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.

Selected References


The Northern Australia – Eastern Indonesia – PNG Super Gas Province

Why So Much Gas and So Little Oil?

Peter Barber & Jim Winterhalder
Isis Petroleum Consultants Pty Ltd
Perth, Western Australia

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This presentation is a working summary of the petroleum potential of the N. Australian margin including New Guinea. It is a dynamic snapshot in time.

We have drawn on the 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

Acknowledgements
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
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:
   2\textsuperscript{nd} Order Transgressive – Regressive Cycles

4. Trap Styles:
   Extensional vs Compressional History
1.1 Plate Tectonic Drivers: Gondwanaland vs SE Asia

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

From Teas (2005)
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

NW Australian Shelf is one of the largest worldwide
1.3 Plate Tectonics Setting: Indicative Current Reserves

<table>
<thead>
<tr>
<th>Basin Setting</th>
<th>North Carnarvon</th>
<th>Browse</th>
<th>Vulcan</th>
<th>Bonaparte</th>
<th>Papua</th>
<th>Bintuni</th>
<th>Salawati</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive margin extension: syn-rift</td>
<td>Post-rift orogenic belt: syn-rift inversion</td>
<td>Syn-orogenic collapse basin</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reserves (Blтр boe Rec)</td>
<td>22.2</td>
<td>7.5</td>
<td>0.7</td>
<td>6.7</td>
<td>4.8</td>
<td>3.7</td>
<td>0.8</td>
</tr>
</tbody>
</table>

**Australian Passive Margin Extension**

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

**Australian – New Guinea**

- 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

- Organofacies D/E
  - Lower delta coals
  - Higher plants
  - 70% gas 30% oil

- Organofacies B
  - Restricted Marine
  - Marine algae
  - 80% oil 20% gas

- Organofacies A
  - Bathyal carbonates
  - Marine algae
  - >80% oil

Gas Prone (with minor oil)

Oil Prone

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

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

Papuan Basin Fold Belt

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

From Hill et al. (2011)
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?
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-KI syn-rift & breakup:
Local restricted marine rifts: oil-prone source pods (D swanese Kimmeridgian)
Possible local KI 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)

Major 2nd floodback (regional seal) with local 3rd order lowstand turbidites
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

- Permian “A” Oil: Ceram & Salawati
- Late Jurassic: “B” mixed oil/gas: Barrow Dampier Exmouth, Vulcan, New Guinea
- Triassic-Mid Jurassic “D/E” Gas & minor oil: NW Shelf
- Salawati Oil Province with Deep Gas
- West Papua Oil Province with Deep Gas
- Bintuni Gas Province with shallow Oil
- NW Shelf Gas Province Local Oil Pods
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

Blue area is YTF

Largest Discovered Field

Predicted Cumulative
Actual Cumulative
Estimated distribution of maximum field size

Reserve Size (Mmboe) vs Rank

1
10
100
1,000
10,000
100,000

Carnarvon Basin
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

Blue area is YTF
### Discovered vs YTF distributions for N. Australian Basins

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

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

- Permian "A" Oil: Ceram & Salawati
- Triassic-Mid Jurassic: "D/E" Gas & minor oil: NW Shelf
- Late Jurassic: "B" mixed oil/gas: Barrow Dampier Exmouth, Vulcan, New Guinea
- West Papua Oil Province with Deep Gas
- Bintuni Gas Province with shallow Oil
- Salawati Oil Province with Deep Gas
- NW Shelf Gas Province Local Oil Pods

Storage capacity:
- 0.8 Bboe
- 1.3 Bboe
- 1.2 Bboe
- 2.6 Bboe
- 3.1 Bboe
- 13.3 Bboe
- 8.1 Bboe
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
THANK YOU

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