Proven and possible petroleum plays of the CO2010 acreage release areas, northern Cooper and Eromanga basins, South Australia

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Introduction

The Cooper and Eromanga basins, spanning northeastern South Australia and south west Queensland, are Australia’s largest onshore petroleum province. In the South Australian part of the basins, total cumulative product sales to end June 2010 were 4.949 tcf of gas, 74.87 mmboe of condensate, 150.2 mmbl of oil and 77.6 mmboe of LPG. In May 2010 PIRSA released vacant acreage in the northern Cooper and Eromanga basins in South Australia, and these CO2010 acreage release areas are now available for licence application (Fig. 1).

The Cooper Basin is a Permo-Carboniferous to Triassic intracratonic basin, overlain by the Jurassic to Cretaceous intracratonic Eromanga Basin (Gravestock, Hibbert and Drexel 1998; Cotton, Scardigno and Hibbert 2006). The Cooper and Eromanga basins collectively contain up to 3700 m of predominantly fluvial, glaciofluvial, lacustrine and deltaic sediment with some Cretaceous marine sediments (Fig. 2). This article describes the proven and untested petroleum plays of the CO2010 acreage release areas.

Source rocks

Cooper Basin

The Patchawarra Trough is the main hydrocarbon kitchen for accumulations in the northern Cooper Basin province. Coal and carbonaceous shale of the Patchawarra Formation represent the principal source rocks of the Cooper Basin, both in source richness and quality (Fig. 3), and overall thickness (Boreham and Hill 1998). Patchawarra Formation total coal thickness is up to 40 m in the Patchawarra Trough. In volumetric terms, the western Patchawarra Trough, where thick Patchawarra Formation shales and coals lie within the present day oil window, represents the most important oil kitchen (Boreham and Hill 1998; Deighton et al. 2003; Fig. 4).

Petroleum Wells (discoveries since 2000)

- Oil
- Gas
- Geothermal

Well terminated in Ordovician sediments

Wells (in text)

Acreage release block

Seismic line

Cooper Basin

Permian edge

Triassic edge

Figure 1  Z horizon (top Warburton Basin) depth map showing CO2010 acreage release areas and oil and gas discoveries since 2000.
Cooper–Eromanga petroleum plays

The best source rocks in the Jurassic–Cretaceous sequence of the Eromanga Basin are the coals and carbonaceous shales of the Birkhead Formation, organic-rich shales and siltstones of the Murta Formation and the highly carbonaceous shales of the Poolowanna Formation (Michaelson and McKirdy 1996). All these units contain varying quantities of Type II/III (oil/gas-prone) and Type II (oil-prone) organic matter.

Hydrocarbon generation and migration

Thermal modelling by Deighton et al. (2003) indicated that generation and expulsion of hydrocarbons from Cooper and Eromanga source rocks in the Patchawarra Trough occurred primarily during the mid Cretaceous.

Vertical migration of oil from Permian (Cooper Basin) source rocks has been widely accepted as the principal source of most Eromanga-reservoired oil in the Cooper province. However organic geochemistry studies have established the possibility that source rocks within both the Eromanga and underlying Cooper Basin sequences have contributed to oil accumulations in Eromanga Basin reservoirs (e.g. Boreham and Summons 1999; Errock 2005; Michaelson and McKirdy 2001).

Figure 2 Stratigraphic summary of the Cooper and Eromanga basins.

Figure 3 Hydrogen index (HI) versus Tmax plot for Patchawarra Formation (from Boreham and Hill 1998). Note that samples with higher HIs have good to very good oil generating potential.

Eromanga Basin

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The distribution of hydrocarbon accumulations is controlled in part by the distribution of regional seals in the Cooper Basin sequence. Where the Permo-Triassic regional seals are thin or absent, multiple oil and gas pools can occur in coaxial Permain–Mesozoic structures. Oil discoveries at the margins of the underlying Cooper Basin have required extensive migration of oil from deeper source regions, in part within the open aquifer systems of the Eromanga Basin (Boreham and Hill 1998; Boreham and Summons 1999; Michaelsen and McKirdy 2001; Altmann and Gordon 2004). The nature of the Cooper Basin edge is variable around the basin, and this influences hydrocarbon migration up into the Eromanga Basin sequence.

The western margin of the Patchawarra Trough is erosional. Hydrocarbons migrating updip from deeper kitchen areas of the Patchawarra Trough can therefore access the overlying Eromanga Basin sequence at the subcrop edge of the regional Early Permian seals (e.g. Altmann and Gordon 2004; Fig. 5). There are a number of recent oil discoveries on the western margin reservoired in channel sands of the Jurassic Birked Formation (e.g. Growler in 2006, Wirraway in 2007, Warhawk in 2008, Tigræk in 2008 and Snatcher in 2009). It is reasonable to conclude that these discoveries are at least partly related to the nature of the Cooper Basin edge and the ease of oil migration up into the Eromanga Basin sequence. It is also possible that some of the hydrocarbon in these fields is derived from intra-formational source beds as shown by Errock (2005) for crude oil from the Christies Field.

The Deramookoo Shelf forms the northern margin of the Patchawarra Trough. There is some argument as to whether the northern margin of the Patchawarra Trough is faulted, or if the E–W-trending Deramookoo Shelf is a palaeotopographic high related to basement structure. Regardless, the end result is the juxtaposition of Permian sediments against basement, overlain by a thick blanket of Nappamerri Group that onlaps the shelf (Fig. 6). This configuration suggests there is potential for stratigraphically trapped hydrocarbons if an updip seal is provided by impermeable basement. However in the Tarragon Field on the Deramookoo Shelf, oil is reservoired in the Triassic Tinchoo Formation and the base of the Birked Formation, suggesting that the basement juxtaposed against the Permian is weathered and fractured, providing a migration pathway up into the overlying sequence.

**Traps**

**Four-way dip-closed anticlines**

In the core Cooper province, Cooper Basin oil and gas exploration and Eromanga Basin oil exploration has typically focused on four-way dip-closed anticlines. 3D seismic is an extremely useful tool for prospect delineation.
Intra-Birkhead Formation channel systems

A number of oil discoveries reservoired in Birkhead Formation channel sands have been made in recent years (Fig. 8). Reservoir quality has been variable as a result of lateral facies changes in the fluvial system. The Growler Field is an example of this lateral variability (Table 1). Both Growler 3 and 4 intersected good sands and this is reflected in the improved oil flow rates compared with Growler 1 and 2. Given the lateral variability it is likely there is a stratigraphic component to traps.

The intra-Birkhead discoveries have been sited on 2D seismic grids to date. However 3D seismic surveys are now being acquired to better image channel systems.

New exploration targets must be selected with care as channel-like features on 3D seismic attribute maps can be filled with clay. In meandering fluvial systems, river meanders can be cut off, becoming ox bow lakes in which silts and clays accumulate. An example of a stratigraphic play in a meandering fluvial system identified using 3D seismic data is provided here from central Saudi Arabia (Al-Zahrani and Neves 2008; Fig. 9). In this example seismic amplitudes along the reservoir horizon have been extracted, and high seismic amplitudes interpreted to indicate better sand development. The depositional model applied is shown with point bar sands accreting in an ox bow channel (see inset). The meandering channel features (dotted black lines) were better imaged by coherence and curvature. (From Al-Zahrani and Neves 2008)

In the Eromanga Basin where vertical closures can be small, falling within the range of possible errors introduced by statics and lateral velocity variations. The Christies oil field is one example of small vertical closure on the western margin of the Patchawarra Trough (Altmann and Gordon 2004; Fig. 7).
### Table 1  Results from some wells testing the intra-Birkhead channel play on the western Cooper margin

<table>
<thead>
<tr>
<th>Well name</th>
<th>Year</th>
<th>Gross oil column (m)</th>
<th>Net pay (m)</th>
<th>N:G (%)</th>
<th>Av. Ø (%)</th>
<th>Av. Sw (%)</th>
<th>Flow rate (bopd)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charo 1</td>
<td>1984</td>
<td>—</td>
<td>3.0</td>
<td>—</td>
<td>12.1</td>
<td>56.9</td>
<td>—</td>
</tr>
<tr>
<td>Charo 2</td>
<td>2007</td>
<td>—</td>
<td>3.2</td>
<td>—</td>
<td>12.7</td>
<td>65.0</td>
<td>—</td>
</tr>
<tr>
<td>Charo 3</td>
<td>2007</td>
<td>—</td>
<td>3.3</td>
<td>—</td>
<td>16.5</td>
<td>66.0</td>
<td>288 (DST)</td>
</tr>
<tr>
<td>Calabonna 1</td>
<td>1990</td>
<td>—</td>
<td>1.5</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Growler 1</td>
<td>2006</td>
<td>16</td>
<td>3.0 (pay sands 0.1–0.5m thick)</td>
<td>18</td>
<td>—</td>
<td>—</td>
<td>25–30 (after completion)</td>
</tr>
<tr>
<td>Growler 2</td>
<td>2007</td>
<td>—</td>
<td>Thin pay sands below tool resolution</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>68 (after completion)</td>
</tr>
<tr>
<td>Growler 3</td>
<td>2008</td>
<td>—</td>
<td>Drilled in middle of channel</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>2040 (cased hole PT)</td>
</tr>
<tr>
<td>Growler 4</td>
<td>2008</td>
<td>—</td>
<td>Drilled in middle of channel</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>240 (cased hole PT)</td>
</tr>
<tr>
<td>Wirraway 1</td>
<td>2007</td>
<td>21</td>
<td>5.5</td>
<td>26</td>
<td>38</td>
<td>—</td>
<td>67 (DST)</td>
</tr>
<tr>
<td>Tigercat 1</td>
<td>2008</td>
<td>18.5</td>
<td>7.0</td>
<td>38</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Warhawk 1</td>
<td>2008</td>
<td>9 m oil shows</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Snatcher 1</td>
<td>2009</td>
<td>14</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>218 (short-term PT)</td>
</tr>
<tr>
<td>Snatcher 2</td>
<td>2009</td>
<td>18.8</td>
<td>13.0</td>
<td>69</td>
<td>—</td>
<td>—</td>
<td>207 (short-term PT)</td>
</tr>
</tbody>
</table>

Source: Open file well completion reports (accessible via SARIG or the PIRSA Petroleum website) and ASX releases.

N:G net-to-gross or pay-to-nonpay ratio; Ø porosity; Sw water saturation; DST drillstem test; PT production test.

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**Figure 10  Composite log extracts from the Wimma 1 and Moomba 77 wells, highlighting the very high mud gas readings recorded whilst drilling deep Patchawarra coals.**

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Unconventional gas

Significant unconventional gas potential remains in the Cooper Basin in the form of gas in low-permeability reservoirs (tight gas), shale gas and coal seam gas.

In the eastern Patchawarra Trough the Early Permian sequence has the necessary elements for a basin-centred gas system, and overpressured gas sandstones with poor reservoir properties have been encountered. The following results were reported for Wimma 1, drilled in the centre of the Patchawarra Trough (Vincent 1982; Fig. 1):

- high mud gas readings in Permian sandstones
- tight Permian section with low water saturations (Sw = 30–40%) indicated by wireline log interpretation
- small gas flows from the Permian sands on drillstem test
- low permeabilities but high formation pressures indicated by the drillstem test pressure charts.

These results suggest that the potential for a basin-centred gas accumulation in the deeper parts of the Patchawarra Trough should be further investigated.

Thick Early Permian coal seams may be a future target for deep coal seam gas. Santos has flowed gas to surface at 100 000 scf/d from a fracced deep Patchawarra coal in Moomba 77 (Santos Ltd 2009). Again at Wimma 1, significantly elevated gas readings (2800 units total gas) were recorded during drilling of a 14 m coal seam in the Patchawarra Formation (Fig. 10). A depth of 1800 m is generally considered the floor for coal seam gas production due to cleat closure and permeability reduction at these depths (Scott 2002), although this depth cutoff can be extended in some areas (e.g. 2100 m in the Piceance Basin, Colorado, United...
may indicate local hydrocarbon generation and migration, although the absence of cut with carbon tetrachloride suggests the fluorescence may be from amber fragments. A drillstem test over the interval recovered 58 m of mud-cut water (2000 ppm Cl) with apparently no hydrocarbons. However analysis of the trapped air above the drillstem test water sample yielded hydrocarbons up to nC5.

The Pandieburra 1 and Putamurdie 1 wells, drilled in 1963, were both sited on single-fold 2D seismic lines, and it is therefore possible that neither of these wells were a valid structural test.

The Cambro-Ordovician Warburton Basin underlies the Eromanga Basin NW of the Cooper Basin. Whilst very little is known about the Warburton Basin in this area due to the paucity of well intersections, maps made by the BMR (now Geoscience Australia) show an interpretation of the Ordovician Larapintine seaway extending across the Amadeus Basin into the Warburton Basin (Veevers 2000). This interpretation suggests that equivalents of the organic-rich Horn Valley Siltstone may have been deposited in the Warburton Basin.

Steeply dipping Lower to Middle Ordovician quartzites and shales were intersected in Pandieburra 1 and Putamurdie 1 (Fig. 13). The shales in Pandieburra 1 were described as black with an organic appearance and gave off a kerosene-like odour when heated (Harrison et al. 1963). If less deformed sediments can be identified on seismic, then the Ordovician section of the Warburton Basin would provide an attractive target for shale gas plays, or may be a potential source rock for the overlying Eromanga Basin sequence. A pre-Permian signature has been identified in sequentially extracted residual oils in the Gidgealpa Field (Hallmann et al. 2006), demonstrating that the underlying Warburton Basin has generated and expelled crude oil elsewhere.

Northern Eromanga Basin frontier area

The Eromanga Basin NW of the Cooper Basin is considered a frontier area and has received little exploration to date. Only three wells have been drilled away from the Cooper Basin edge (Koonchera 1, Pandieburra 1 and Putamurdie 1), and much of the sparse seismic coverage is pre-1980s vintage (Fig. 13). This is somewhat surprising given that Type II and II/III Jurassic source rocks in the oil generation window have been intersected in the few wells drilled (Fig. 14). Two of three samples from the Birkhead Formation in Putamurdie 1 plot as Type II source rocks in the oil window, suggesting the intra-Birkhead channel play could be pursued in this area if a sufficient volume of source rocks and a sandy channel system can be identified.

The presence of ‘spotty golden fluorescence’ recorded in fine-grained quartz sandstones of the Poolowanna Formation in Pandieburra 1 (Harrison Campbell and Higginbotham 1963),
and to identify play fairways. Significant additional exploration is required in this area to map potential reservoirs. The northern Cooper and Eromanga basins in South Australia continue to yield new hydrocarbon discoveries as exploration matures and new hydrocarbon plays are developed and tested.

The intra-Birkhead Formation channel play has yielded a number of recent discoveries, and more discoveries are expected in the future following the acquisition of extensive 3D seismic surveys. Unconventional gas plays (tight gas, shale gas, coal seam gas) offer future opportunities in the Early Permian section of the Patchawarra Trough.

The Eromanga Basin NW of the Cooper Basin is a frontier area, with minimal seismic coverage, and only three wells drilled. However Jurassic source rocks in the oil generation window have been identified and Ordovician source rocks in the underlying Warburton Basin are inferred. Significant additional exploration is required in this area to map potential kitchen areas and migration pathways, and to identify play fairways.

**Conclusion**


**References**


Harrison J, Campbell IR and Higginbotham GT 1963. Delhi-Santos Pandiebubra No. 1 well completion report, Delhi Australian Petroleum Ltd, Well Completion Report 00312. Department of Primary Industries and Resources South Australia, Adelaide.


Vacant acreage is currently available for the pursuit of the hydrocarbon plays described in this article. The closing date for CO2010-A, B, C and D applications is 4.00 pm, Thursday 10 March 2011. Please refer to <www.petroleum.pir.sa.gov.au> for further information regarding the CO2010 acreage release, including the bidding and award process.

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New books trace the history of the Olympic Dam Mine

The Olympic Dam story: How Western Mining defied the odds to discover and develop the world’s largest mineral deposit by David Upton, 180 pp. (Self published, UPTON Financial PR)

The Olympic Dam story explains how Western Mining Corporation’s pursuit of the best science, persistence, teamwork and a dash of good luck led from an exploration base in a suburban garage to a super-giant copper, uranium and gold resource.

The book also describes how Western Mining overcame the main challenges of developing Olympic Dam, a multi-billion dollar project more difficult than ever envisaged with the unexpected discovery of uranium.

By writing for general readers as well as for professionals, David Upton makes the story accessible to anyone and provides a glimpse inside an industry that underwrites Australia’s prosperity.

The Olympic Dam story is an important addition to mineral exploration history and includes many previously unpublished maps, extracts and personal recollections of key individuals in the search as well as a foreword by Sir Arvi Parbo, former Western Mining chairman and managing director.

A mirage in the desert? The discovery, evaluation and development of the Olympic Dam ore body at Roxby Downs, South Australia, 1975-88, by R Keith Johns, 67 pp. (Published by O’Neil Historical & Editorial Services)

A mirage in the desert provides the history behind Western Mining Corporation’s development of the giant Olympic Dam copper, uranium, gold and silver mine from its discovery in 1975 until official opening of the mine in 1988. The author, Keith Johns, provides a personal account, from the inside, as the government officer most involved with the Olympic Dam Project throughout this period.

The occurrence of uranium in the ore body ensured that the mine’s development became a controversial issue. The book provides historical insights on this and other issues with which the developers would have to contend. They include access within the Woomera Prohibited Area; stratification of mining tenure within defined opal fields; Aboriginal mythology and sacred sites; and government policies on uranium mining, conversion and enrichment, and construction of nuclear power plants.

The book is well illustrated with photos, explanatory maps and a time-line of events.

Both books can be purchased from PIRSA Customer Services, phone +61 8 8463 3000, email <PIRSA.CustomerServices@sa.gov.au>. Prices are $35 for The Olympic Dam story and $25 for A mirage in the desert. Please note that postage and handling is an additional cost.