The Northern Australia - Eastern Indonesia- PNG Super Gas Province: Why So Much Gas and So Little Oil?*

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Abstract

The Northern Australia-East Indonesia Super Gas Province of Late Palaeozoic-Mesozoic age, extends from the Northern Carnarvon Basin through the Browse Basin into the Timor Sea (collectively known as the North West Shelf), along the southern edge of the Papua-PNG obduction zone into the Coral Sea.

Numerous LNG projects along the North West Shelf (North Rankin, Wheatstone, Gorgon, Ichthys, Bayu-Undan) or in West Papua (Wiriager), and PNG, indicate the overwhelming gas-prone nature of Late Palaeozoic-Mesozoic petroleum systems along the former Northern Australian continental margin. Some 80% of all hydrocarbons discovered to date in this region comprise gas. This presentation explores the reasons why this should be the case and identifies where sweet spots exist for finding oil as well as gas.

The distribution of oil- vs. gas-prone source rocks is controlled by successive Late Palaeozoic-Mesozoic passive margin extension, listric ramp-flat detachments, rifting and breakup, overprinted by 2nd and 3rd order global eustatic cycles of the northern Australian margin and its tectonic interaction and obduction during the Cenozoic with the West Papua-PNG foldbelt. Inherent within these tectono-eustatic cycles occur two major source rock types: Organofacies B (algal marine) and D/E (mixed terrestrial/algal)

Oil-prone Organofacies B with original TOC's and HI's of over 6% and 600 HI, respectively, only occur in localised Oxfordian-Kimmeridgian rhomboid syn-rifts, separated by incipient fracture zone, such as the Dampier, Vulcan and PNG foreland basins. Conversely, Organofacies D/E exhibit TOC and HI ranges of 2% and 300, respectively, and are much more widespread. These occur in lower delta-plain coals throughout the pre-, syn- and post-rift, accommodated by pronounced extension during the Late Permian-Triassic along basal detachments, depositing thick Upper Permo-Triassic to Jurassic fluvio-deltaic sediments with stacked coaly facies.

Two hundred TCF of in-place gas has been found along the entire Northern Australian margin from the Northern Carnarvon Basin through West Papua to PNG. Yet-to-find fractal analysis suggests that substantial gas resources remain to be discovered, some of which will be

reservoired in multi-TCF accumulations, offering considerable exploration incentives. Future oil discoveries will tend to be modest, being limited to existing rhomboid syn-rift basins, such as the Dampier and Vulcan sub-basins, or the obducted basins of the West Papua-PNG fold belt.

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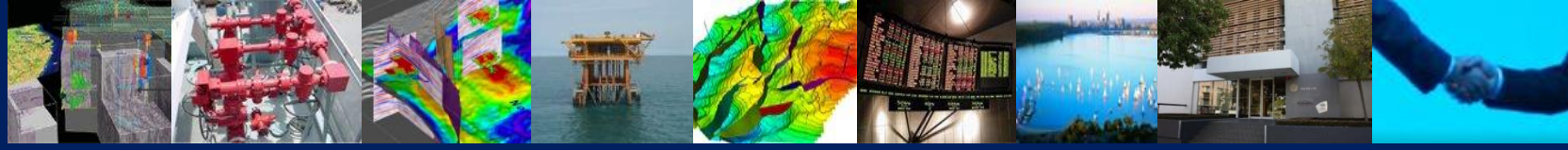

The
Northern Australia – Eastern Indonesia – PNG Super Gas Province

Why So Much Gas and So Little Oil?

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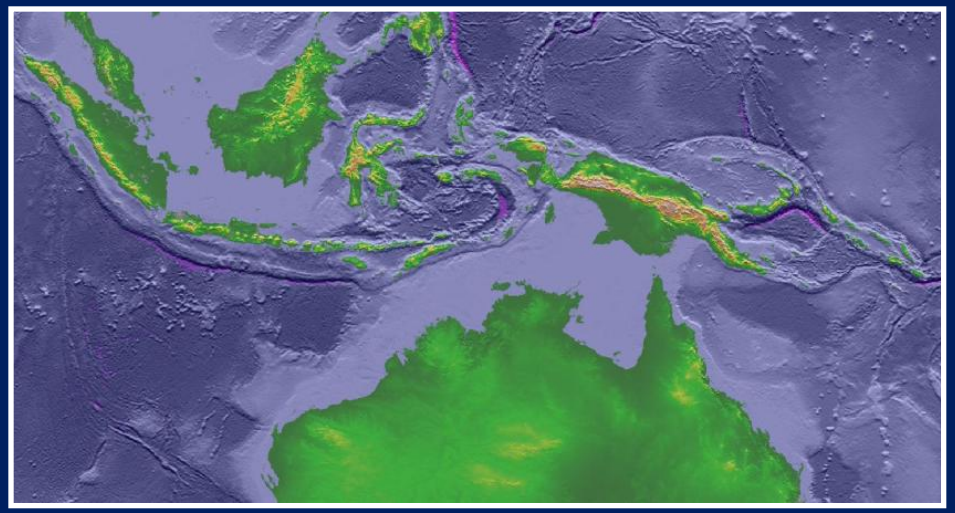
18th September 2012

Acknowledgements

This presentation is a working summary of the petroleum potential of the N. Australian margin including New Guinea

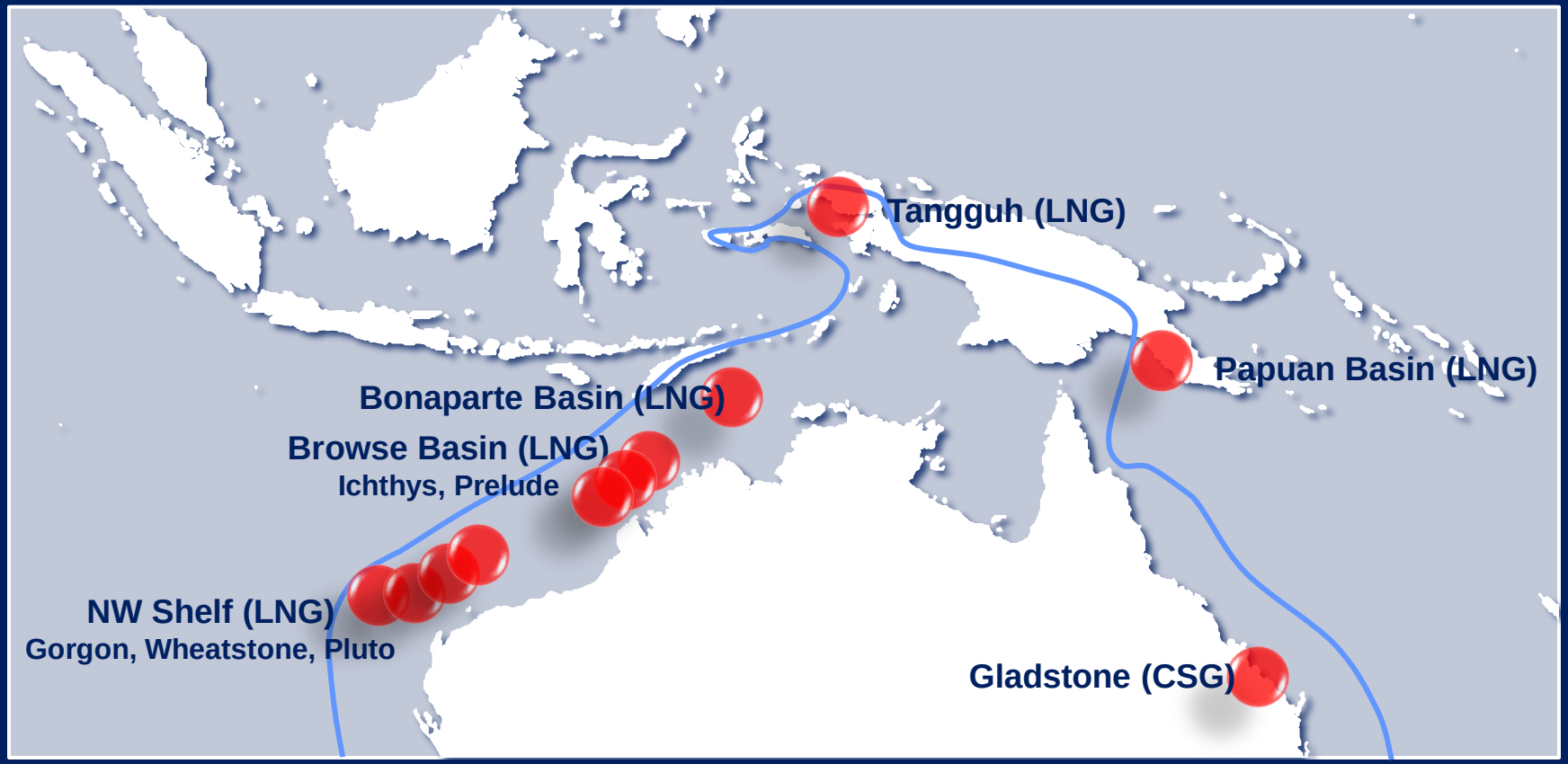
It is dynamic snapshot in time

We have drawn on following key published work:



- **NW Shelf Australia Petroleum Systems:** Longley et al. (Woodside 2002)
- **N Australia Oil Families:** Bradshaw, Summons, Edwards & Kennard (GA 1997)
- **West Papua Petroleum Systems:** Satyana et al. (BPMigas 2003, 2009)
- **PNG Tectonics & Petroleum Systems:** Hill et al.(Oil Search 2004-2011)
- **Australia v SE Plate Tectonics** Hall et al. (RHUL 2000-2012)
- **Timor Sea, Browse & N Carnarvon Basins:** ISIS non-exclusive reports

Northern Australia Margin
Current and Future Gas Project Areas

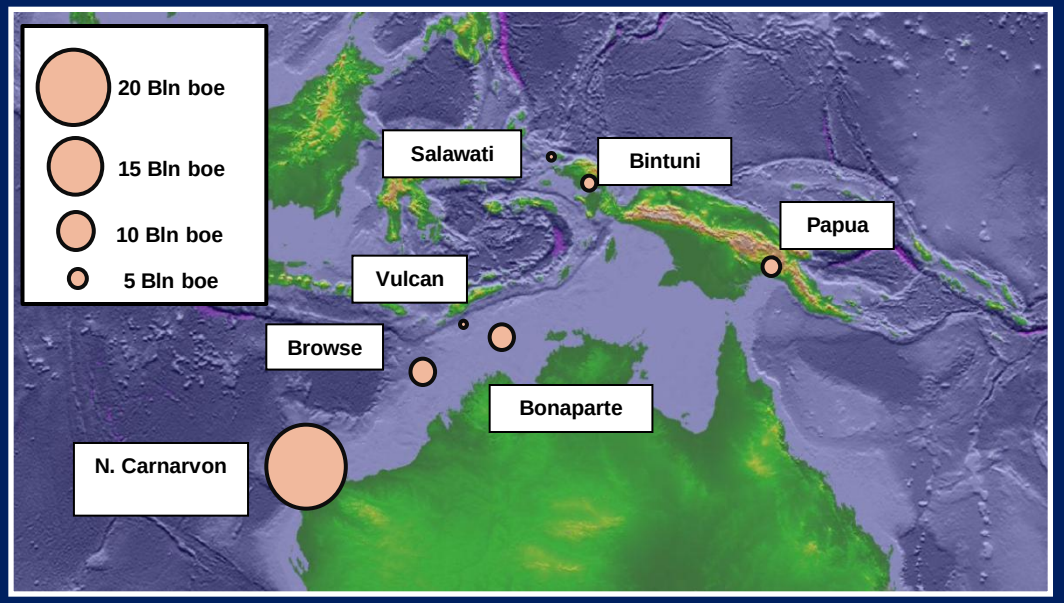


- 11 LNG Projects under construction or planned
- US$220 billion investment
- By 2020 Australia will be No 1 LNG producer worldwide
- LNG exports to double to 360 MMTpa by 2035

Predominance of Gas

Late Permian Gondwana & Mesozoic Westralian Super System (Geoscience Australia 1996)

- 7 key basins (12 total)
- At least 375 Oil & Gas Fields
- >270 tcf gas
- >8.2 billion bbl Oil & Cond
- Total: >46 Billion boe



- **22 Giant Gas Fields (>3 TCF rec)**
  - 17 in Australia, 3 in West Papua, & 2 in PNG
- **1 Giant Oil Field (>500 Million Bbls rec)**
  - 1 in West Papua

Relative mix is 80% gas vs 20% oil

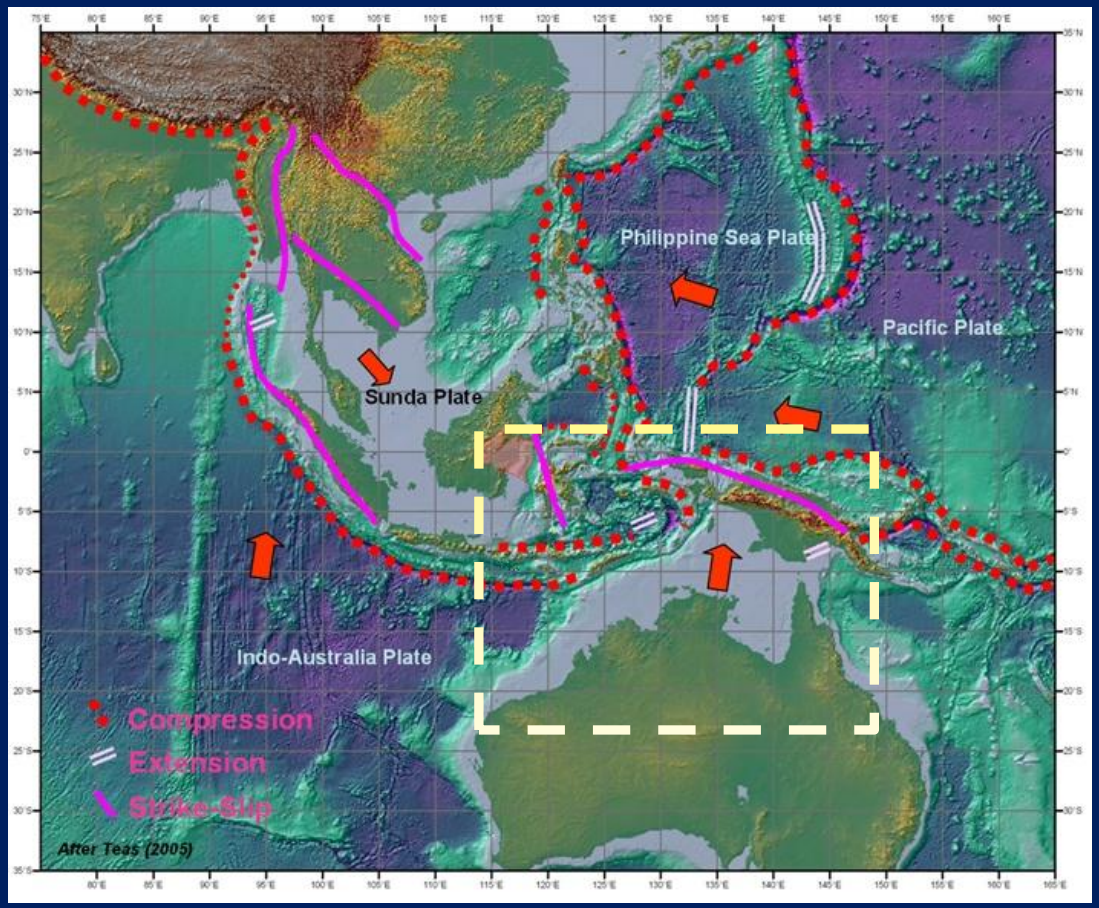
Notes:

1. *Primary source Australian state DPE's*
2. *Reserve estimates are recoverable*
3. *P50 values quoted*

What Are The Key Oil vs Gas Drivers?

1. **Plate Tectonics:**
   - Crustal Architecture Foundation
2. **Petroleum Systems:**
   - Organic Matter Type
3. **Eustasy:**
   - 2nd Order Transgressive – Regressive Cycles
4. **Trap Styles:**
   - Extensional vs Compressional History

1.1 Plate Tectonic Drivers: Gondwanaland vs SE Asia



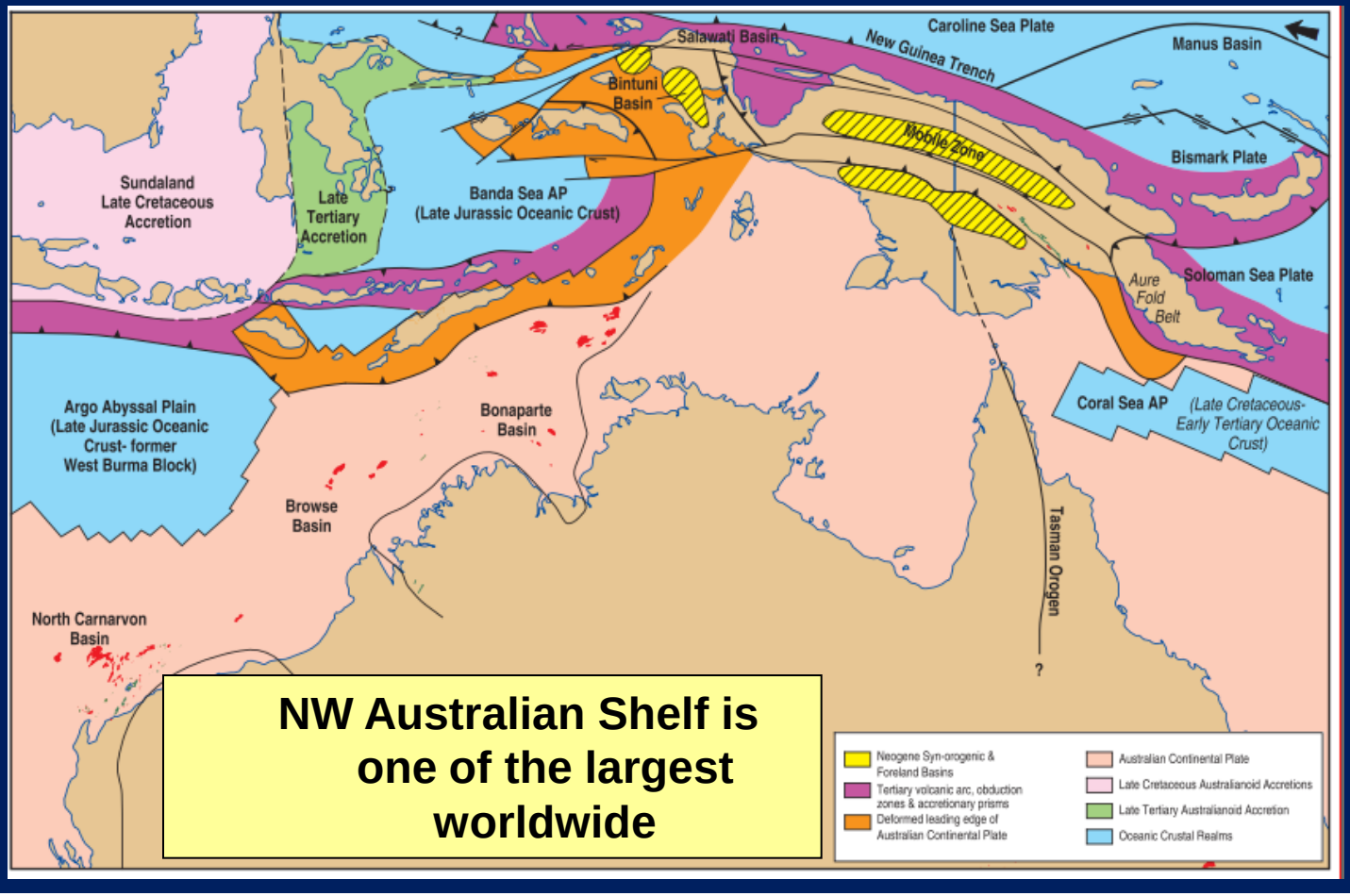
From Teas (2005)

Gondwanaland breakup interaction with SE Asia island arc systems

Interplay of 3 Main Vectors:

- **Northward subducting Indo-Australian plate.**
- **Westward subducting Pacific/Philippines plate.**
- **Southeasterly extruding Sunda plate**

1.2 Plate Tectonic Drivers: Present Day Plate Tectonic Terrains



Resultant plate tectonic controls on petroleum provinces:

- **Extensional terrains: Syn-rift rhomboids/post-rift sag, i.e., NW Shelf: Exmouth-Timor Sea**
- **Compressional terrains: Post-rift inversion: Papua Mobile Belt**
- **Wrench terrains: Syn-orogenic collapse: Salawati Basin**

1.3 Plate Tectonics Setting: Indicative Current Reserves

Basin	North Carnarvon	Browse	Vulcan	Bonaparte	Papua	Bintuni	Salawati
Basin Setting	Passive margin extension: syn-rift				Post-rift orogenic belt: syn-rift inversion		Syn-orogenic collapse basin
Reserves (Bln boe) Rec)	22.2	7.5	0.7	6.7	4.8	3.7	0.8

<u>Australian Passive Margin Extension</u>

- Long-lived Permian – Mesozoic subsidence history
- Relatively stable, large extensive shelf
- Tertiary sediment offlap loading

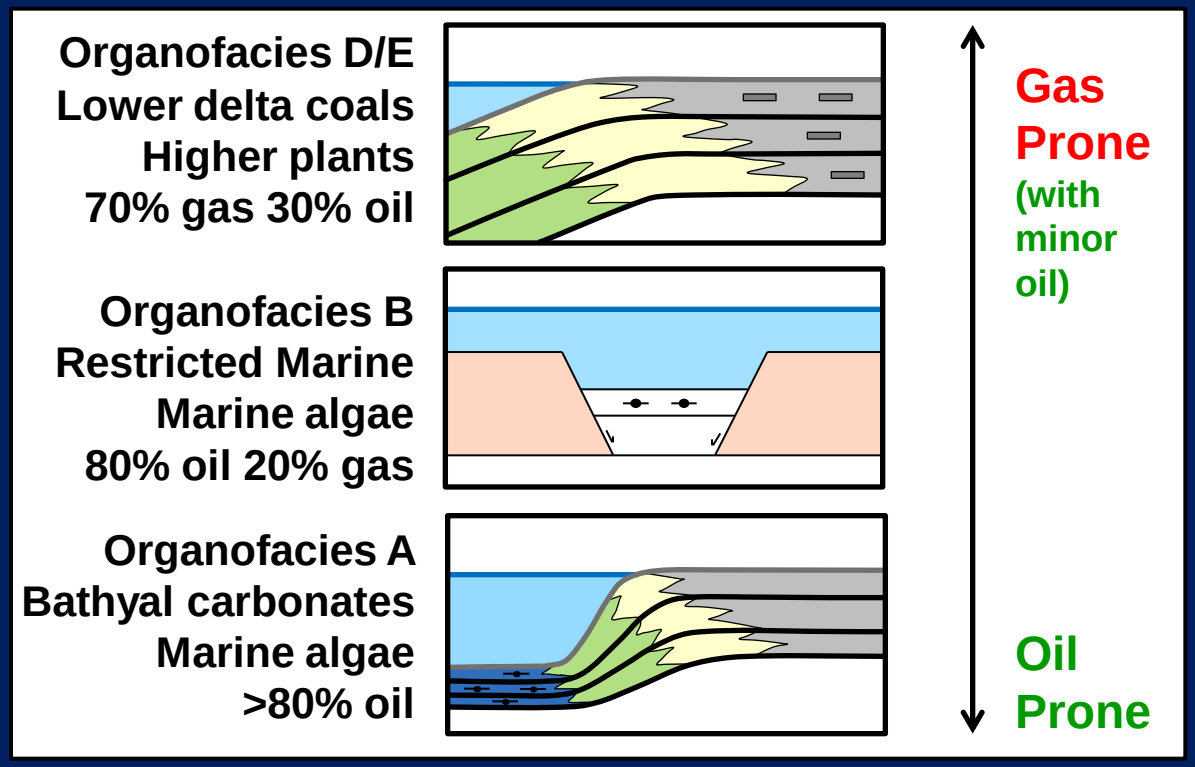
<u>Australian – New Guinea</u>

- Initial long-lived stable pre-Tertiary history
- Unstable, massive shortening in Tertiary
- Fold belt loading

Late Tertiary loading in both areas: increased maturity – gas window.

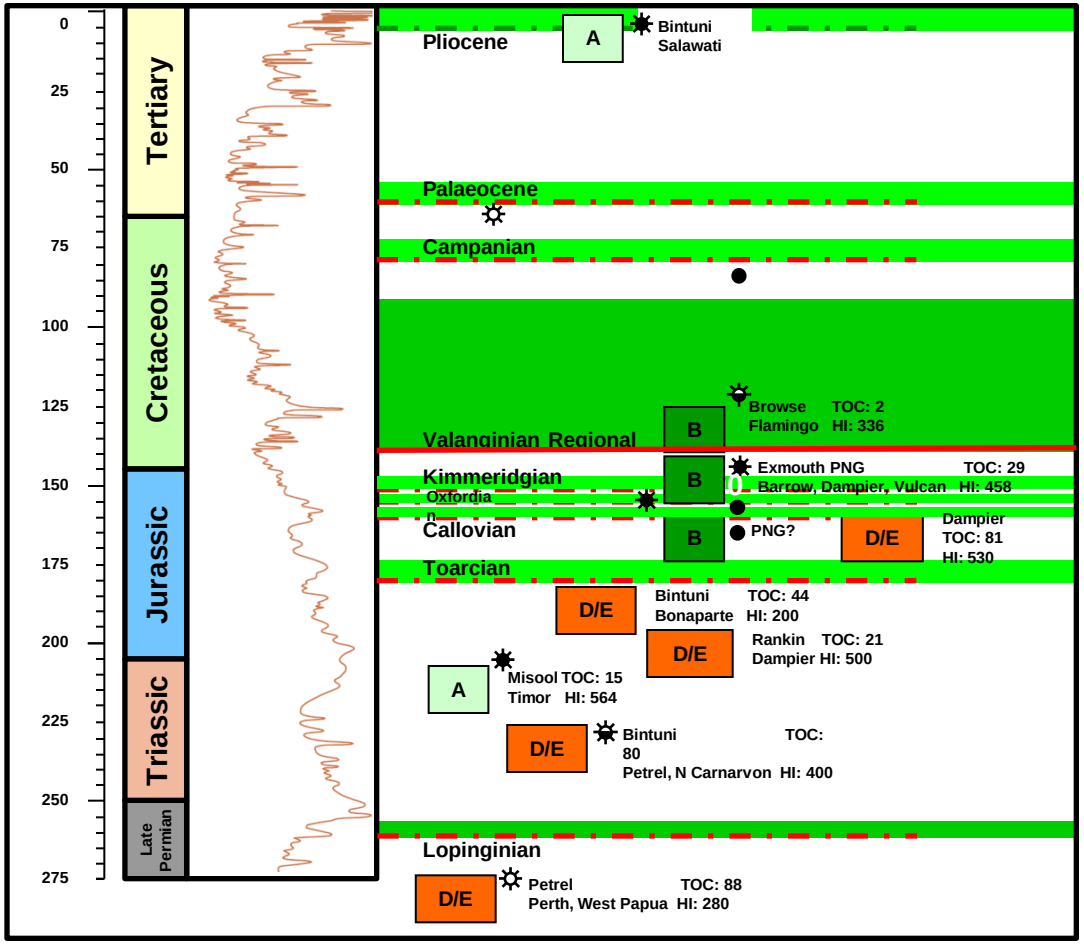
2.1 Petroleum Systems Drivers: Organic Matter Type

3 main types of organofacies (Pepper & Corvi 1995) indicated within the Northern Australian Late Gondwana & Westralian systems



Limited abundance of oil-prone macerals along N Australian Margin is key factor relating to predominance of gas

2.2 Petroleum Systems Drivers
Source Rock Packaging



Key source rock qualities:

A: TOC: 15
HI: 554

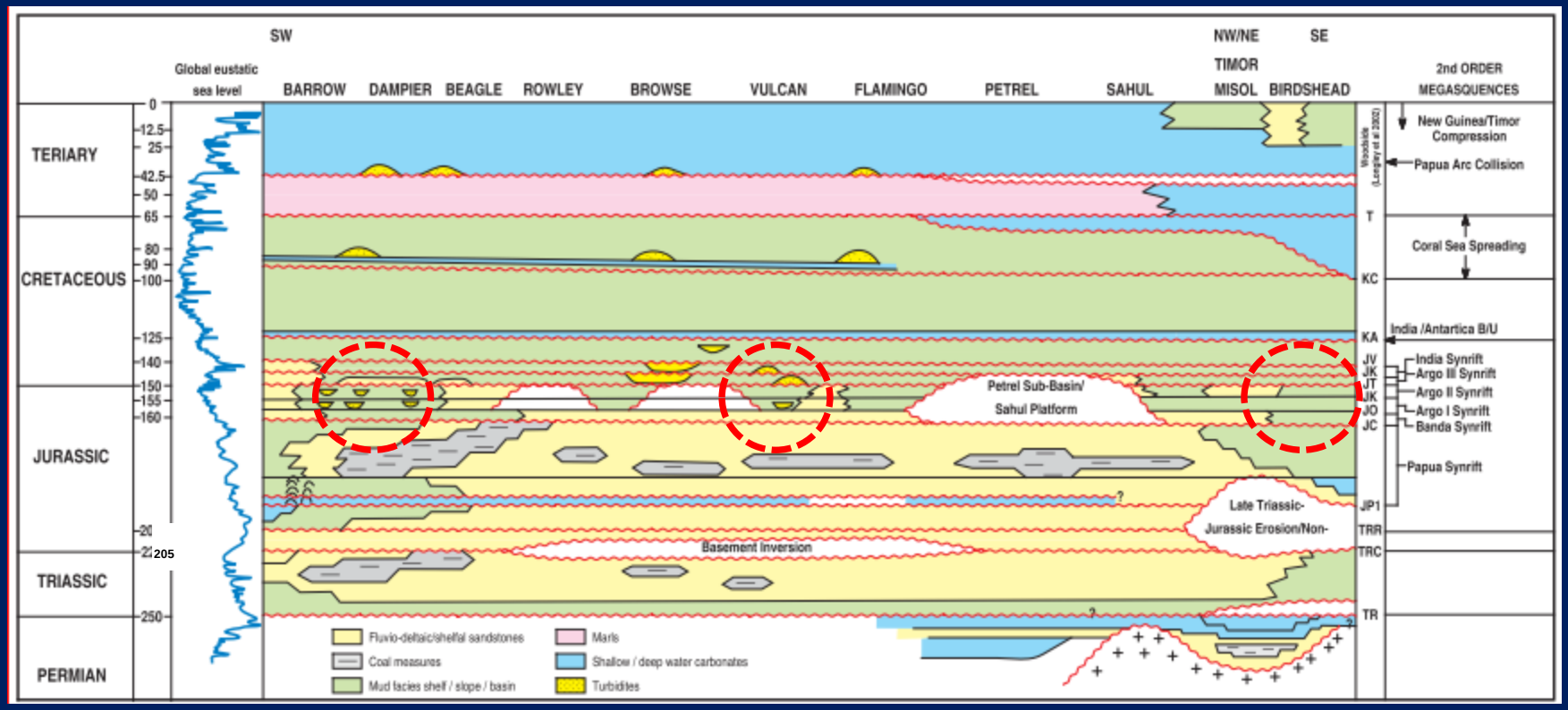
B: TOC: 21-88
HI:280-530

D/E: TOC: 2-29
HI:336-458

Main influence on source pods / types is tectonic controls on EOD

Key source rock sequences occur in pre- and syn-rift 2

3. Eustasy Drivers Chronostratigraphy



NWS

Post-Rift 2

Syn 2

Pre-Rift 2

Post –rift 1

Impact of 2nd order cycles on source and reservoir distribution

- **Widespread Triassic to Mid-Jurassic deltas/paralics:**
  - Source (D/E) coals and Reservoir
- **Localised Late Jurassic syn-rift oil source pods**
- **90-95% of accumulations beneath Valanginian regional seal**
  - Challenge to find reserves up and down section

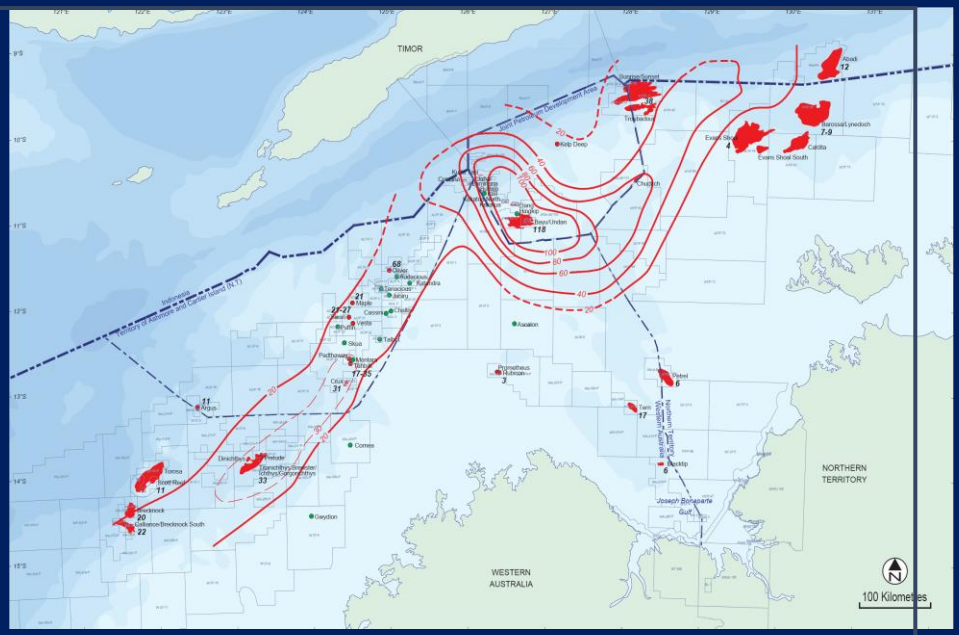
Adapted from Longley (2002)

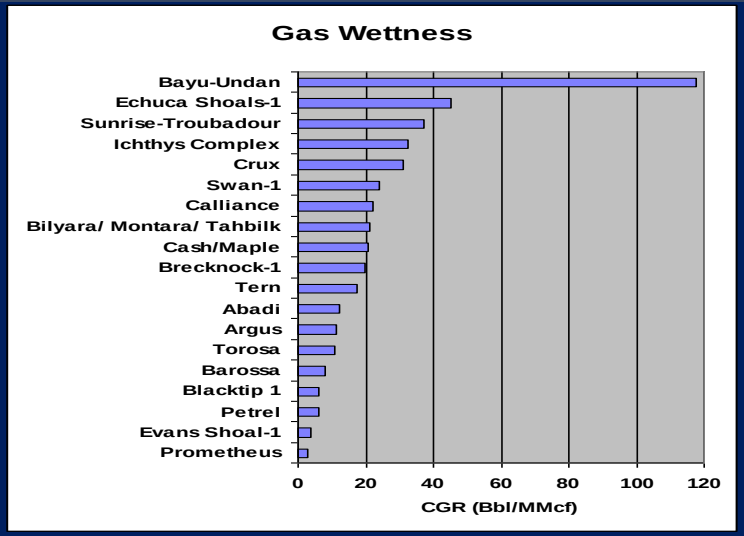
3.1 Petroleum Systems Drivers
Gas Condensate Ratios & Phase

Despite magnitude of gas presence, high GCR in places

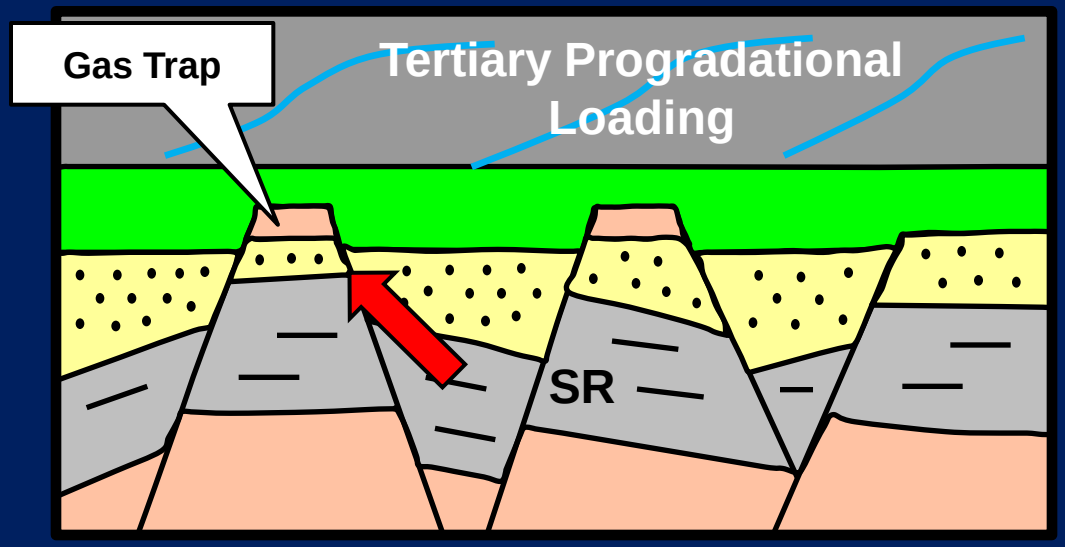
GCR Modifiers:

- Facies distribution
- Maturation, Phase, Rate of Burial & Expulsion Efficiency:
  - Rapid subsidence = early expulsion of gas & condensate in same phase
- Levels of TOC:
  - Lean Organofacies "B" SR will not expel oil but remain in situ, cracking to gas
- High levels of GOR improves economics
  - Fast track production at Bayu (CCR >100 bbls/MMcf)

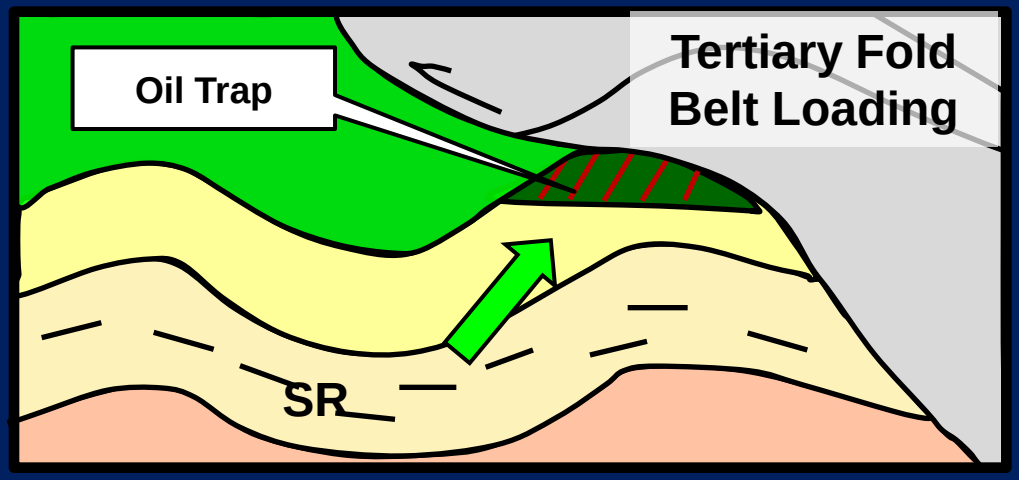




4.1 Extensional vs Compressional Regimes GCR Drivers



- Passive Margin Block Faulting
- Slow loading: late gas phase only

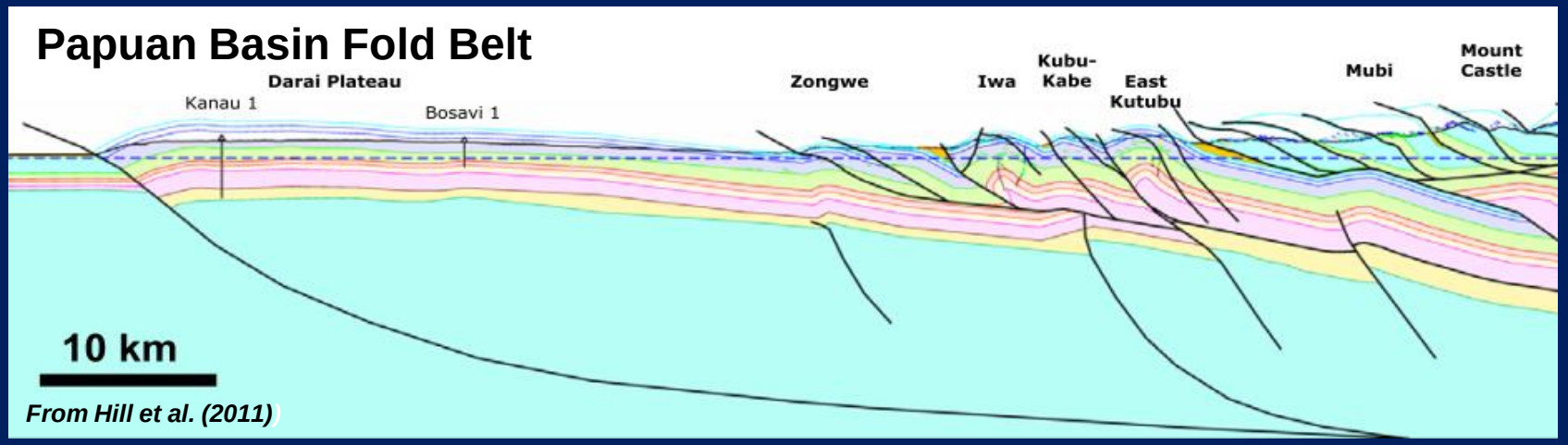


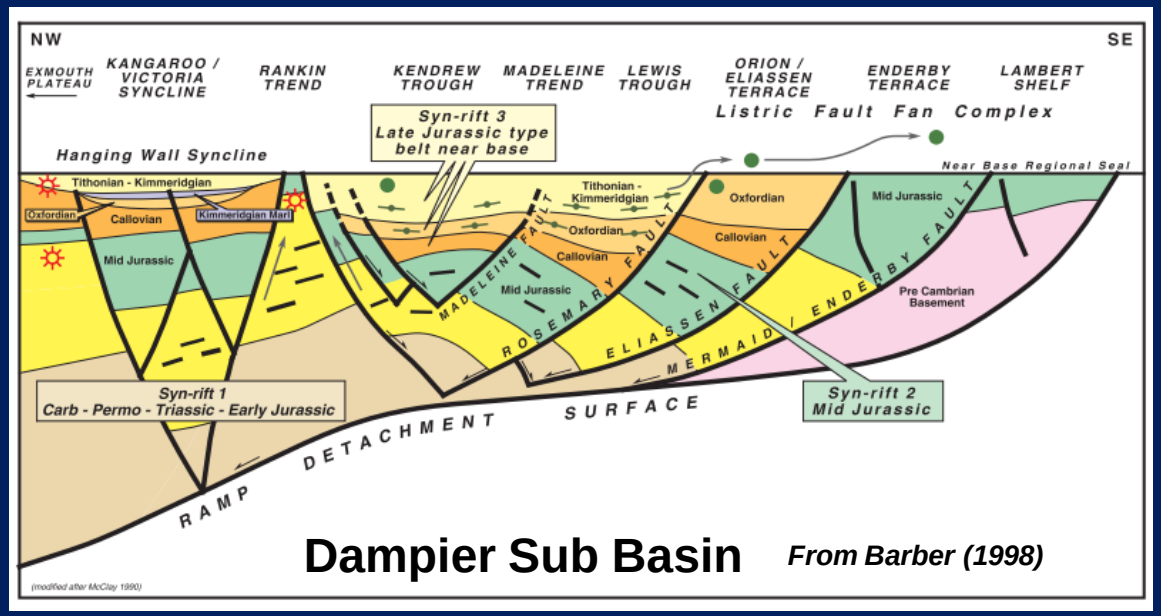
- Inversion & compressional folds (thin & thick skinned):
- Rapid loading: Liquids & gas expulsion same phase

Fast Tertiary Burial = higher P/T increase & fracturing = same phase Gas Condensate

4. Trap Style Drivers: Emerging Plays

Extensional & Compressional Regimes



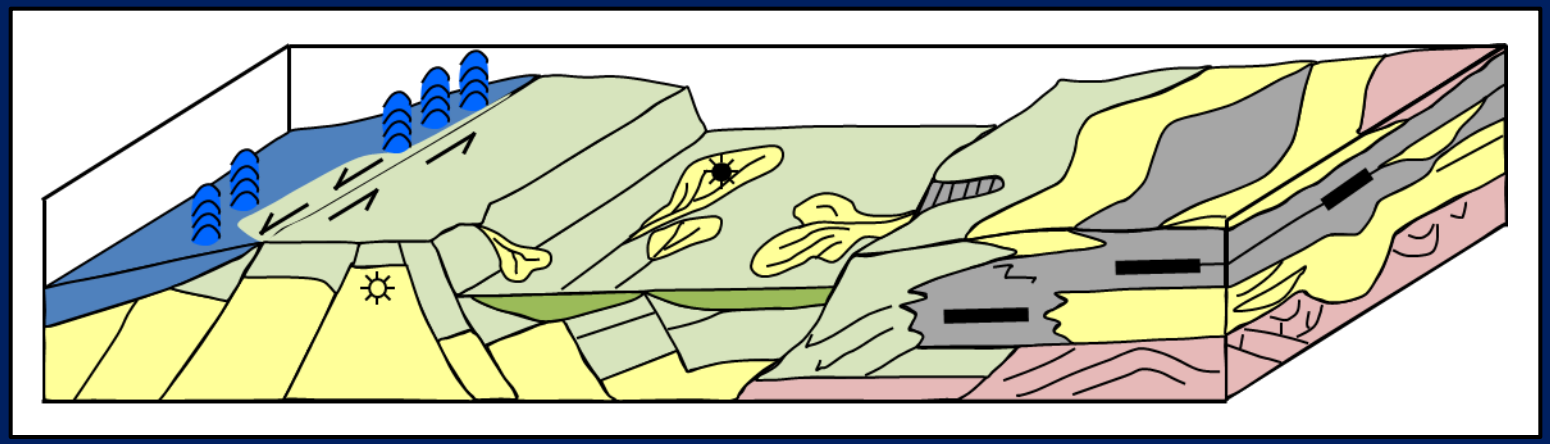


PNG Fold Belt emerging plays: Basal inversion detachment footwall traps: Mid/Upper Jurassic sands

Dampier Basin emerging plays

- Base Oxf & Kimm LST BFF beneath local seal
- *M australis* BTS within regional seal on peri-rift

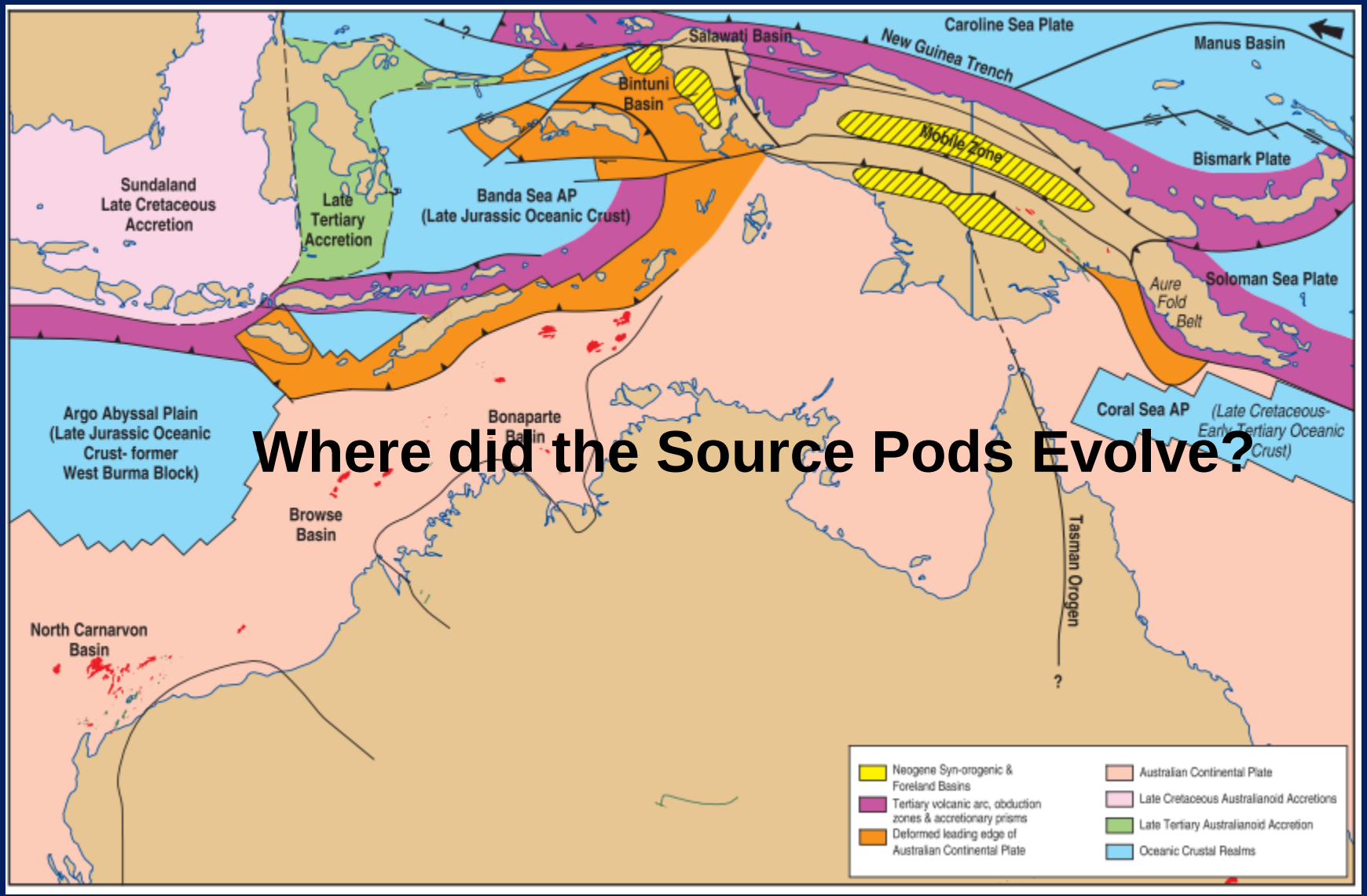
Overall Syn-Rift Petroleum Systems Model



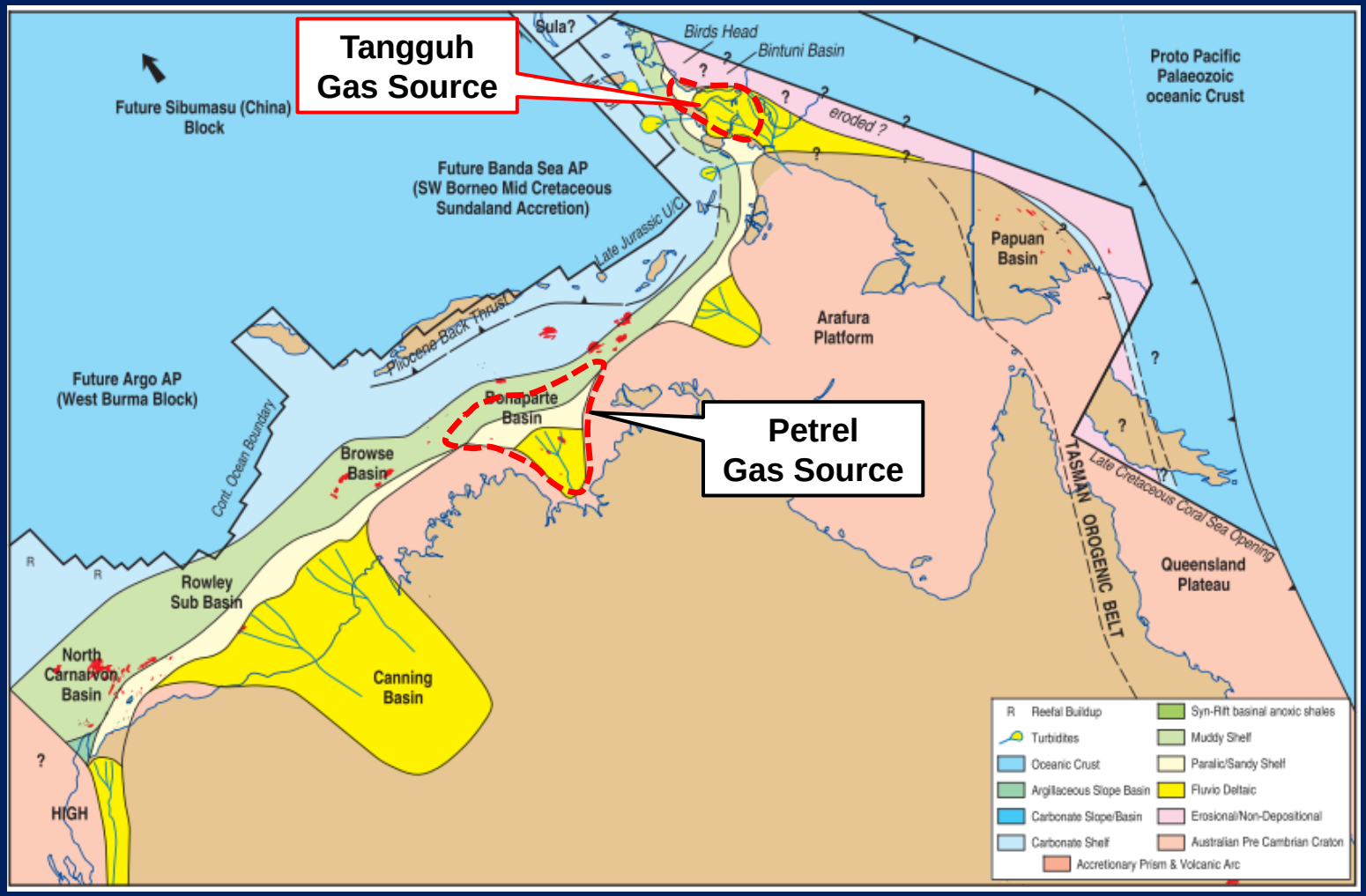
Source rocks:
1. Lower Mid Jurassic coals (Type D/E)
2. Upper Jurassic syn-rift restricted marine (Type B)
3. Triassic pre-rift deep carbonate (Type A)

Reservoirs:
1. Mid Jurassic paralics
2. Triassic paralics horst block
3. Up Jurassic axial turbidites, shelfal Cretaceous sands
4. Mid Jurassic carbonate buildups

In PNG compressional regimes, listric faults are loci for inversions


Where did the Source Pods Evolve?
Caroline Sea Plate
Salawati Basin
New Guinea Trench
Manus Basin
Bintuni Basin
Mobile Zone
Bismark Plate
Sundaland Late Cretaceous Accretion
Late Tertiary Accretion
Banda Sea AP (Late Jurassic Oceanic Crust)
Aure Fold Belt
Soloman Sea Plate
Coral Sea AP
(Late Cretaceous-Early Tertiary Oceanic Crust)
Argo Abyssal Plain (Late Jurassic Oceanic Crust- former West Burma Block)
Bonaparte Basin
Browse Basin
Tasman Orogen
North Carnarvon Basin
Neogene Syn-orogenic & Foreland Basins
Tertiary volcanic arc, obduction zones & accretionary prisms
Deformed leading edge of Australian Continental Plate
Australian Continental Plate
Late Cretaceous Australianoid Accretions
Late Tertiary Australianoid Accretion
Oceanic Crustal Realms

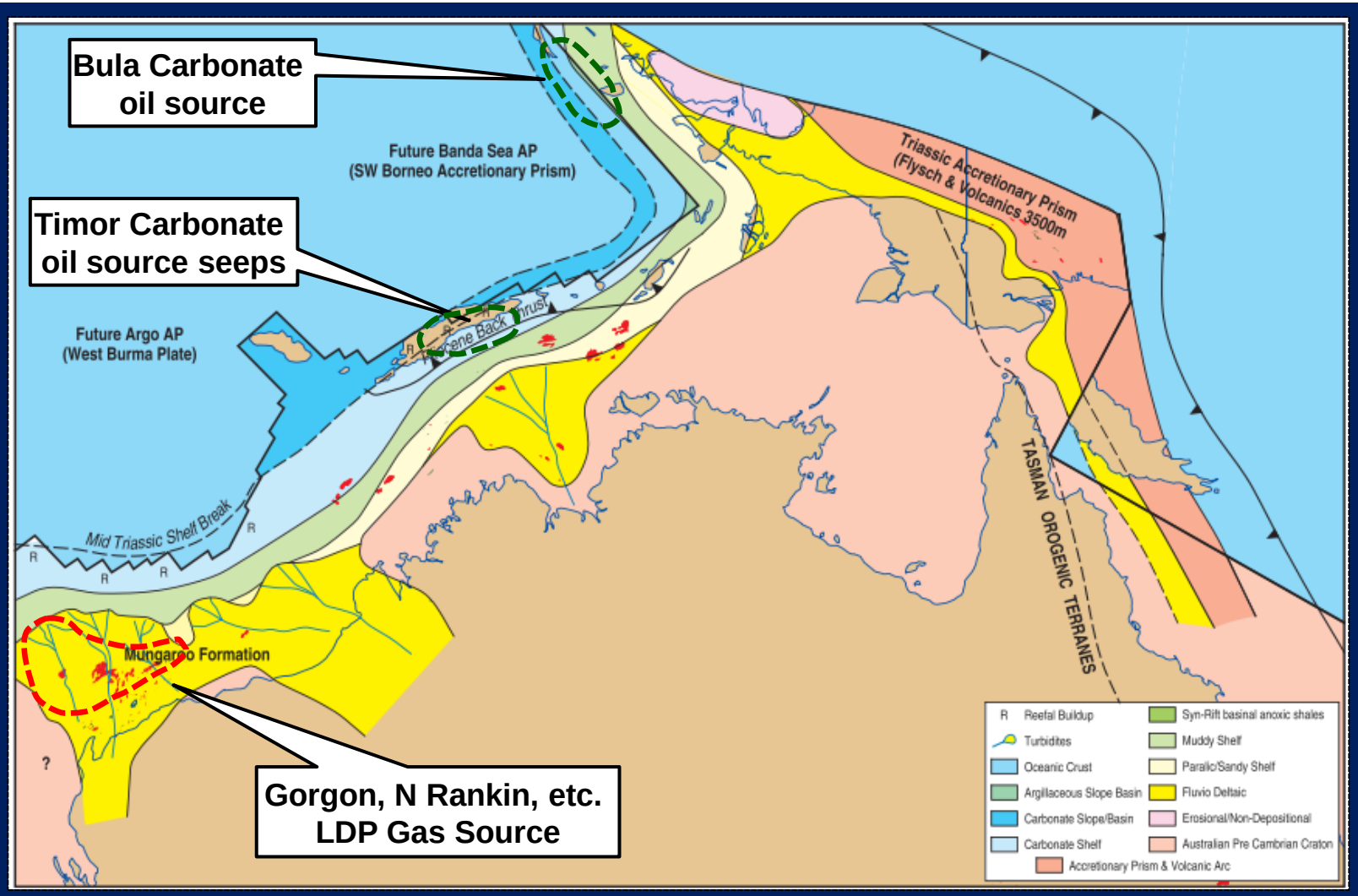
Late Permian (225-250 Ma) EOD & Petroleum Systems



Major crustal extension during Permian: Sibumasu breakup:

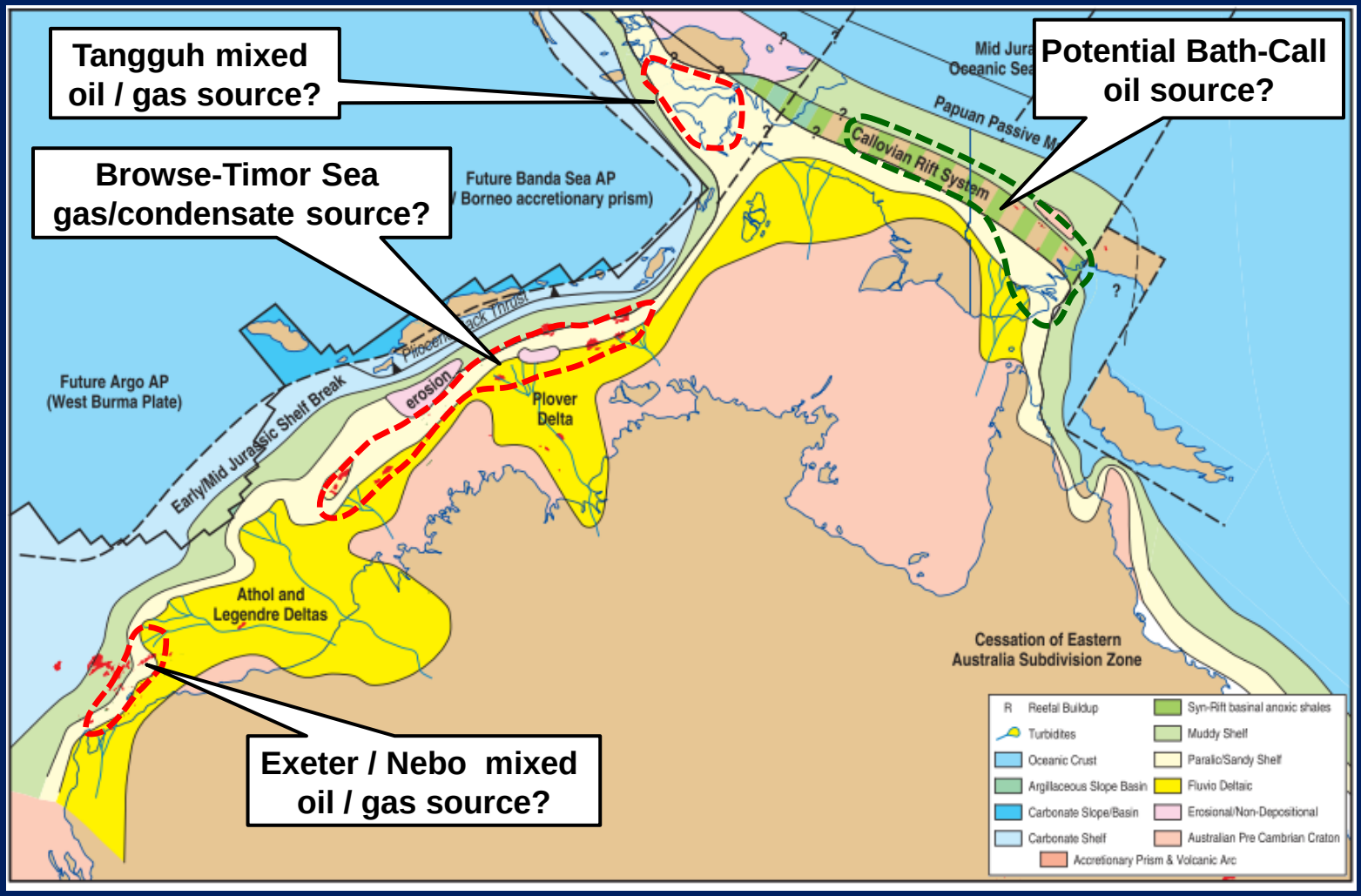
Extensive lower delta plain (“LDP”) coal source: Tangguh & Petrel Fields

Mid Triassic (205-250Ma) EOD & Petroleum Systems



- Continuing post-Sibumasu breakup subsidence & crustal extension
- Massive LDP coal source: Gorgon, Io Janz: N Carnarvon Gas Fields
- Bathyal carbonate source: Bula Field: Seram/Misool & Timor seeps

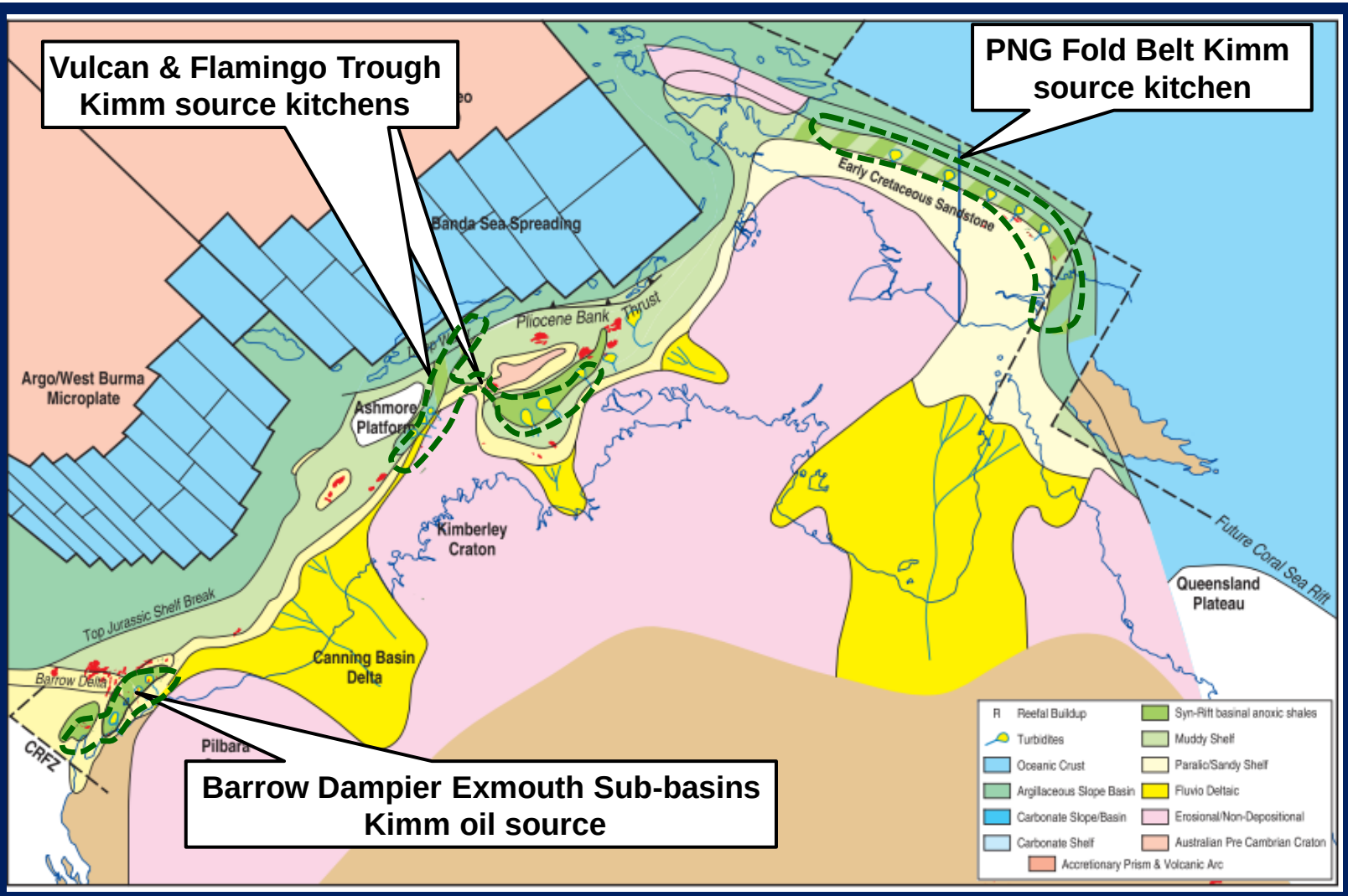
Early – Mid Jurassic (160-205Ma) EOD & Petroleum Systems



NW margin: subsidence / accommodation: extensive LDP coals

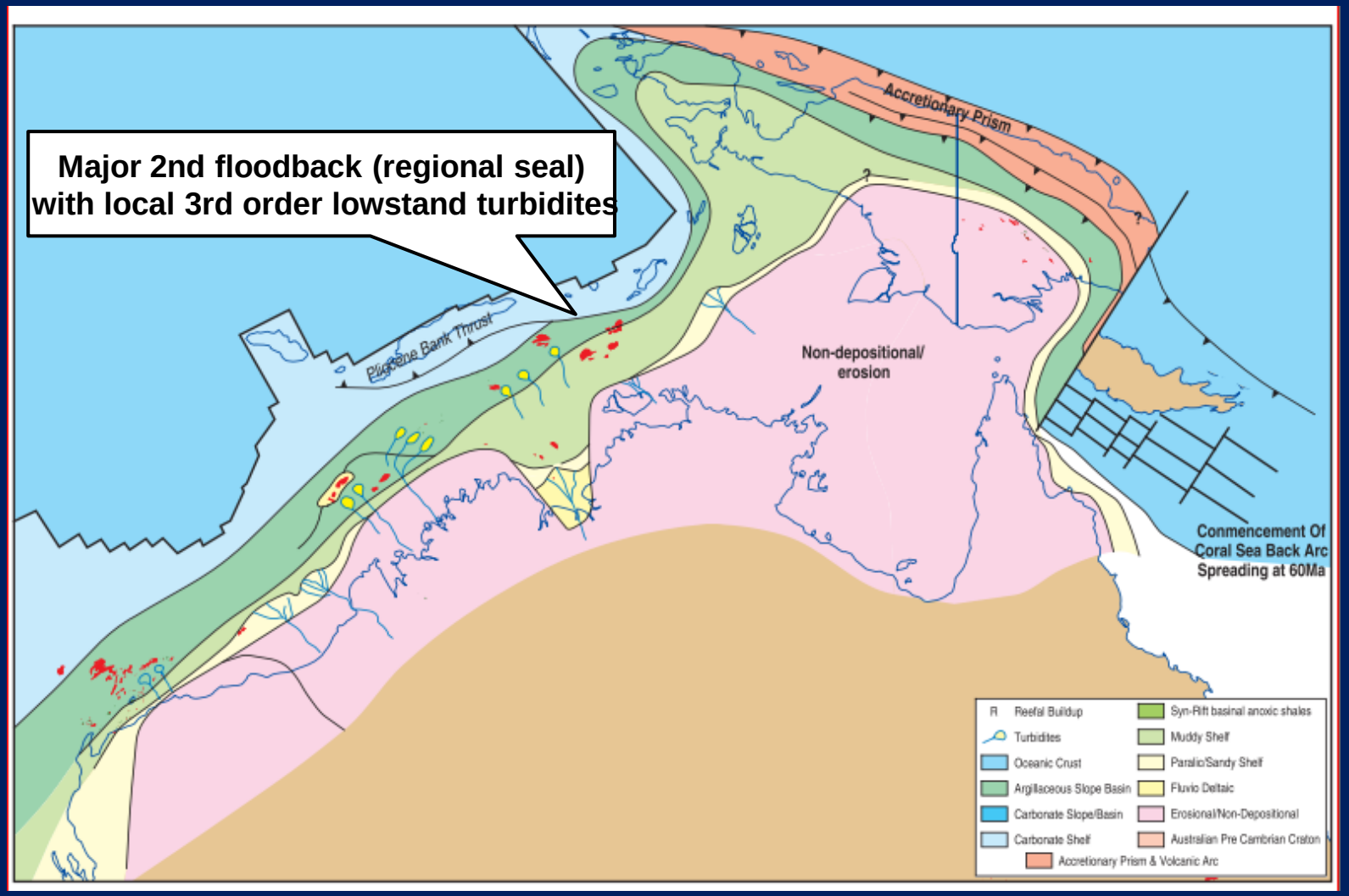
Cessation Tasman terrains - initial passive margin/syn-rift? in New Guinea

Late Jurassic-Early Cretaceous (140-160 Ma) EOD & Petroleum Systems



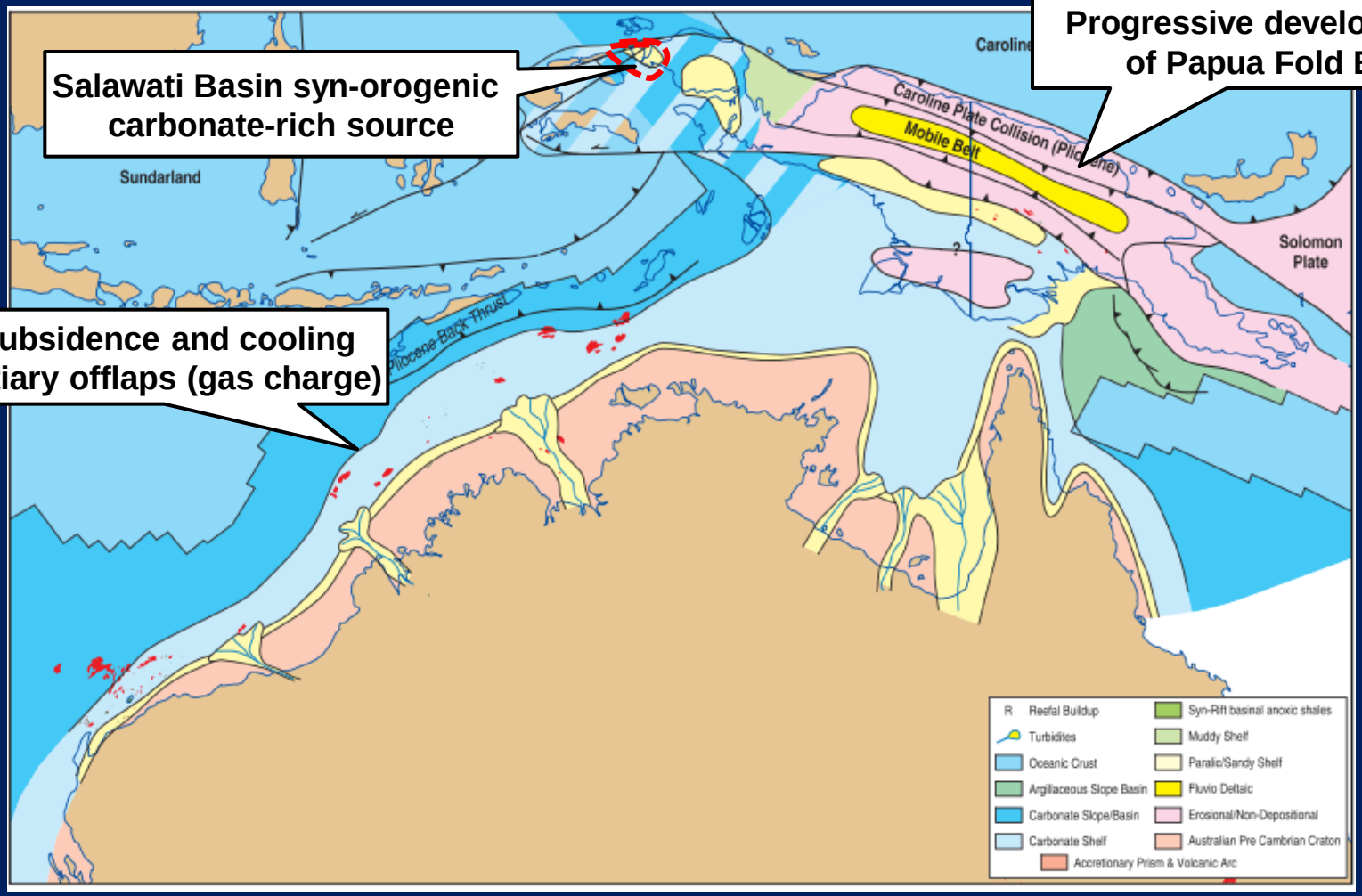
NW margin: progressive Ju-Kl syn-rift & breakup:
Local restricted marine rifts: oil-prone source pods (D swanese Kimmeridgian)
Possible local Kl source: Bayu Gas Condensate Field

Late Cretaceous (65 – 140 Ma) EOD & Petroleum Systems



Post-rift passive margin cooling and major floodback towards craton (Late Cretaceous 2nd order regional seal: ~95% all accumulations)

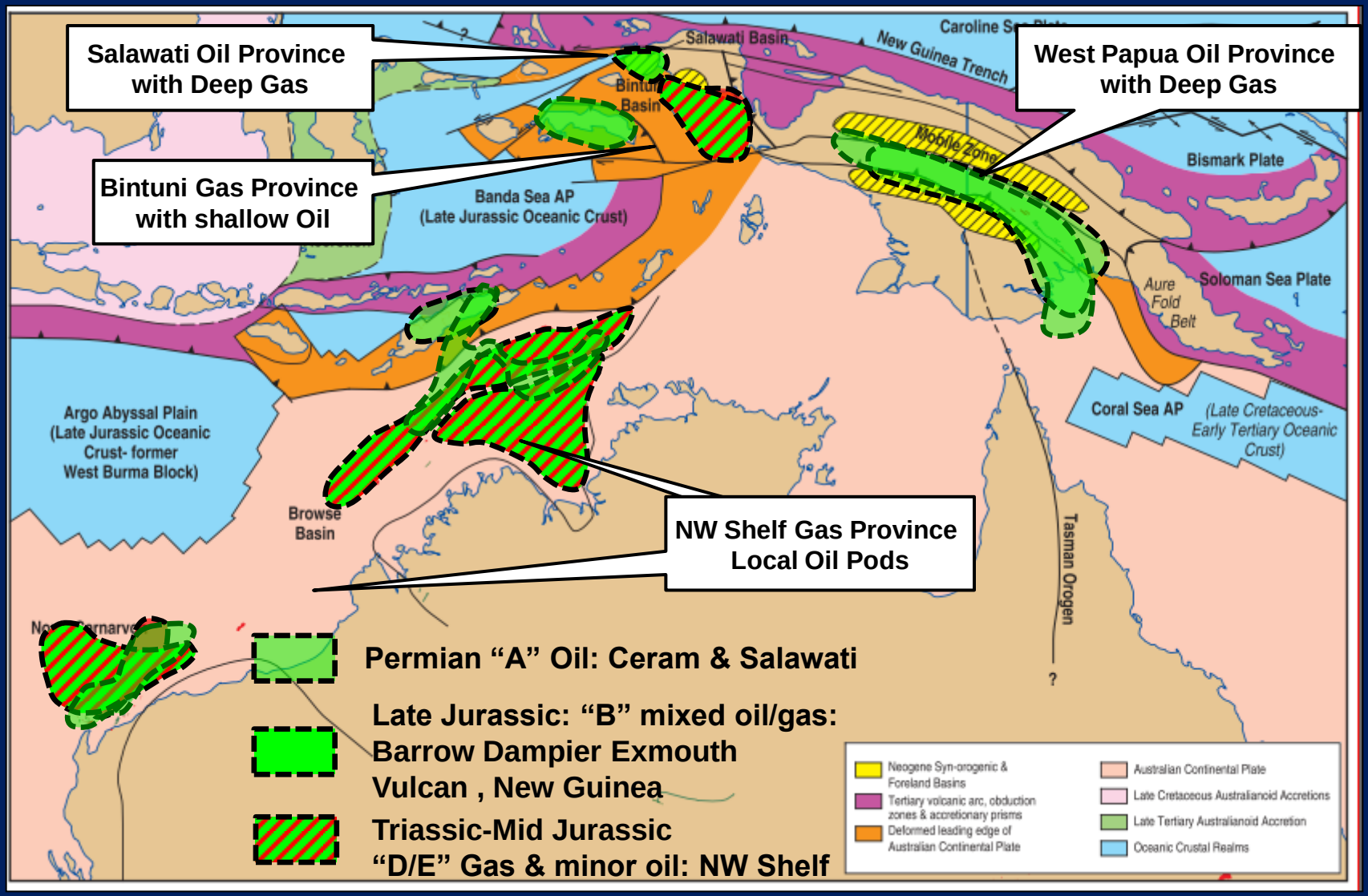
Late Cenozoic: Miocene (0-25.5 Ma) EOD & Petroleum Systems



NW Shelf: continued cooling / subsidence and Tertiary carbonate progrades

New Guinea fold belt: 1. Early thick-skinned inversion & 2. Later thin-skinned compressional regimes: major trapping ; Salawati syn-orogenic basin

Future Potential
Composite Petroleum Systems



What About the Yet To Find ("YTF")?

In nature, ranking and field size distribution follows a log-normal distribution

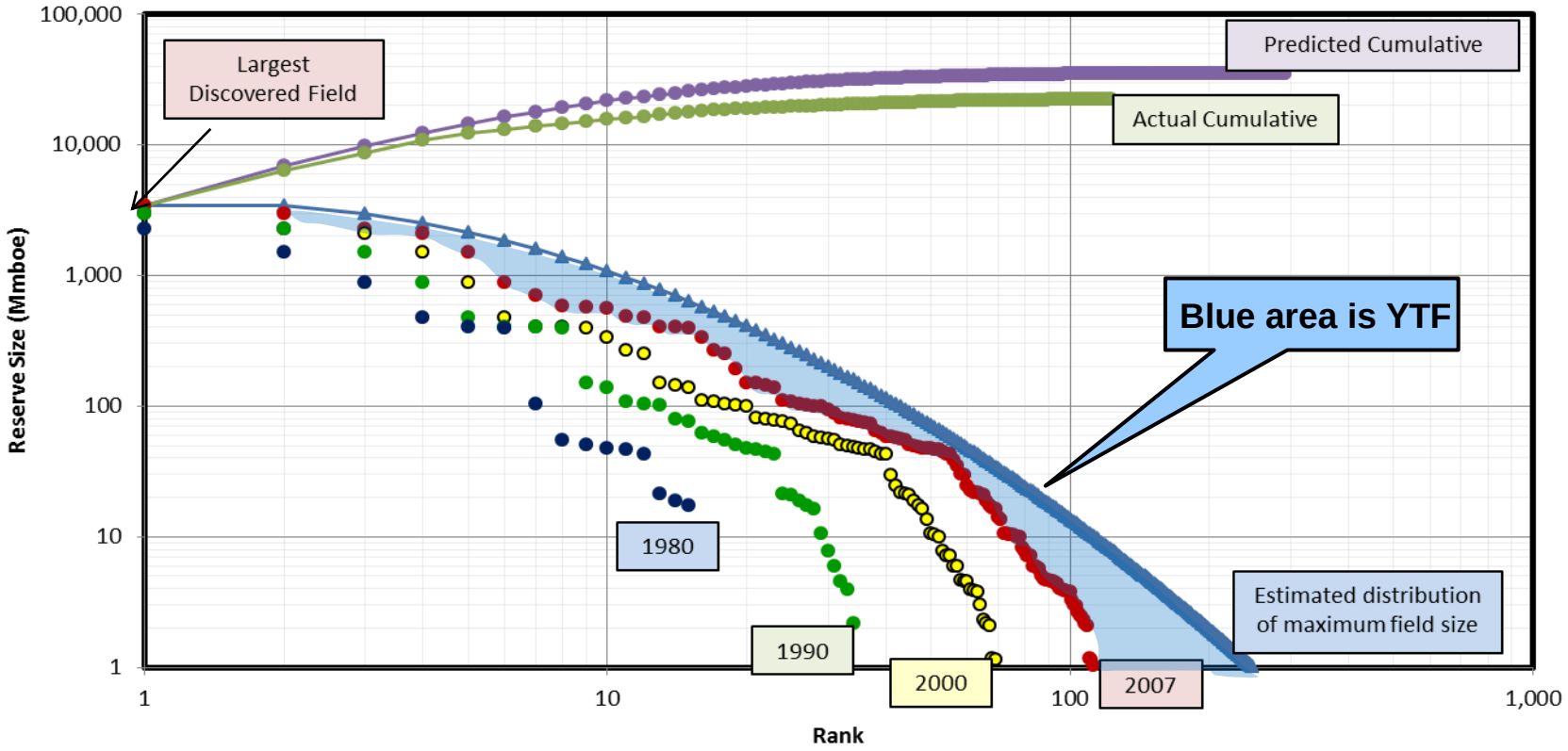
Log-normal distribution is propagated from the largest field in the basin with apparent breaks in the existing distribution indicated by missing fields with ranked size

While subjective (should be used in conjunction with other analyses such as historical creaming curves), it provides some indication of the YTF

2 case examples presented of log /parabolic function

1. Carnarvon Basin: Maturing E & P Province
2. Papua Basin: Immature exploration

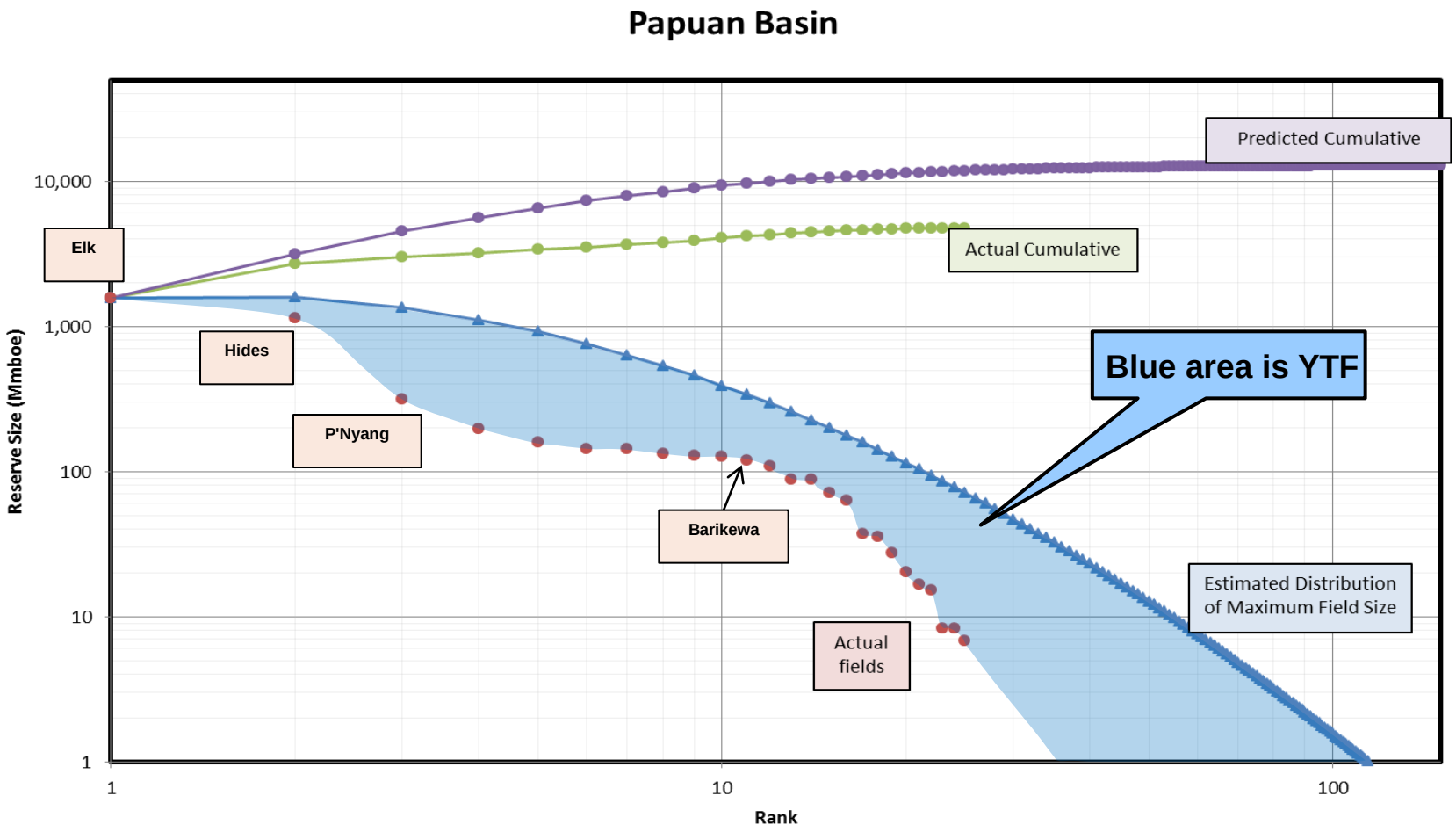
Carnarvon Basin Parabolic Reserves: Maturing E & P Province



Total reserves discovered:	22.2 Billion boe
Estimated ultimate reserves:	35.5 Billion boe
Yet to be found:	13.3 Billion boe

Fields > 10 MMboe (estimate):	112
Fields > 10 MMboe (actual):	76
Fields >100 MMboe (estimate):	42
Fields >100 MMboe (Actual):	27

Papuan Basin
Immature with Considerable Upside



Total reserves discovered:	4.8 Billion boe
Estimated ultimate reserves:	12.9 Billion boe
Yet to be found:	8.1 Billion boe

Fields > 10 MMboe (estimate):	54
Fields > 10 MMboe (actual):	22
Fields >100 MMboe (estimate):	21
Fields >100 MMboe (Actual):	12

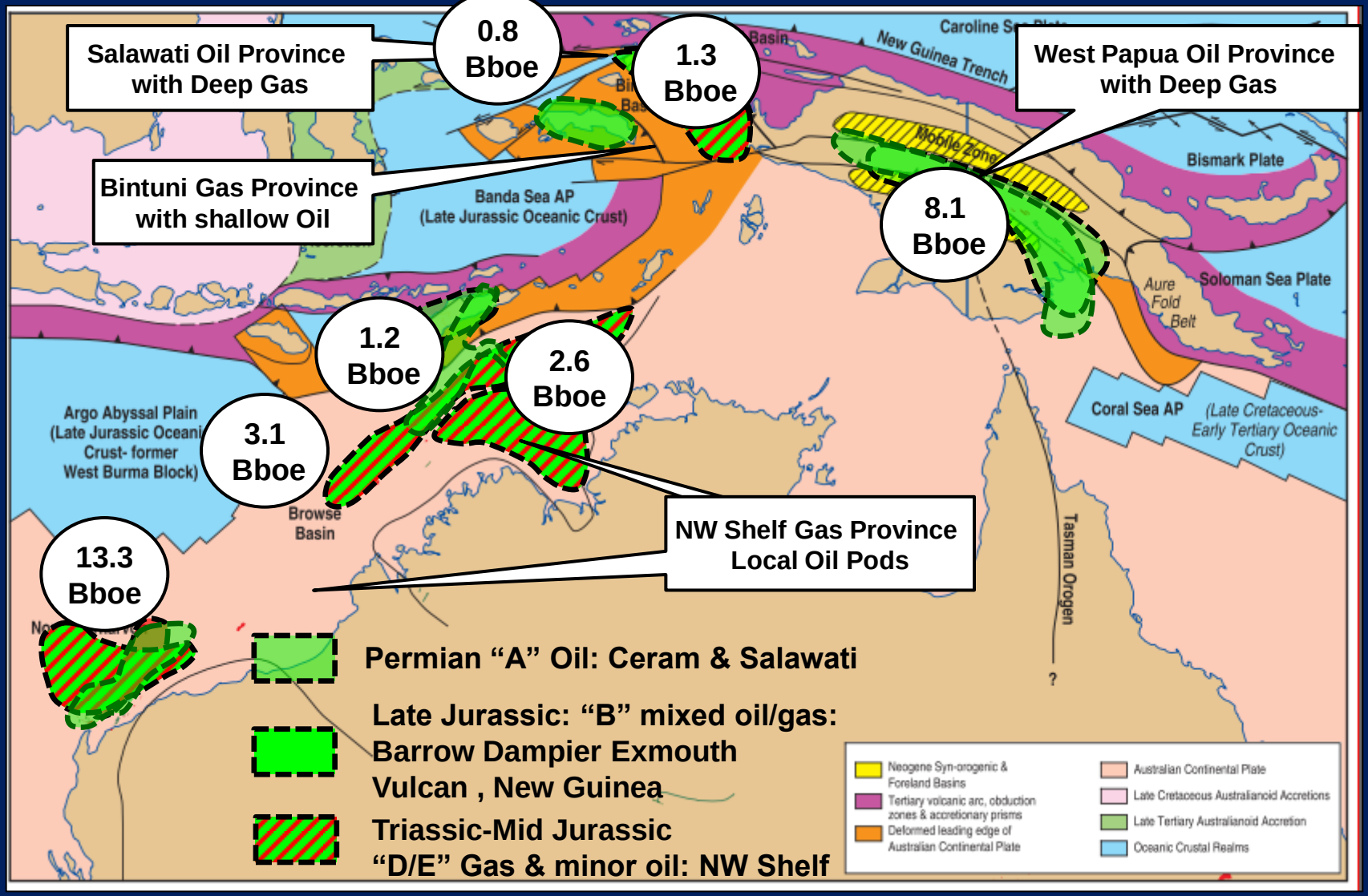
Australian Northern Margin YTF

Discovered vs YTF distributions for N. Australian Basins

Bln boe rec	North Carnarvon	Browse	Vulcan	Bonaparte	PNG	Bintuni	Salawati	Total
Discovered	22.2	7.5	0.7	6.7	4.8	3.7	0.8	46.4
Yet to Find	13.3	3.1	1.2	2.6	8.1	1.3	0.1	29.7
Estimated Total	35.5	10.6	1.9	9.3	12.9	5	0.9	76.1

- **46.4 Billion Bbls Total Discovered So Far in 7 key Basins**
- **29.7 Billion Bbls Oil Equivalent: YTF**

Future Potential
YTF Possibilities



Conclusions
Quo Vadis?

Discovered YTF distributions for N. Australian Basins

- 46.4 Billion boe Total Discovered So Far in 7 key Basins
- 29.7 Billion boe YTF
  - If 80% 20% GOR ratio applied, YTF is mostly gas due to:
    - Gas-prone source and deep, slow burial along large, stable shelf
- Exceptions apply:
    - Under-explored local oil-prone Kimmeridgian syn-rift basins such as the Papua Basin.

- Carnarvon Basin: Largest overall rating, potential for large fields, most potential for modest size fields
- Papuan Basin: YTF oil pools will be large, unless deep early inversion targets are late gas charged

With special thanks to the ISIS Perth team in preparing this paper, notably the following:

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- **Mike Bubrzyski, Adrian Ellins & Simon Barber: CAD & IT**