The Source of Oil and Gas Accumulations in the Browse Basin, North West Shelf of Australia: A Geochemical Assessment

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Abstract

The Browse Basin located offshore on Australia's North West Shelf hosts considerable, but as yet undeveloped, petroleum resources with 36 Tcf EUR (Estimated Ultimate Recovery) of gas and 1148 MMbbl of condensate. It is poised to become Australia's next major conventional liquefied natural gas (LNG) province with the Ichthys, Prelude and Concerto fields expected to be in production by the end of 2016. Significant gas accumulations are also found along, and to the northeast of, the Brecknock–Scott Reef Trend (Calliance, Brecknock, Torosa and Poseidon) and in the Heywood Graben (Crux). Despite the economic importance of these fields and the extensive ongoing exploration activity, the origin of hydrocarbons remains ambiguous and a thorough geochemical evaluation of reservoir fluids and source rocks was carried out to redefine the petroleum systems of the Browse Basin. Geochemical data reveal that the gas-prone source rocks occurring throughout the Lower to Middle Jurassic Plover Formation have pervasively charged reservoirs of the Browse Basin at numerous stratigraphic levels.

On the other hand, oil-prone source rocks within the Upper Jurassic Lower Vulcan and Lower Cretaceous Echuca Shoals formations appear to be charge limited. The fluvio-deltaic sediments of the Plover Formation are the primary source for the dry gas found in the Plover reservoirs of the Brecknock–Scott Reef Trend and Ichthys fields. The Plover source rocks have also contributed to the wet gas accumulations reservoired within the Upper Jurassic Brewster Member of the Ichthys and Prelude/Concerto fields with additional inputs from the Lower Vulcan Formation. Gases from the Crux Field in the Heywood Graben are isotopically more enriched in 13C than any gases generated from the Caswell Sub-basin depocenter, suggesting derivation from coal-rich facies within thick Jurassic syn-rift sediments. The few sub-economic oil discoveries made in the Browse Basin are confined to the central Caswell Sub-basin (Caswell) and to the Yampi Shelf (Cornea, Gwydion and surrounds) where oil, together with some gas, is found in Cretaceous reservoirs. Molecular and carbon isotopic data show that the oil, and the
gas to some extent, is derived from marine organic matter within the Echuca Shoals Formation. However, accumulations on the Yampi Shelf also contain gases sourced from Plover source rocks, emphasising the migration of multiple hydrocarbon charges towards the basin margins.

**References Cited**


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Geoscience Australia, Energy Systems Group, Resources Division and GeoMark Research, Ltd
Gas accumulations in Calliance/Brecknock/Torosa, Ichthys/Prelude and Crux
Browse Basin oil and gas accumulations

- Gas accumulations in Calliance/Brecknock/Torosa, Ichthys/Prelude and Crux

- Ichthys/Prelude: on track to deliver first LNG volumes in 2016
Gas accumulations in Calliance/Brecknock/Torosa, Ichthys/Prelude and Crux

Ichthys/Prelude: on track to deliver first LNG volumes in 2016

Oil accumulations:
- Cornea/Gwydion 1
- Caswell 1 and 2
## Browse Basin Stratigraphy: Source Rocks

<table>
<thead>
<tr>
<th>Period</th>
<th>Epoch</th>
<th>Stage</th>
<th>Caswell and Barcoo sub-basins</th>
<th>Yampi and Leveque shelves</th>
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<td>Early</td>
<td>Cretaceous</td>
<td>120</td>
<td>Albian</td>
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<td></td>
<td></td>
<td>110</td>
<td>Aptian</td>
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<td></td>
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<td>100</td>
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<td>70</td>
<td>Barremian</td>
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<td>60</td>
<td>Bajocian</td>
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<td>50</td>
<td>Callovian</td>
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<tr>
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<td></td>
<td>40</td>
<td>Oxfordian</td>
<td>1.9</td>
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<td>30</td>
<td>Kimmeridgian</td>
<td>1.9</td>
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<tr>
<td></td>
<td></td>
<td>20</td>
<td>Tithonian</td>
<td>1.9</td>
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</tbody>
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### Echuca Shoals Fm.: Source of oils in the Browse Basin

Blevin et al., 1998

**BBHR study**

- Echuca Shoals
- Lower Vulcan
- Plover
Accumulations by Reservoir: Post-Berriasian Cretaceous

Post-Berriasian Cretaceous Reservoirs
Compound-specific Isotopes

[Graph showing compound-specific isotopes with time in minutes on the x-axis and FID intensity on the y-axis. Peaks for different carbon numbers are labeled, including neo-pentane, and isotopic abundance is shown on the right side of the graph.]
Browse Basin Gas & Oil/Condensate Families

Sourced by the Lower Cretaceous Echuca Shoals Fm.
Browse Basin Gas & Oil/Condensate Families

Sourced by the Lower Cretaceous Echuca Shoals Fm.

Echuca Shoals source rocks

\( \delta^{13}C \) (‰ VPDB) vs. \( n \)-alkane carbon number

- Caswell 2 oil
- Cornea 1 oil
- Gwydion 1 oil
- Kalyptea 1 ST1 gas & cond.
- Kalyptea 1 ST1 E Shoals SR
- Discorbis 1 E Shoals SR
- Adele 1 gas
Gas accumulations: Brecknock/Scott Reef Trend

**Scott Reef Trend Plover:**
- CGR < 20 bbl/MMscf
- Gas dryness average: 91%

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<table>
<thead>
<tr>
<th>Age (Ma)</th>
<th>Period</th>
<th>Epoch</th>
<th>Stage</th>
<th>Caswell and Barcoo sub-basins</th>
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<td>Undifferentiated Woodbine Group</td>
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<td>Bassett Formation</td>
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<td>Puffin Formation</td>
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<td>Barcoo Sub-basins</td>
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<td>Montara Pm</td>
</tr>
</tbody>
</table>

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**Map:**
- Petroleum field
- Basin boundary
- Sub-basin boundary
- Reservoir formation
  - Feneron/Gibson/Woolaston
  - Echuca/Jamieson/Heywood
  - Vulcan
  - Plover/Ashmore volcanics
  - Nome/Challia/Pollard
  - Kinmore

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Source of Brecknock/Scott Reef Trend Fluids

Brecknock/Scott Reef Trend

Sourced by the
Lower Cretaceous Echuca Shoals Fm.

Mixed terrestrial-marine

Marine

Source of Brecknock/Scott Reef Trend Fluids

Argus 1 gas & cond.
Brecknock 2 gas & cond.
Brecknock 3 gas & cond.
Kronos 1 gas & cond.
North Scott Reef 1 cond.
Scott Reef 1 cond.
Torosa 1 gas & cond.
Caswell 2 oil
Cornea 1 oil
Gwydion 1 oil
Kalyptea 1ST1 gas & cond.

δ¹³C (‰ VPDB)

n-alkane carbon number

AAPG/SEG ICE Melbourne 2015
Source of Brecknock/Scott Reef Trend Fluids

- **Brecknock/Scott Reef Trend**
  - Sourced by the E-M. Jurassic Plover Fm.
  - Mixed terrestrial-marine

- **Plover source rocks**
  - Sourced by the Lower Cretaceous Echuca Shoals Fm.
Gas accumulations: Ichthys/Prelude

Map of the Ichthys/Prelude gas accumulations in the Browse Basin, highlighting the locations of Vulcan and Plover fields.
Gas accumulations: Ichthys/Prelude

Gas dryness average 92%
CGR average 6 bbl/MMscf
Gas dryness average 82%
CGR average 60 bbl/MMscf
Source of Ichthys/Prelude Fluids: Plover reservoirs

- Ichthys/Prelude gases
  - Plover reservoir
  - Sourced by the Lower Cretaceous Echuca Shoals Fm.

- Brecknock/Scott Reef Trend
  - Sourced by the E-M. Jurassic Plover Fm.

- Sourced by the Lower Cretaceous Echuca Shoals Fm.
Source of Ichthys/Prelude Fluids: Brewster Member reservoirs

Dry gases

Wet gases

Brewster Member-reservoired fluids

Sourced by the Lower Cretaceous Echuca Shoals Fm.
**Dinichthys 1 condensate**
Brewster Member reservoir

**Heywood 1 Lower Vulcan**
Source rock

**Steranes**
m/z 218

**Hopanes**
m/z 191

**Abundance**

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**Hopanes**

- 19T
- 20T
- 21T
- 22T
- 23T
- 24T
- 25T
- 26T
- 27T
- 28T
- 29T
- 30H
- 31H
- 32H
- 33H
- 34H
- 35H
- Tm
- Ts

**Tricyclics**

- 27dia
- 27iso
- 28iso
- 29iso

---

**Steranes**
m/z 191

- 19T
- 20T
- 21T
- 22T
- 23T
- 24T
- 25T
- 26T
- 27T
- 28T
- 29T
- 30H
- 31H
- 32H
- 33H
- 34H
- 35H
- Tm
- Ts

**Hopanes**
m/z 218

- 27dia
- 27iso
- 28iso
- 29iso
Source of Ichthys/Prelude Fluids: Brewster Member reservoirs

- Plover reservoirs: gases/condensates
- Brewster Member: Ichthys/Prelude gases/oils
- Echuca Shoals: gases/condensates
- Lower Vulcan source rocks: contribution from Upper Jurassic lower Vulcan Fm.
Gas accumulations: Crux field

Gas dryness average 91%
CGR ~ 20-35 bbl/MMscf
Source of Crux Fluids

- Heywood Graben
- Brewster Member
- Ichthys/Prelude
- Echuca Shoals
- Plover reservoirs

δ¹³C (%oo VPDB)

n-alkane carbon number

Crux 1 gas & cond.
Crux 3 cond.

Terrestrial
Source of Crux Fluids

Heywood Graben: Sourced by coaly facies within Jurassic sediments

- Plover reservoirs
- Brewster Member
- Ichthys/Prelude
- Echuca Shoals sourced

- Crux 1 gas & cond.
- Crux 3 cond.

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Source of gases on Yampi Shelf
Source of gases on Yampi Shelf

- Gases very dry
  - Gas dryness > 98%
- Shallow reservoirs (< 1000 m)
- Oils biodegraded to various extent: Cornea 1/Cornea South 2/Focus 1/Sparkle 1/Gwydion 1
- Gases affected by in-reservoir biodegradation
Geochemical analyses of gases: *neo*-pentane

- *neo*-pentane (Boreham and Edwards, 2008)
  - Resistant to biodegradation
  - Excellent source correlation tool
Source of gases on Yampi Shelf

- Brecknock 2 gas
- Brecknock 3 gas
- Kronos 1 gas
- Torosa 4 gas
- Dinichthys Nth 1 gas
- Gorgonichthys 1 gas
- Ichthys 1A gas Plover
- Ichthys West 1 gas
- Crux 1 gas
- Burnside 1 ST1
- Dinichthys 1 gas
- Ichthys 1A gas Brewster Mbr
- Ichthys Deep 1 gas
- Titanichthys 1 gas
- Adele 1 gas
- Kalyptea 1 ST1 gas

$\delta^{13}C$ (%o VPDB)

n-alkane

AAPG/SEG ICE Melbourne 2015
Source of gases on Yampi Shelf

- Brecknock 2 gas
- Brecknock 3 gas
- Kronos 1 gas
- Torosa 4 gas
- Dinichthys Nth 1 gas
- Gorgonichthys 1 gas
- Ichthys 1A gas Plover
- Ichthys West 1 gas
- Crux 1 gas
- Burnside 1 ST1
- Dinichthys 1 gas
- Ichthys 1A gas Brewster Mbr
- Ichthys Deep 1 gas
- Titanichthys 1 gas
- Adele 1 gas
- Kalyptea 1 ST1 gas

δ¹³C (%° VPDB)

n-alkane

Echuca Shoals sourced

Brewster Member

Plover

Crux
Source of gases on Yampi Shelf

- Brecknock 2 gas
- Brecknock 3 gas
- Kronos 1 gas
- Torosa 4 gas
- Dinichthys Nth 1 gas
- Gorgonichthys 1 gas
- Ichthys 1A gas Plover
- Ichthys West 1 gas
- Crux 1 gas
- Burnside 1 ST1
- Dinichthys 1 gas
- Ichthys 1A gas Brewster Mbr
- Ichthys Deep 1 gas
- Titanichthys 1 gas
- Adele 1 gas
- Kalyptea 1 ST1 gas

δ¹³C (%o VPDB) vs n-alkane

Echuca Shoals sourced

Brewster Member

Plover

Crux
Source of gases on Yampi Shelf

Yampi Shelf gases derived from Plover Fm.
Gas & Condensate Families; Plover-sourced

Plover-sourced
Dry gas

Edwards et al, 2006 AAPG
Ichthys Gas & Condensate; Plover/Vulcan sourced

Brewster Member reservoirs Ichthys

Vulcan- + Plover- sourced

Wet gases

Edwards et al, 2006 AAPG
Crux Gas/Condensate; Plover/Vulcan-Sourced

Heywood Graben

Plover & Vulcan-sourced gas

Edwards et al, 2006 AAPG
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Andrew Murray (Murray Partners)
Paul Stephenson (GSWA)
More on the Browse Basin from Geoscience Australia

→ C. Nicholson et al. in CO₂ Storage: Results Thus Far - Tuesday morning (presentation)

Browse Basin 2014 Marine Survey—Investigating Containment for Potential Late Cretaceous CO₂ Storage Plays

→ N. Rollet et al. in CO₂ Storage: Site Selection - Tuesday afternoon (presentation)

Cretaceous Stratigraphic Play Fairways and Risk Assessment in the Browse Basin: Implications for CO₂ Storage

→ S. T. Abbott et al. in Seismic Stratigraphy - Tuesday afternoon (presentation)

Seven Cretaceous Low-Order Depositional Sequences From the Browse Basin, North West Shelf, Australia: A Framework for CO₂ Storage Studies

→ M. E. Lech et al. in Marita Bradshaw – Palaeographic Evolution of Oz - Tuesday morning (poster)

Paleogeographic Evolution of Early Campanian to Maastrichtian Supersequences in the Caswell Sub-Basin—Implications for CO₂ Storage and Hydrocarbon Entrapment
Thank you

Any questions?

Resources Division

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