Reassessment of the petroleum prospectivity of the Browse Basin, offshore Northwest Australia

Geoscience Australia

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Browse Basin Regional Context

- Large undeveloped gas resources (41 Tcf)
- Significant condensate volumes
- Production infrastructure in development for the Ichthys and Prelude fields
- Small light oil accumulations within the Cretaceous succession
- Yet still underexplored by global standards

→ High-grade areas with increased (liquids potential) prospectivity
Data compilation and acquisition

Data review

- Regional 2D and 3D seismic
- 60 key wells for sequence stratigraphy (biostratigraphy, Geological Time scale 2012→2016 update, well composites, synthetics, petrophysics)
- 38 key wells for petroleum system model (subsidence curve, burial history, lithology, etc.)

New pre-competitive data

- Surveys: potential field aeromagnetic and marine seabed, biota and seepage
- Source rock sampling and analyses
- Fluid composition analyses
- Initiated as Permo-Carboniferous intracratonic half-graben
- Rifting of Sibumasu from Australia & formation of Neo-Tethys

Inversion/ minor extension
Thermal subsidence
Extension
Regional Tectonic Evolution

Reactivation of early syn-rift faults controlled distribution and nature of the sedimentary fill.

Browse Basin
### Regional sediment deposition through time

<table>
<thead>
<tr>
<th>Ma</th>
<th>Period</th>
<th>Epoch</th>
</tr>
</thead>
<tbody>
<tr>
<td>325</td>
<td>Carboniferous</td>
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<tr>
<td>300</td>
<td>Permian</td>
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<td>175</td>
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<tr>
<td>150</td>
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<tr>
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<tr>
<td>25</td>
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<td></td>
</tr>
<tr>
<td>5</td>
<td>Quaternary/Neogene</td>
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</table>

- **Inversion**
- **Thermal subsidence**
- **Extension/magmatism**
- **Inversion/minor extension**
- **Extension**

The Jurassic and older seismic horizon interpretation has been provided by Bradshaw Geoscience Consultants.

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The thickness of deposits in meters:
- 5000 m
- 4000 m
- 2000 m
- 2000 m
- 2000 m

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**Regional Sediment Deposition Through Time**

- **Inversion**
- **Thermal subsidence**
- **Extension/magmatism**
- **Inversion/minor extension**
- **Extension**

The Jurassic and older seismic horizon interpretation has been provided by Bradshaw Geoscience Consultants.
### Revised Cretaceous Tectonostratigraphic Framework

- Cretaceous supersequences mapped across the basin
- Aligned with the internationally accepted Geological Timescale 2012 $\rightarrow$ 2016 update

<table>
<thead>
<tr>
<th>Age (Ma BP)</th>
<th>Period</th>
<th>Epoch</th>
<th>Stage</th>
<th>Sequences</th>
<th>INAG borehole sections (SA 2018)</th>
<th>BBHRSequences (GA 1997)</th>
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<tbody>
<tr>
<td>145</td>
<td>Aptian</td>
<td>Early</td>
<td>Aptian</td>
<td>K20</td>
<td>BB10</td>
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<td>T10</td>
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<td>Kapt</td>
<td>Kapt</td>
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</tbody>
</table>
Sediment geometry evolution

Isopachs (m)

**Upper Cretaceous** – maximum flood at end of K50
- K60–K64
- K65–K69

**Lower Cretaceous** – shoreline migration into the basin
- K10
- K20
- K30
- K40

Cenozoic
- Paleogene
- Maastrichtian
- Campanian–Maastrichtian
- Turonian–Campanian

Cretaceous
- Hauterivian–Barremian
- Valanginian–Hauterivian
- Aptian–Cenomanian

Paleogene
- From Rollet et al., 2016

**From Rollet et al., 2016**

**SEAPEX Exploration Conference 2017**
Fairmont Hotel, Singapore 26th – 28th April 2017
Palaeogeographic mapping

Insights into lateral and temporal distribution of reservoirs and seals

Upper Cretaceous – more sand-prone  Lower Cretaceous – more mud-prone

From Rollet et al., 2016
Stratigraphic traps

Submarine Fan

Clinoform Topset

Uppermost portion of prograding clinoform wedge

Basin-Margin

Stacked shelfal/fluvial sands

From Abbott et al., in prep.
Stratigraphic traps

From Abbott et al., in prep.
Cretaceous petroleum prospectivity: high-graded areas

Stratigraphic traps:

- Stacked basin margin (K10–K40)
- Clinoform topsets (K10–K40 & K60)
- Submarine fans (K30 & K60)
Known hydrocarbon occurrences

- Several stratigraphic plays
- Hydrocarbon occurrences are present throughout the Cretaceous section
- What active source kitchen may have generated these fluids?
Oil and gas families source rock correlation

From Edwards et al., 2016
Petroleum System Analysis

• Pseudo-3D petroleum systems model (Zetaware software)
  • Regional 3D geological model calibrated using corrected temperature & maturity data for 38 wells

• Input parameters include:
  • customised lithologies
  • palaeowater depths
  • rifting events (timing and beta factors)
  • top Permian assumed for thermal model boundary (Transient heatflow from base lithosphere)

From Palu et al., 2017
Source rocks characteristics (TOC, HI, kinetics)

**Echuca Shoals**

- **K20–K30**
  - **TOC**: 1.6% (median)
  - **HI**: 139 mg HC/ g TOC
  - **Kerogen type**: DE with significant marine influence

- **J40–K10**
  - **TOC**: 1.4% (median)
  - **HI**: 168 mg HC/ g TOC
  - **Kerogen type**: DE with some marine influence

- **J10–J20**
  - **TOC**: 1.8% (median)
  - **HI**: 107 mg HC/ g TOC
  - **Kerogen type**: DE with some marine influence

**Vulcan**

**Plover**

Source rock characteristics → predominantly gas-prone

*From Palu et al., 2017*
Source rocks estimated thickness

**Echuca Shoals**

- Estimated shale thickness from sequence isochore maps and lithological constraints from 60 key wells.
Source rocks: Transformation ratio

- The proportion of kerogen transformed to hydrocarbons, equivalent to source rock maturity
- Calculated from burial and thermal history + kinetics
Source rocks: Transformation ratio

### Timing of expulsion:

<table>
<thead>
<tr>
<th></th>
<th>K20–K30</th>
<th>J40–K10</th>
<th>J10–J20</th>
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</thead>
<tbody>
<tr>
<td>Caswell</td>
<td>Middle Eocene</td>
<td>Late Cretaceous</td>
<td>L. Jurassic – L. Cretaceous</td>
</tr>
<tr>
<td>Barcoo</td>
<td>Late Eocene</td>
<td>Early Cretaceous</td>
<td>E. Jurassic – L. Cretaceous</td>
</tr>
</tbody>
</table>
Hydrocarbons expelled

<table>
<thead>
<tr>
<th>Stage</th>
<th>Echuca Shoals</th>
<th>Vulcan</th>
<th>Plover</th>
</tr>
</thead>
<tbody>
<tr>
<td>K20–K30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J40–K10</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>J10–J20</td>
<td></td>
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</tr>
</tbody>
</table>

### Echuca Shoals
- **Liquids**: Valleys, 30 mmbbl/km²
- **Gas**: Valleys, 180 Bcf/km²

### Vulcan
- **Liquids**: Valleys, 30 mmbbl/km²
- **Gas**: Valleys, 180 Bcf/km²

### Plover
- **Liquids**: Valleys, 30 mmbbl/km²
- **Gas**: Valleys, 180 Bcf/km²
J10–J20 Plover-sourced hydrocarbons
J40–K10 Vulcan-sourced hydrocarbons

ICHTHYS/PRILEDE (K10)

BURNSIDE (K10)
K20–K30 Echuca Shoals-sourced hydrocarbons

**Echuca Shoals**

**Kalyptea (K10)**

**Cornea (K40)**

**Mixed with Plover gas**

**Gwydion (K30)**

Adele (K30)/Rondo
J10–K10 supersequences (Heywood Graben)-sourced
Sources of Hydrocarbons

No data

Westralian 1
E-M Jurassic gas
Plover–Plover Fm

Westralian 2/3
Jurassic wet gas
Vulcan–Brewster Mbr

Westralian 3
E Cret oil & gas
Echuca Shoals–Echuca S./Jamieson

Biodegradation and gas leakage
Condensates may drop out as pressure reduces (dew point systems; Edwards et al., 2016; Palu et al., 2017)

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Potential Risk: Fault Reactivation/Seal Integrity

- Miocene to recent AU-IND-EUR convergence
- Resulted in reactivation of the Barcoo Fault System
- Abundant small-scale extensional faults in Caswell Sub-basin show seafloor offsets
- Seismic data suggests some deep plumbing connectivity

Current Stress Field - $S_{H\text{max}}$

From Rollet et al., 2016
Redefining play concepts – K10 example

Ichthys Field – Brewster Member

New model: suggests siliciclastic platform sediments related to deltaic lobes which may be present elsewhere

From Abbott et al., 2016
Redefining play concepts – K10 example

- New opportunities?
- Alternate play locations where shelf builds basinward
- Underexplored Heywood Graben
- with access to underlying potential Jurassic source kitchens (J10–J20 Plover and J40–K10 Vulcan)

2017 proposed Acreage Release
2016 closed Acreage Release

"Brewster Member"
Siliciclastic platform - Fluvial, coastal and shelf (sand prone)
Slope (silt/mud prone)
Basin floor (mud prone)
Cretaceous stratigraphic plays with access to charge

- K10 Brewster Member volumetrically most significant Cretaceous reservoir
- Others Cretaceous plays add further hydrocarbon volumes
Cretaceous stratigraphic plays with access to charge

K10
K20
K30
K40
K50
K60.0-K64.0
K65.0-K69.0

2017 proposed Acreage Release
2016 closed Acreage Release

- Basin margin play
- Clinoform topsets play
- Submarine fan play
- Shallow faults zone

Petroleum well
- Oil discovery
- Gas discovery
- Oil and gas discovery
- Oil show
- Gas show
- Oil and gas show

Hydrocarbons sourced from
- K20-K30 supersequences
- J30-K10 supersequences
- J10-J20 supersequences
- Unknown (no data)
Conclusions

New insights into petroleum prospectivity of the Browse Basin:

• Sequence stratigraphy and palaeogeography highlight Cretaceous stratigraphic traps across the basin

• Geochemistry and petroleum system analysis identified Jurassic and Cretaceous source kitchens that have charged traps

• J10–J20 Plover gas saturated dew point system may add liquids potential to Cretaceous traps, particularly along underexplored areas of the basin margin

• Integrated studies are important to predict the petroleum resource potential of Australia’s sedimentary basins
List of products on:

Email: nadege.rollet@ga.gov.au

Web: www.ga.gov.au/about/projects/resources/browse-basin-petroleum-systems-study