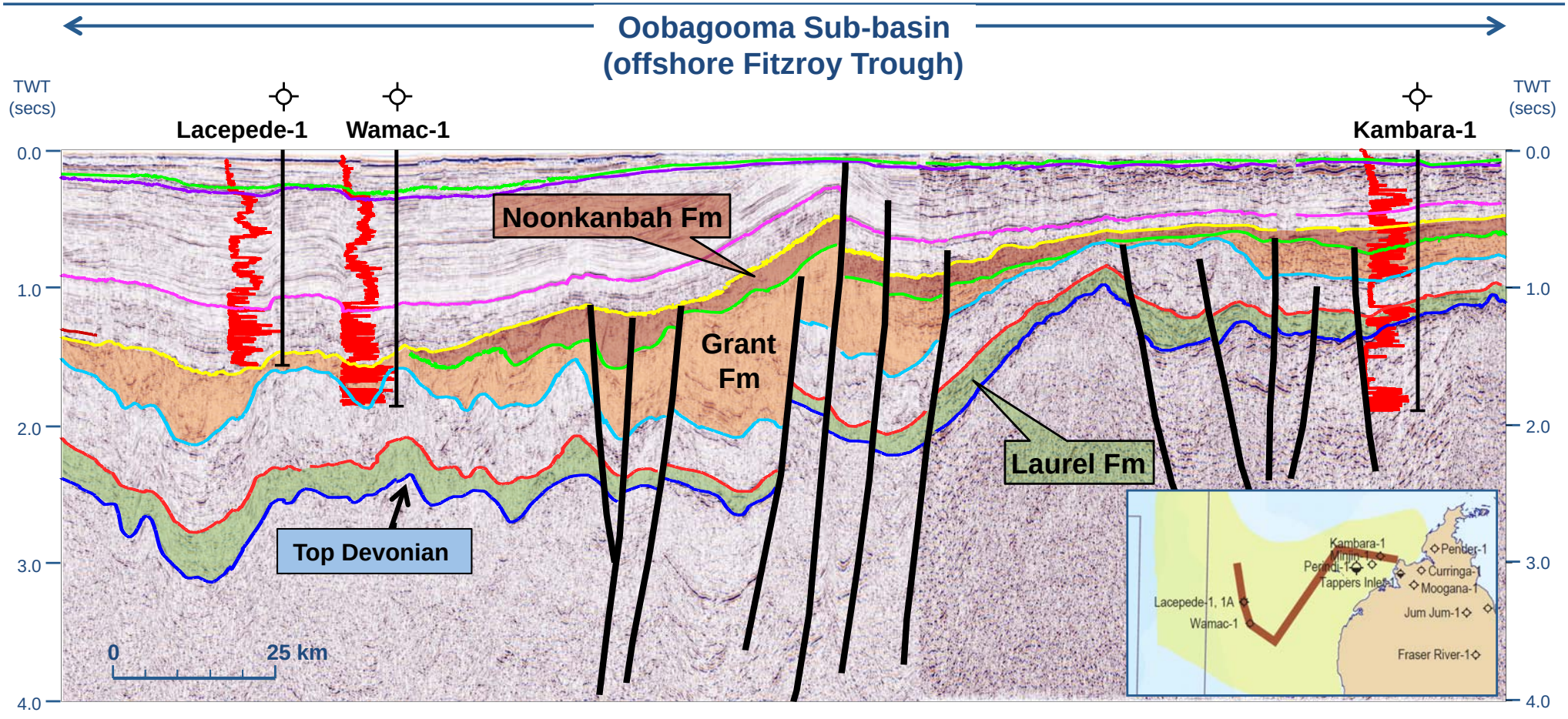


- **Expulsion continues in the W and NW of the Oobagooma Sub-basin during Cretaceous and Tertiary times and continues to the present day**

Structural Timing

- Flattening of 2D seismic lines indicates that structuring on a major inversion structure occurred in more than one stage
- The first phase of inversion occurred prior to the Late Jurassic and most likely corresponds with the Late Permian to Early Triassic Fitzroy Movement
- Further structural growth occurred during the Cretaceous
- Given that expulsion of hydrocarbons is modelled to have occurred prior to and during the Cretaceous and Tertiary and is continuing to the present day makes the timing favourable for entrapment of hydrocarbons
- Other inversion structural leads exist within the Oobagooma Sub-basin

Extension to Offshore - Kambara to Lacepede



Seismic Line through Arquebus-1A